A predetermined and variable synthesized capacitance which may be incorporated into the resonant portion of an electronic oscillator for the purpose of tuning the oscillator comprises a programmable operational amplifier circuit. The operational amplifier circuit has its output connected to its inverting input, in a "follower" configuration, by a network which is low impedance at the operational frequency of the circuit. The output of the operational amplifier is also connected to the non-inverting input by a capacitor. The non-inverting input appears as a synthesized capacitance which may be varied with a variation in gain-bandwidth product of the operational amplifier circuit. The gain-bandwidth product may, in turn, be varied with a variation in input set current with a digital to analog converter whose output is varied with a command word. The output impedance of the circuit may also be varied by varying the output set current. This circuit may provide very small changes in oscillator frequency with relatively large control voltages unaffected by noise.
PROGRAMMABLE ELECTRONIC SYNTHESIZED CAPACITANCE

ORIGIN OF THE INVENTION

The invention described herein was made by an employee of the United States Government, and may be manufactured and used by or for the Government for governmental purposes without the payment of any royalties thereon or therefor.

TECHNICAL FIELD

This invention pertains to amplifiers and, more particularly, to an amplifier which functions as a variable electronic capacitance.

BACKGROUND ART

Numerous oscillator circuits have been designed with the capability of providing controlled output frequency variation within a given range. To produce these frequency variations obviously requires some variation of circuit parameters and usually involves some variation in circuit capacitance. The prior art includes a system for digitally correcting an oscillator frequency by first converting the digital information to an analog voltage which is applied to a varactor diode. Any changes in digital code changes the analog voltage and varies the varactor capacitance which, in turn, changes the oscillator frequency. In this type of system, it is difficult to achieve a very small change in capacitance in the varactor capacitance to achieve a very small deviation in oscillator frequency without complex circuitry because very small voltage changes are required to produce these small variations in capacitance and these small variations in voltages are in the noise level of the diode. Further, the changes in capacitance are non-linear with respect to variations in applied voltages. Other systems involve digitally or manually switching in various combinations of capacitors that are made available in the form of a bank of capacitors. For the digitally switched systems that include a bank of capacitors, very small changes in capacitance are difficult to achieve because of the physical limitations related to the capacitors that may be employed. The smallest lumped constant capacitor is typically in the order of 0.1 pF. Tolerance, physical size, and cost may present substantial problems depending on the required system parameters. Further, each capacitor in the bank must be physically connected into the system by different leads, each having a different stray capacitance which changes with environment. In addition to the problems associated with the digitally switched systems, the mechanically switched systems have failure problems traditionally associated with switches, especially those which are miniature. Thus, the prior art is only capable of easily achieving predictable and stable variations in capacitance which are relatively large in order to produce, for instance, relatively large changes in oscillator frequency.

STATEMENT OF THE INVENTION

Accordingly, it is an object of this invention to provide an electronically synthesized capacitance which may be varied in small increments.

It is yet another object of the invention to provide an electronically synthesized capacitance which is small and stable.

It is still another object of the invention to provide an electronically synthesized capacitance which may be varied by relatively large control voltages.

Briefly, these and other objects are achieved in a programmable Norton type amplifier whose input current can be controlled by a digital signal applied to a digital to analog converter, the variation in input set current changing the amplifier gain-bandwidth and, in turn changing the capacitance appearing at the non-inverting input of the amplifier.

THE SOLE FIGURE IS A SCHEMATIC REPRESENTATION OF THE ELECTRONICALLY SYNTHESIZED CAPACITANCE OF THIS INVENTION.

DETAILED DESCRIPTION OF THE INVENTION

The electronically synthesized and variable capacitance provided by programmable amplifier circuit 10 is shown in the FIGURE as including a single operational amplifier chip 12, which may be an LM359 Norton type, current differencing, amplifier chip. The Norton amplifier is chosen for this embodiment because of its comparatively high frequency characteristic. Any programmable operational amplifier, such as an OP-32, will also function according to the invention. The programmability refers to the capability to vary power consumption, phase shift, slew rate, and most importantly for this application, bandwidth of the amplifier chip.

The power supply terminal 14 of the operational amplifier chip is connected to a power supply voltage +V. The chip also has a non-inverting input, an inverting input, an output, and a set current input and output. The inverting input terminal 18 is connected by a lead 20 to one side of a parallel R-C network comprised of a feedback and bias resistor R1 and a feedback capacitor C1. The other side of the parallel network is connected by a lead 22 to an output terminal 24. Terminal 24 is also connected, by a lead 26, to one side of a feedback capacitor C2, the other side of capacitor C2 being connected by a lead 28 to the non-inverting input terminal 30. The other side of capacitor C2 and, indirectly, terminal 30, provides the synthesized capacitance output 40, designated as Ceq, via lead 32. Power supply voltage +V is also connected to terminal 30 by a bias resistor R2. A filter capacitor C3 is connected between the power supply and ground.

Separate input set current circuitry is provided by a summer 34, which is connected via a resistor R3 to the input set current terminal 36. The output set current terminal 38 is connected to ground through a resistor R4.

Capacitor C2, which is connected between the chip output terminal 24 and the non-inverting input in a feedback configuration, plays a large part in establishing the synthesized capacitance, Ceq, at the overall circuit output 40. The amplifier chip output, at terminal 24, is connected to the inverting input terminal 18, through resistor/capacitor network R1, C1, also in a feedback configuration. This configuration constitutes a traditional “follower” for A.C. signals when capacitor C1 is
The ground of the synthesized capacitance may be connections. It should be understood that the circuit, by itself, is functioning to form part of a resonant circuit in place of a conventional capacitor. One possible oscillator circuit is intended to operate from 15 MHz to 1 GHz, it should be understood that the principles of the invention are not so limited. Depending on the operational amplifier chip employed, the circuit may operate from the audio range to the multi-gigahertz range.

The input set current is determined by the output voltage of summer 34 and resistor R3. Typically, the summer will be an operational amplifier in a summer configuration with a plurality of resistor inputs and a resistor as the feedback component. The input signals to the summer 34, as shown, are a temperature compensation voltage, a bias voltage and the output from a digital to analog converter (DAC) (not shown). The temperature compensation voltage is intended to compensate for the diode voltage drops in the operational amplifier chip which are temperature dependent but subject to very small changes. Compensation is only important where very small changes in output voltage, such control is only useful where the oscillator in which the invention is to be used is very stable. It should be apparent that,
The closest standard resistor in magnitude is 390KΩ. Accordingly, the value of resistor R3 employed in circuit 10 is 390KΩ.

The output set current, \( I_{out} \), establishes the class A bias for and controls the current through a Darlington Pair (not shown) which is internal to chip 12 and comprises the output circuit for the chip. The higher the level of output set current, the lower the output impedance of the Darlington Pair and the greater the load that they can drive. The specifications for chip 12 show that a Darlington Pair output current of 5 ma results in an approximate 5Ω output impedance which is low enough so that the capacitance, \( C_{eq} \), is not substantially affected by loading once circuit 10 is placed into the resonant circuit of an oscillator. The output set current, \( I_{out} \), is effectively a bias current for the Darlington Pair. Again, from a graph in the specifications for the operational amplifier chip, a 0.2 ma output set current will produce a 5 ma output current for the Darlington Pair. To determine the magnitude of resistor \( R_4 \) required to produce an output set current of 0.2 ma, the specifications give the following formula:

\[
R_4 = \frac{12 \text{ V (supply voltage)} - 0.6 \text{ V (one diode drop)}}{I_{out}} = \frac{11.4 \text{ V}}{0.2 \text{ ma}} \approx 56\text{KΩ}
\]

When using an OP-32, there is no adjustment for output impedance. Accordingly, there is no terminal available for an \( R_4 \) connection.

As disclosed, circuit 10 will operate in the following approximate manner:

<table>
<thead>
<tr>
<th>Summer Output</th>
<th>( I_{out} )</th>
<th>GBWP</th>
<th>( C_{eq} )</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.0 V</td>
<td>20 μA</td>
<td>25 MHz</td>
<td>0.0185 pf</td>
<td>5 MHz</td>
</tr>
<tr>
<td>5.5 V</td>
<td>17.5 μA</td>
<td>17.5 MHz</td>
<td>0.0200 pf</td>
<td>5.5 Hz</td>
</tr>
<tr>
<td>10.5 V</td>
<td>22.5 μA</td>
<td>22.5 MHz</td>
<td>0.0309 pf</td>
<td>5 MHz + 2.5 Hz</td>
</tr>
</tbody>
</table>

Circuit 10, thus described, will accurately stabilize a stable 5 MHz crystal oscillator a total of 5.0 Hz by controlling a 10 bit (1024 step) DAC. The frequency change per step of the DAC is \( 5 \times 10^{-3} \) Hz. For the case of a 5 MHz oscillator, therefore, each step of the DAC corresponds to 1 part in \( 10^7 \) in terms of frequency. These small changes in oscillator frequency are achieved by relatively large voltages so that noise is not a primary consideration. In particular, noise at the output of the DAC, at the nanovolt level, will have essentially no effect on the oscillator frequency, \( F \), because each step of the DAC will be about 5 mv (1024 DAC steps divided into the 5 V DAC output range). Circuit 10 is, accordingly, very suitable for satellite communications for the purpose of varying oscillator frequency by very small increments by an easily transmitted serial command word. By choosing suitable scale factors for the oscillator, a 0.5 Hz deviation in oscillator frequency may be controlled in \( 5 \times 10^{-4} \) steps with each step corresponding to 1 part in \( 10^{10} \) in terms of frequency.

I claim:

1. A variable electronic capacitance comprising:
   a programmable operational amplifier with inverting and non-inverting inputs, an output, and an input for input set current;
a low impedance network connected between said output and said inverting input in a follower configuration; a capacitance connected between said output and said non-inverting input; and means to vary said input set current.

2. The electronic capacitance of claim 1 wherein said low impedance network is a parallel resistance/capacitance network where the capacitance forms a low impedance at a predetermined operational frequency.

3. The electronic capacitance of claim 1 wherein said capacitance connected between said output and said non-inverting input is a lumped constant capacitor.

4. The electronic capacitance of claim 1 wherein said means to vary input set current includes a resistor connected at one end to said input for input set current and connected at the other end to a variable voltage source.

5. The electronic capacitance of claim 1 wherein said direct current voltage source also being indirectly connected to said non-inverting terminal to provide a signal thereto; and variable voltage means connected to said input program terminal for varying said input set current.

6. The electronic capacitance of claim 5 wherein a bias voltage also drives said summer.

7. The electronic capacitance of claim 6 wherein a temperature compensation voltage also drives said summer.

8. The electronic capacitance of claim 1 wherein a resistor is connected at one end to said non-inverting input and at the other end to supply voltage.

9. The electronic capacitance of claim 1 wherein said non-inverting input provides a variable capacitance means.

10. The electronic capacitance of claim 9 wherein said non-inverting input is connectable to an oscillator circuit.

11. The electronic capacitance of claim 10 wherein said non-inverting input is connectable to a tuned portion of said oscillator circuit.

12. The electronic capacitance of claim 1 wherein said programmable operational amplifier also includes a terminal for output set current which is connected to a means to limit said output set current.

13. The electronic capacitance of claim 12 wherein said means to limit output set current is a resistor.

14. A variable electronic capacitance comprising: a programmable operational amplifier having inverting and non-inverting input terminals, an output terminal, an input program terminal for accepting input set current, and a power supply terminal; circuit means for connecting said power supply terminal to a direct current voltage; circuit means for interconnecting said output terminal to said inverting input terminal and placing said operational amplifier into a follower configuration; capacitance means for connecting said output terminal and said non-inverting input terminal and providing a feedback signal to said non-inverting input terminal; said direct current voltage source also being indirectly connected to said non-inverting terminal to provide a signal thereto; and variable voltage means connected to said input program terminal for varying said input set current.

15. The variable electronic capacitance of claim 14 wherein said circuit means is a parallel resistance/capacitance network which is low impedance at the operational frequency of said variable electronic capacitance.

16. The variable electronic capacitance of claim 14 wherein said non-inverting input terminal is connectable to an oscillator circuit.

17. The variable electronic capacitance of claim 16 wherein said non-inverting input terminal is connectable to a tuned portion of said oscillator circuit.

18. The variable electronic capacitance of claim 14 wherein said variable voltage means includes a digital to analog converter.

19. The variable electronic capacitance of claim 14 wherein said capacitance means is a capacitor directly connected between said output terminal and said non-inverting input terminal.