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IMPROVEMENTS IN OR RELATING TO CONTROLLED GAIN AMPLIFIERS

This invention relates to controlled gain amplifiers whose gain can be varied in dependence upon a control voltage applied to a feedback network.

It is known to provide an amplifier with a variable transconductance feedback network so that the gain of the amplifier can be varied in response to a control voltage applied to that network. Such arrangements are commonly used in automatic gain control circuits and in amplifiers with a programmable gain.

In a circuit which is constructed with MOS (metal-oxide semiconductor) technology, it is often difficult to obtain a variable transconductance network with a wide enough range of values for a sufficient range of gain control with essentially undistorted signal transmission. As a result, the circuit has a severely restricted range or requires too much power or chip area.

According to this invention a controlled gain amplifier includes a first amplifier, and a negative feedback network connected between the output and an input of the first amplifier, the transconductance of the feedback network being variable in dependence upon a control signal, the feedback network including first and second capacitors connected serially, first switch means for connecting one side of the first capacitor to the said input of the first amplifier

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during first phase periods and to a reference potential terminal during second phase periods, the first phase periods not overlapping the second phase periods, second switch means for connecting one side of the second capacitor to the output of the first amplifier during the first phase periods and to a reference potential terminal during the second phase periods, and variable resistance means responsive to the control signal and providing at least one current path from a common node of the first and second capacitors to a reference potential terminal. An amplifier embodying the invention affords improved control of the signal-band gain over a wide gain range with relatively low distortion while using low power consumption devices which require a relatively small amount of area on an integrated circuit chip.

In one embodiment the variable resistance means is provided with a network for suppressing distortion when the bias current in a transistor contained in the variable resistance means is low, in this case corresponding to a high input signal level to the amplifier.

The invention will now be described by way of example with reference to the accompanying drawings, in which:

FIG. 1 is a schematic circuit diagram of a controlled gain amplifier embodying the invention having a switched capacitor variable transconductance feedback network;

FIG. 2 is a schematic circuit diagram of a toggle switch such as may be used in the feedback network of the amplifier of FIG. 1;

FIG. 3 is a schematic circuit diagram of the amplifier of FIG. 1 with its feedback network modified to include a distortion suppression network for high amplitude input signals; and

FIG. 4 is a schematic circuit diagram of another controlled gain amplifier embodying the invention

including a dual variable resistance network.

Referring now to FIG. 1, a controlled gain amplifier 10 is realized with N-channel MOS devices and includes a primary operational amplifier 12 having an inverting input port 14, a non-inverting input port 16, and an output port 18. The non-inverting input port 16 is connected to a reference potential, which in this particular instance is ground potential. The term "reference potential" as used herein means a potential which is substantially constant as compared to the signal potential. An input resistor 20, which accepts a signal 22 from a signal source, is

connected to the inverting input port 14. The signal source is not shown, and the resistor 20 may also be realized as a switched capacitor. The particular circuitry of the operational amplifier 12 itself is not material, and
5 can be in accordance with one of various arrangements which are well known to those of ordinary skill in the art of amplifiers.

A first through-switched capacitor 24 and a second through-switched capacitor 26 are connected
10 serially.

The term "through-switched" as used herein describes a two-terminal component of a switched-capacitor circuit as having neither terminal directly connected to ground in one of the two switching phases.
15 A first toggle switch 28 connected in series between the inverting input port 14 and the first capacitor 24 is adapted to switch the inverting input port 14 side of the first capacitor 24 alternately between the inverting input port 14 and ground. A second toggle
20 switch 30 connected in series between the amplifier output port 18 and the second capacitor 26 is adapted to switch the amplifier output port 18 side of the second capacitor 26 alternately between the amplifier output port 18 and ground.

25 The first toggle switch 28, which is similar to the second toggle switch 30, is shown in more detail in FIG. 2. It is a pair of enhancement mode MOS transistors 31, 32 with their respective sources 33, 34 connected together and their respective gates 35, 36
30 connected to a clock source 38 which supplies first phase ϕ_1 and second phase ϕ_2 non-overlapping pulse trains to them at a pulse rate f_c which is here chosen to be 112 kHz (kilohertz). The ϕ_1 phase notation adjacent the solid line arrows in FIG. 1 indicates that the switches 28, 30 as
35 shown are in the ϕ_1 condition.

A variable resistance network 42, shown within the largest broken line rectangle of FIG. 1, couples the common node 40 of the capacitors 24, 26 to ground. It includes an enhancement mode MOS dynamic resistance element transistor 44 with drain and gate grounded. Its source is connected to the capacitor common node 40 and to the drain of an enhancement mode MOS transistor 46, which has its source coupled to a negative supply voltage $-V_{SS}$ and acts as a controlled current source. A control voltage V_c from a control voltage source 50 is supplied to the gate 52 of the current source transistor 46 to vary the resistance of the variable resistance network 42 by changing the bias current for the resistance element transistor 44.

In the operation of the controlled gain amplifier 10, the control voltage V_c applied to the gate 52 of the current source transistor 46 determines the bias current for the resistance element transistor 44 to thereby determine the resistance between the common node 40 and ground. Since this resistance determines the discharge rate to a constant potential of the capacitors 24, 26 the charge packet transferred between the capacitor 24 and the inverting input port 14 of the amplifier 12 in one cycle of operation can thereby be controlled by the control voltage V_c . This charge packet is added to the input signal 22 at a summing node 54 to provide negative feedback proportional to the output voltage of the amplifier 12.

In another embodiment, shown in FIG. 3, a controlled gain amplifier 56 includes a distortion suppression network 58 within the smaller broken line rectangle. This network 58 suppresses signal distortion which can result from a low bias current condition in the resistance element transistor 44, a condition corresponding to high amplitude input signals, by essentially extending the range of resistance values which the resistance element transistor 44 can present without unduly distorting the waveshape of the output signal which is fed back through the capacitor 24.

The network 58 includes a secondary operational amplifier 62. The gate of the transistor 44 is connected through a toggle switch 66, alternately to the output port 64 of the secondary operational amplifier 62 and ground. A resistance element 78 couples the signal input 22 to an inverting input port 70. The non-inverting input port 71 of the secondary amplifier 62 is grounded. A second toggle switch 72 connects one side of two capacitors 74, 76 alternately between ground and the inverting input port 70 of the secondary amplifier 62. The other side of the first capacitor 74 of these two is connected to the common node 40, while that of the second capacitor 76 is toggled between the output node 64 of the amplifier 62 and ground. The drain of the resistance element transistor 44 is connected either to ground or to a positive supply voltage. A non-switched feedback capacitor 68 couples the output port 64 to the inverting input port 70 of amplifier 62, serving to limit the bandwidth of the secondary amplifier 62. A feedback capacitor may likewise be applied across the primary amplifier 12 for a similar purpose.

The variable resistance network 42 includes a third transistor 79 which serves to extend the resistance range to lower values for a given upper limit on the control voltage.

Another embodiment of the invention is the controlled gain amplifier 80 of FIG. 4, which includes a dual resistance network 82. The network 82 connects the common node 40 to ground through a resistance path provided by transistor 84 which presents a resistance varying in response to a control voltage V_c . It also connects the common node 40 to the inverting input 14 of the operational amplifier 12 through another resistance path provided by a transistor 86 which presents a resistance also varying in response to the control voltage V_c . The inverting input 14 is a reference potential in that it is a virtual ground node which does not significantly change potential for

small signals. The gate electrodes of the transistors 84, 86 are coupled to the control voltage source 50 through a fixed resistor 88. Two capacitors 90, 92 of equal values serve to suppress distortion in the transistors 84, 86

5 resulting from large signal amplitudes.

The consolidation of the two control voltage-responsive resistance paths in the dual resistance network 82 permits some shared function economizing of elements. However, it would also be feasible to use two
10 separate resistance networks to make the connections. Moreover, a controlled gain amplifier can be realized in a number of different ways by providing various control voltage-responsive resistance connections from the common node 40 to a reference voltage in such a
15 manner that the feedback current of the amplifier 12 is thereby affected by the control voltage V_c . The resistor 88 and other resistors can also be replaced in known ways with switched capacitor arrangements.

A typical implementation for the variable gain
20 amplifiers 10, 56 would be an AGC (automated gain control) circuit. In such a circuit, the control voltage V_c would be derived from the output 18 of the amplifier 12 by detecting the signal peaks and passing them through a low-pass filter with a positive dc voltage output bias and
25 having appropriate slew capabilities (fast for attack and slow for recovery, i.e. fast in the process of increasing gain and slow in the process of decreasing gain).

The particular values of the various circuit components in the variable gain amplifiers 10, 56 are
30 necessarily specific to the implementation intended and can be readily ascertained by one skilled in the art of integrated circuit amplifier design.

The above variable gain amplifiers, 10, 56 could also be realized by the use of P-type MOS devices connected
35 in a "mirror-image" fashion as compared to the devices of the amplifiers 10, 56 to reflect their opposite device polarity.

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While in the circuit diagrams for the amplifiers 10, 56, 80 ground potential and the virtual ground potential of the inverting input port 14 are used as the reference potentials, an amplifier can be readily
5 designed by one skilled in the art of amplifiers to use other reference potentials which may be available for a particular circuit application.

The feedback network of an amplifier can also include an inverter and be connected between the output and
10 the non-inverting input.

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CLAIMS

1. A controlled gain amplifier including
a first amplifier, and a negative feedback network
connected between the output and an input of the
5 first amplifier, the transconductance of the feedback
network being variable in dependence upon a control
signal, and the feedback network including first and
second capacitors connected serially, first switch means
for connecting one side of the first capacitor to the
10 said input of the first amplifier during first phase
periods and to a reference potential terminal during
second phase periods, the first phase periods not
overlapping the second phase periods, second switch
means for connecting one side of the second capacitor
15 to the output of the first amplifier during the first
phase periods and to a reference potential terminal
during the second phase periods, and variable resistance
means responsive to the control signal and providing at
least one current path from a common node of the first
20 and second capacitors to a reference potential terminal.

2. An amplifier as claimed in claim 1 wherein
the variable resistance means includes a first
transistor connected to provide a dynamic resistance
path between the common node and a reference potential
25 terminal, and a second transistor for providing for the
first transistor a bias current which varies in
dependence upon the control signal.

3. An amplifier as claimed in claim 2 wherein
the said input of the first amplifier is an inverting
30 input, and there is provided a distortion suppression
network responsive to an input signal to the controlled
gain amplifier and connected to a control electrode
of the first transistor for reducing output signal
waveshape distortion at high input signal levels, the
35 suppression network including a first impedance
connected between the inverting input and a terminal
for receiving the input signal, a second amplifier
38 having an inverting input connected to the input signal



terminal through a second impedance, and a non-inverting input connected to a reference potential terminal, third and fourth capacitors connected together at one side to form a common node, the other side of the third capacitor being connected to the common node of the first and second capacitors, and the other side of the fourth capacitor being connected to the control electrode of the first transistor, third switch means for connecting the control electrode of the first transistor during the first phase periods to the output of the second amplifier and during the second phase periods to a reference potential terminal, fourth switch means for connecting the common node of the third and fourth capacitors during the first phase periods to the inverting input of the second amplifier and during the second phase periods to a reference potential terminal, and a fifth capacitor connected between the inverting input and output of the second amplifier.

4. An amplifier as claimed in claim 3 wherein the transistors are field effect transistors.

5. An amplifier as claimed in claim 3 or 4 wherein the transistors are MOS devices.

6. An amplifier as claimed in claim 1 wherein the said input of the first amplifier is an inverting input, and there is provided further variable resistance means responsive to the control signal and providing a current path from the common node of the first and second capacitors to the inverting input.

7. A controlled gain amplifier substantially as herein described with reference to fig. 1, 3 or 4, or to fig. 2 with fig. 1, 3 or 4 of the accompanying drawings.

