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IMPROVED CHARGE PUMP CIRCUIT FOR HIGH SIDE SWITCHBACKGROUND OF THE INVENTION

This invention relates to high side switches, and more particularly relates to a novel circuit for the charge pump of such circuits which has reduced noise, increased efficiency and is more easily integrated into a common semiconductor chip which includes the power device of the high side switch.

High side switches are well-known for numerous applications in which a load with a grounded terminal must be driven from a power supply and which includes a MOS gate controlled ("MOSgated") power device having a gate terminal which requires a potential higher than that of the power supply to turn on the switch. A "charge pump" circuit is commonly provided to produce the higher voltage needed to turn on the MOSgated power device when commanded to do so by an input signal. Such devices are commonly integrated circuit chips in which the power MOSgated device, charge pump and other control circuits are integrated in a common semiconductor chip.

Presently available high side drivers have several problems including the following:

- Severe noise is generated in both the supply voltage and ground pins in many applications, due to the high frequency (1 MHz) charging and discharging of the voltage doubling capacitor in the charge pump.

- The charge pump capacitor requires an excessively thick oxide and silicon area when integrated into a silicon chip for high supply voltage applications, for example, those greater than 12 volts.

● The turn-off switch needed to disconnect the power MOSgated device from the charge pump in the device "off" condition is difficult to implement in an N channel chip embodiment where high voltage P channel control MOSFETs are not available.

● The monolithic implementation of the voltage doubler diode in the charge pump is difficult, and it cannot be integrated as a simple P/N diode in the N⁺ epitaxial substrate of a conventional integrated circuit employing a self-isolated vertical conduction process.

● The output voltage of the charge pump circuit is reduced by the diode forward voltage drops in the charge pump doubler circuit, which has a major effect in low voltage applications.

The present invention provides a novel charge pump circuit for high side switches which has low noise and high efficiency, and is more easily integratable in the same chip containing the power MOSgated device.

BRIEF DESCRIPTION OF THE INVENTION

In accordance with the present invention, a novel charge pump circuit is provided for a high side switch in which the charge pump is disconnected from the ground terminal of the integrated circuit and is connected instead to a floating node. The floating node is then connected to the integrated circuit ground by a constant current source. Therefore, the current from the source terminal pin is constant, thus reducing noise at the ground and source voltage pins.

Since the charge pump is connected to a floating node, it is possible to clamp the charge pump voltage to a low voltage, even though the output voltage

of the device is higher. Therefore, the voltage across the charge pump capacitor is low, even for a high voltage device, and its size is limited.

5 As a further feature of the invention, a turn-off control switch connected between the charge pump input terminal and the supply source terminal is implemented as an N channel control MOSFET in an integrated circuit chip containing an N channel MOSgated power device section. The control N channel MOSFET is
10 then connected to a positive feedback circuit to the charge pump. A novel starter circuit is employed to initially turn on the control N channel MOSFET.

As a still further feature of the invention, the voltage doubler diodes are implemented as synchronous
15 rectifiers consisting of a MOSFET in place of one diode, and a resistor and MOSFET for the other diode. These components are easily integrated into the N⁺ epitaxial substrate of an integrated circuit containing an N channel MOSgated main power device.

20 Other features and advantages of the present invention will become apparent from the following description of the invention which refers to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

25 Figure 1 is a circuit diagram of a known high side switch.

Figure 2 shows a prior art charge pump circuit, formed as a voltage doubler, which is used for the circuit of Figure 1 to provide gate drive for the
30 MOSgated power device.

Figure 3 shows the gate voltage provided to the MOSgated power device of Figure 2 as a function of time.

Figure 4 shows the novel high side circuit of the invention in which any desired charge pump circuit is
5 connected to a floating node.

Figure 4a shows the circuit of Figure 4 with a preferred embodiment for a constant current circuit connecting the floating node of any desired charge pump circuit to the integrated circuit ground.

10 Figure 5 shows the circuit of Figure 4 with the charge pump of Figure 2, and with a modified constant current circuit embodiment.

Figure 5a shows a preferred implementation in silicon of an added transistor in the constant current
15 circuit of Figure 5 to enable the device to withstand high voltage.

Figure 6 shows the current of the constant current circuit, superimposed on the charge pump output current for the circuit of Figure 5 to demonstrate the
20 reduced noise level at the power and ground pins of the circuit.

Figure 7 shows the circuit of Figure 4, modified to employ an auxiliary MOSFET to implement the off switch, schematically shown in Figures 4 and 5.

25 Figure 8 shows the circuit of Figure 5 which is modified to contain the auxiliary power MOSFET of Figure 7 and a novel start-up circuit.

Figure 9 shows the circuit of Figure 8 with a modified start-up circuit.

30 Figure 10 is a block diagram of a high side circuit, which employs the novel auxiliary MOSFET of Figures 7, 8 and 9, in combination with a novel start-up circuit and a known type of grounded charge pump.

Figure 11 is a cross-section of a portion of an integrated circuit chip which contains a charge pump diode connected to the main device gate to show the problems of its integration into the chip.

5 Figure 12 shows the charge pump circuit of Figure 2 in which the diode connected to the power MOSFET gate is replaced by a transistor and resistor which are easily integratable into a common silicon chip with the power MOSgated device.

10 Figures 13a, 13b and 13c show the operation of the circuit of Figure 12 on a common time base.

Figure 14 shows the circuit of Figure 12 in which the resistor of the resistor-transistor combination is replaced by a depletion mode transistor.

15 Figure 15 shows an improvement of the circuit of Figure 14 to permit the application of the full voltage of $2V_{CC}$ to the gate of the power device.

Figures 16a, 16b and 16c show waveforms which describe the operation of the circuit of Figure 15.

20 Figure 17 shows the circuit of Figure 15 with a push-pull implementation.

Figures 18a to 18d are waveforms on a common time base to explain the operation of the circuit of Figure 17.

25 DETAILED DESCRIPTION OF THE DRAWINGS

Referring first to Figure 1, there is shown a typical prior art high side switching circuit. Such circuits are used in many applications, for example, automotive, in which it is necessary to drive a load having a grounded terminal. Thus, in Figure 1, a battery 30 is connected to load 31 through an N channel power MOSFET 32. The negative terminal of battery 30 and one

30

side of load 31 are connected to a common ground, for example, an automobile chassis. The positive terminal of battery 30 is at a voltage V_{CC} , which may be 12 volts. The power MOSFET 32 may be any other desired MOSgated device, such as an IGBT, or MOSgated thyristor or the like.

When MOSFET 32 is in the on state, its source is close to the power supply potential V_{CC} . In order to have a low drain-to-source voltage drop, it is necessary to bias the gate G of MOSFET 32 at a potential of 5 to 10 volts above the potential of source S, which is 5 to 10 volts above V_{CC} . In most cases, particularly where the high side switch is implemented as a stand-alone IC, no supply voltage above V_{CC} is available in the system, and a voltage above V_{CC} has to be generated on the chip. This is commonly done by a capacitive voltage multiplier, often called a charge pump.

Figure 2 shows a known voltage doubler circuit 40 commonly used in high side switches, connected to the high side switch of Figure 1. The doubler circuit 40 employs a square wave oscillator circuit 41, the output of which is bufferized by buffer 42. The output node 43 of buffer 42 is connected to capacitor 44 which is connected to and charged through diode 45 from source V_{CC} . The node between capacitor 44 and diode 45 is connected to diode 46 which is, in turn, connected to the gate of MOSFET 32. Two switching devices, shown as switches 47 and 48, are provided in which switch 47 is operable to connect and disconnect node 49 from power supply 30 and switch 48 closes in the MOSFET 32 off state to pull the gate of MOSFET 32 to ground (or to the source of MOSFET 32).

The charge pump 40 operates as follows:

When node 43 at the output of buffer 42 is low, capacitor 44 is charged from V_{CC} through diode 45. When the node 43 at the output of buffer 42 is high, the charge of capacitor 44 is transferred to the gate of MOSFET 32, through diode 46. The voltage on the gate of MOSFET 32 then increases in step fashion, as shown in Figure 3, and the voltage at the gate of MOSFET 32 approaches $2V_{CC}$ to turn on MOSFET 32.

To turn off MOSFET 32, switch 48 closes to pull the gate voltage to ground and switch 47 is opened to isolate node 49 from the power supply.

The circuit of Figure 2 has the following drawbacks:

1. The charging and discharging of capacitor 44 at high frequency, typically 1 MHz, generates high frequency current in the V_{CC} and ground pin nodes and related package pins of the IC 40, causing severe noise problems in many applications.

2. It is difficult to implement switch 47 into a single silicon chip for the entire circuit with most available processes, especially when no P channel MOSFETs are available.

3. It is difficult to extend the use of the circuit to applications with high V_{CC} voltages because the full V_{CC} is applied across capacitor 44. Therefore, to implement capacitor 44 in an integrated circuit for high voltage, prohibitively thick oxides and greater silicon area are required.

Figure 4 shows a first embodiment of the present invention, in which the circuit of Figure 2 is modified by connecting the ground lead 50 of charge pump 40 (shown as a block in Figure 4) to a floating node 51. The floating node 51 is then connected to ground 52 by a

constant current source circuit 53. A voltage regulator, for example, a zener diode 54 connects nodes 49 and 51.

The charge pump 40 can be of any desired type, including, but not limited to that of Figure 2. A significant feature of the circuit of Figure 4 is that the charge pump 40 is connected to floating node 51 instead of the ground node 52. The current in the ground pins and V_{CC} pins of the circuit will therefore be pure direct current, in view of the constant current source 53, so that the operation of charge pump 40 generates no noise at these pins.

Figure 4a shows the circuit of Figure 4 with constant current source 53 implemented as an N channel MOSFET 60, the gate of which is driven by cascaded control MOSFETs 61 and 62 which are enhancement and depletion mode MOSFETs respectively.

Figure 5 shows the circuit of Figure 4, using the charge pump of Figure 2 and a modified constant current source. More specifically, the current source in Figure 5 includes an added N channel MOSFET 70 which is easily integrated, as will be later described.

In the circuit of Figures 4, 4a and 5, the supply voltage V_{CC} is greater than the knee voltage of zener diode 54. If the current i_{33} in the constant current circuit 53 is greater than the current i_{41} of charge pump 41 then, as shown in Figure 6, the current in the ground and V_{CC} pins (or terminals) of the IC circuit will be a pure direct current. Therefore, the high frequency current of the charge pump generates zero or very low noise. Presently available high side switches, such as the IR6000, made by International Rectifier Corporation, and the BTS410E made by Siemens have peak-to-peak V_{CC} /ground currents in excess of .1 milliamper.

Circuits employing the floating node 53 of Figures 4, 4a and 5 have a noise of 20 microamperes peak-to-peak which is hardly discernable from background noise.

5 A further advantage of the circuits of Figures 4, 4a and 5 is that the voltage across capacitor 44 is limited to the zener voltage ($V_{CC}-V_{51}$) where V_{51} is the voltage at node 51. Therefore, a high voltage charge pump circuit can be built with low voltage capacitors with thin oxides and smaller die area without sacrificing
10 reliability. By way of example, the circuit of Figure 5 may operate with a V_{CC} of up to 60 volts while the voltage applied to the charge pump capacitor is limited to 7 volts.

As previously mentioned, the constant current
15 circuit 53 in Figure 5 contains an added MOSFET 70. MOSFET 70 is a relatively high voltage MOSFET to be used in high voltage applications to remove high voltage from MOSFET 60. A fixed gate voltage, for example, 7 volts, is applied to the gate of MOSFET 70 and it is easily
20 integrated into the common chip which contains all other circuit elements of Figure 5.

The implementation of MOSFET 70 as a lightly doped drain MOSFET is shown in Figure 5a which is a cross-section of a portion of the chip. Thus, the chip
25 71 has a lightly doped N^- substrate 72 which receives all of the junctions which make up the circuit. The power section of the chip which defines the power MOSFET 32 consists of any desired junction pattern and can be a vertical conduction device having a plurality of spaced P
30 base diffusions 73 which contain respective sources, such as N^+ source 74. The channel regions of each of bases 73 are covered by a MOSgate 75 which may be a polysilicon gate. The gate 75 is conventionally insulated from

source electrode 76 which contacts each of the bases 73 and their respective sources 74. A drain electrode 76a is formed on the bottom of chip 72 and is connected to V_{CC} .

5 P-wells, such as P-well 77, are also diffused into the same chip to contain control circuits for the main power device. Figure 5a shows one such P-well 77 which contains MOSFET 70. Thus, MOSFET 70 is an N channel device comprising an N^+ source diffusion 78, an
10 N^+ drain diffusion 79 and an N^+ drain contact diffusion 80. Its polysilicon gate 81 extends across the P channel region between diffusions 78 and 79. Thus, the MOSFET 70 is easily formed in chip 71, using many of the same process steps which form the power section 32.

15 The chip 71 is conventionally housed after its completion and externally available terminal pins extend through the housing to the various electrodes of the device. Thus, a V_{CC} terminal pin will be connected to the drain electrode 76a and a source terminal pin will be
20 connected to the source electrode at node 82 in Figures 4a and 5. A ground terminal pin will also be connected to the ground nodes in the chip 71 which are shown in the circuit of Figures 4a and 5.

 Figure 7 shows the circuit of Figure 4 with the
25 switch 47 implemented as an auxiliary N channel power MOSFET 90 which can easily be integrated into the IC chip 71 of Figure 5a with any conventional power MOSFET process since MOSFETs 32 and 90 have a common drain.

 Switch 48 in Figure 7 is implemented as a
30 lateral NMOS transistor with a lightly doped drain, similar to MOSFET 70.

 During steady state operation of the circuit of Figure 7, charge pump 40 provides a voltage at node 91

which is connected to the gate of power MOSFET 90 which is 5 to 10 volts above V_{CC} . MOSFET 90 is thus turned fully on and the charge pump 40 receives power from V_{CC} .

5 In order to turn on the circuit of Figure 7, a start-up circuit is needed, as shown in Figure 8, to initially pull up node 49 to start the charge pumping action. Thus, in Figure 8, a start up circuit consisting of diode 91, switch 92 and voltage source 93 are provided. Voltage source 93 has a low voltage which may
10 be derived from V_{CC} . Switch 92 may be implemented as a low voltage transistor.

In operation of the circuit of Figure 8, at turn on, switch 92 closes to provide an initial voltage to charge pump 40. The charge pump 40 will then begin to
15 supply itself from V_{CC} through transistor 90 which is turned on and the circuit will operate as previously described.

Figure 9 shows another embodiment of the start-up circuit of Figure 8 and employs transistors 100 and
20 101 and resistor 102. In operation of the circuit of Figure 9, at turn-on, the gate of transistor 100 is pulled to ground by start control circuit 103. The base of bipolar transistor 101 is pulled up by resistor 102 which is implemented as a depletion mode transistor which
25 has a high resistance value equivalent to about 1 megohm. Thus, node 49 is pulled up to $(V_{CC} - 0.6)$ volts, starting the charge pump 40 operation.

The novel auxiliary MOSFET 90 and any desired start-up circuit 110 can be used with the circuit of
30 Figure 2 in which the charge pump 40 is referenced to ground, as well as with the novel charge pump circuit with a floating node as in Figure 4. Figure 10 is a block diagram of such a circuit.

The charge pump circuit of the preceding figures employs diode 46 in the charging circuit. It is difficult and sometimes impossible to integrate this diode into a monolithic integrated circuit. Figure 11 shows an attempt to integrate diode 46 into the P-well 120 in the N⁻ substrate 72 of Figure 5a. Diode 46 is formed by N⁺ diffusion 121 in well 120. Electrodes 122 and 123 are connected to regions 120 and 121 respectively to form the electrodes of the diode 46. Since the epitaxial substrate 72 is the drain of power MOSFET 32, and is connected to V_{CC}, diode 46 cannot be integrated as a simple PN diode because its anode has to be able to float several volts above V_{CC}. However, this is impossible because of the parasitic diode 124 between the anode of diode 46 and V_{CC}. A simple integration of diode 46 is therefore impossible.

Another drawback of the diodes 45 and 46 in the charge pump of Figure 2 is that they reduce the output voltage of the charge pump 40 by their forward voltage drops to $(2V_{CC} - 2V_f)$ (where $2V_f$ is the forward voltage drop of diodes 45 and 46). This can be a substantial reduction for low V_{CC} applications such as laptop computers or automotive applications.

Figure 12 shows a modified charge pump circuit in which diode 46 is replaced by more easily integratable components and with a reduced forward voltage drop in the output of the charge pump circuit. Thus, diode 46 is replaced by enhancement mode transistor 130, depletion mode transistor 131, resistor 132, and a substrate diode 133 of transistor 131. These components are easily integrated into the substrate 72 of Figure 11.

The operation of the circuit of Figure 12 is described as follows, in connection with Figures 13a, 13b

and 13c which show the voltages at nodes 134-43, 135, and 136 respectively. Thus, the first time the output of buffer 42 at node 43 goes high, the node 136 at the gate of MOSFET 32 charges up to $(V_{CC} - V_f)$, through the
5 substrate diode 133 of depletion mode transistor 131. When the output at node 43 goes low, capacitor 44 charges up through diode 45. During this period, transistor 131 is in its off state; its source at node 134 and its drain at node 136 being at $(V_{CC} - V_f)$ while its gate at node 135
10 and its substrate are at 0 volts. Thus, transistor 131 is off and the gate of power MOSFET 32 is isolated from the remainder of the circuit.

When node 43 goes high, node 134 rises to $(2V_{CC} - V_f)$. Transistor 130 then turns off, enabling the gate
15 of transistor 131 to reach the potential of its source through resistor 132. Since transistor 131 is a depletion mode device, it turns on with 0 volts between gate and source. Therefore, the charge on capacitor 44 will transfer to the gate of MOSFET 32 through transistor
20 131.

This process continues each cycle until the node 136 potential shown in Figure 13c reaches the limit of $(2V_{CC} - V_f)$. Note that this limit is higher than that of the prior art circuit of Figure 2 by one diode drop V_f ,
25 because there is only one diode in the current path. Furthermore, transistors 130, 131 and resistor 132 may be easily integrated into the IC because the substrate of transistor 131 never exceeds V_{CC} .

Figure 14 shows an embodiment of the circuit of
30 Figure 12 in which resistor 132 of Figure 12 is replaced by a depletion mode MOSFET 140 which is easily integrated into the IC substrate.

Figure 15 shows a modification of the circuit of Figure 12 which even further reduces the voltage drop of the output of the charge pump at the gate of MOSFET 32 and eliminates all diode drops. Thus, transistor 150, resistor 151, capacitor 152, diode 153 and transistor 154 are added to the circuit of Figure 15 to avoid the drop produced by diode 45 in Figure 12. Note that MOSFET 150 replaces diode 45 of the circuit of Figure 12.

The operation of the circuit of Figure 15 is best understood from the curves of Figures 16a, 16b and 16c. The potentials at nodes 134-43, 160-161 and 135-162 respectively in Figure 15 are shown in Figures 16a, 16b and 16c. The first time the output at node 43 goes high, the gate of power MOSFET 32 at node 136 charges to $(V_{CC} - V_f)$ through the substrate diode 133 of depletion mode transistor 131. At the same time, node 161 is low and capacitor 152 is charged up to $(V_{CC} - V_f)$ through diode 153.

When node 161 goes high, node 43 goes low. Since capacitor 152 is already charged to $(V_{CC} - V_f)$, node 160 will be boosted to $(2V_{CC} - V_f)$. Since transistor 154 is off, node 162 will also be boosted to $(2V_{CC} - V_f)$ and transistor 150 will be fully "on." Capacitor 44 will then charge up to V_{CC} through transistor 150. For the same reasons described in connection with the circuit of Figure 12, transistor 131 will be off during this time and the gate of MOSFET 32 is isolated from the circuit.

When node 43 next goes high, transistor 154 turns on and node 162 falls to 0 volts, turning off transistor 150, allowing node 134 to rise to $2V_{CC}$. For the same reasons as in Figure 12, transistor 131 turns on

and the charge on capacitor 44 will transfer through the transistor 131 to the gate of MOSFET 32.

5 The same process repeats each cycle until the voltage at node 136 reaches $2V_{CC}$. Thus, the voltage at node 136 is $2V_T$ higher than that of the charge pump of Figure 2 because there is no diode in the current path.

10 Figure 17 shows the basic circuit of Figure 8 implemented as a push-pull circuit. The two halves of the circuit are symmetric, the left-hand side of the circuit using the same numerals as in Figure 8 and the right-hand side of the circuit using the same numerals with the suffix "a". Only a portion of the high side switch is shown, particularly the power MOSFET 32 having its gate connected to node 136 as shown by the dotted-line connection.

15 The operation of the circuit of Figure 17 is best understood by reference to Figures 18a, 18b, 18c and 18d which show the voltages at nodes 134-43, 134a-43a, 135-135a and 136 in Figure 17 respectively. It will be seen in Figures 18a, 18b and 18c that the potentials at nodes 134, 43 and 135 are in opposite phase to the potentials at nodes 134a, 43a and 135a respectively.

20 When node 43 is low, node 43a is at V_{CC} and node 134a is at $2V_{CC}$. Therefore, transistor 150 is fully "on" and capacitor 44 is charged up to V_{CC} through transistor 150. During this period, transistor 130 is "on" so that transistor 131 is "off." Similarly, transistor 130a is "off" so that transistor 131a is "on" and the charge of capacitor 44a is transferred to the node 136 and the gate of power MOSFET 32.

30 Node 43 then goes to V_{CC} , and node 134 is boosted to $2V_{CC}$. This turns transistor 150a fully "on," which turns "off" transistor 150 and prevents the

discharge of capacitor 44 through transistor 150. Since transistor 150a is "on" and node 43a is low, capacitor 44a will be charged up to V_{CC} through transistor 150a. During this period, transistor 130a is "on" so transistor 131a is "off". Similarly, transistor 130 is "off" so transistor 131 is "on" and the charge of capacitor 44 is transferred to the gate of power MOSFET 32.

The same process takes place at each clock half cycle until the voltage on the gate of MOSFET 32 reaches the limit of $2V_{CC}$. As in the circuit of Figure 12, the output voltage of the charge pump is unaffected by any diode drop because there is no diode in the current path.

Note that the circuit of Figure 17 doubles the apparent frequency of the charge pump and thus reduces the ripple at node 136 by a factor of 2.

Although the present invention has been described in relation to particular embodiments thereof, many other variations and modifications and other uses will become apparent to those skilled in the art. It is preferred, therefore, that the present invention be limited not by the specific disclosure herein, but only by the appended claims.



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WHAT IS CLAIMED IS:

1. A high side switch circuit comprising,
which is characterized in containing in combination: a
MOS gate controlled power semiconductor device having
first and second power electrodes and a control
5 electrode; a charge pump circuit having first and second
power terminals and an output terminal; a constant
current source circuit having input and output terminals;
a V_{CC} input voltage terminal connected to said first
power electrode of said MOS gate controlled power
10 semiconductor device and connectable to a source of
power; a load terminal connected to said second power
electrode of said MOS gate controlled power semiconductor
device and connectable to a grounded load that is capable
of being energized from said source of power when said
15 MOS gate controlled power semiconductor device is closed;
and a ground terminal connectable to said grounded load;
said charge pump circuit being operable to produce an
output voltage at its said output terminal which is
higher than said V_{CC} input voltage; said first power
20 terminal of said charge pump circuit being connected with
said V_{CC} input voltage terminal; said second power
terminal of said charge pump circuit connected to said
input terminal of said constant current circuit; said
output terminal of said constant current circuit
25 connected to said ground terminal, whereby said second
power terminal has a floating potential; said output
terminal of said charge pump circuit being connected to
said control electrode of said MOS gate controlled power
semiconductor device for providing a voltage sufficiently
30 higher than the voltage of said second terminal to turn
on said MOS gate controlled power semiconductor device.





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2. The circuit of claim 1 which is further characterized in that said MOS gate controlled power semiconductor device is a power MOSFET.

5 3. The circuit of claims 1 or 2 which is further characterized in including first switching means operable to connect and disconnect said charge pump first power terminal to said V_{CC} input voltage terminal and second switching means for connecting and disconnecting said control electrode of said MOS gate controlled power device to said ground terminal when said first switching means disconnects and connects said pump first power terminal to said V_{CC} input terminal respectively.

5 4. The circuit of claims 1, 2 or 3 which is further characterized in including voltage clamp means connected between said first and second power terminals of said charge pump circuit to limit the voltage therebetween.

5. The circuit of claims 1, 2, 3 or 4 which is further characterized in that said voltage clamp means comprises a zener diode.

5 6. The circuit of claims 1 to 5 which is further characterized in that said charge pump circuit comprises, in combination: a square wave oscillator connected to and operated from said first and second power terminals of said charge pump circuit and having an oscillator output terminal, an inverter buffer connected to said oscillator output terminal, a charge storage capacitor, a first diode and a second diode; said inverter buffer having an output connected in series with



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10 said capacitor and said first diode to said control
electrode of said MOS gate controlled power device; said
second diode connected from said V_{CC} input voltage
terminal to the node between said capacitor and said
first diode whereby, when the output of said inverter
15 buffer is low, said capacitor is charged from the voltage
at said V_{CC} terminal and through said second diode and,
when said output of said inverter buffer is high, the
voltage of said capacitor plus the voltage of said V_{CC}
terminal are applied in series through said first diode
20 to said control terminal of said MOS gate controlled
power device.

7. The circuit of claims 1 to 6 which is
further characterized in that said constant current
circuit comprises a first control MOSFET having drain and
source electrodes connected to said second power terminal
5 of said charge pump circuit and said ground terminal
respectively and a cascaded enhancement mode MOSFET and
depletion mode MOSFET connected between an auxiliary
voltage source and said ground terminal; the node between
said enhancement mode and depletion mode MOSFETs
10 connected to their respective gates and to the gate of
said first control MOSFET.

8. The circuit of claim 7 which is further
characterized in including a second control MOSFET in
combination with said first MOSFET to increase the
voltage between said second power terminal of said charge
5 pump circuit and said ground terminal without breakdown
of said first control MOSFET.

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9. The circuit of claims 1 to 8 is further characterized in including an auxiliary power MOSFET having first and second power terminals and a gate terminal; said first and second power terminals of said auxiliary power MOSFET connected to said first power terminal of said charge pump circuit and said V_{CC} input voltage terminal respectively; said gate terminal of said auxiliary power MOSFET connected to said control electrode of said MOS gate controlled power semiconductor device.

10. The circuit of claim 9 which is further characterized in including starter circuit means coupled between a auxiliary supply voltage source and said charge pump circuit for starting said charge pump circuit before said auxiliary power MOSFET conducts.

11. A high side switch circuit characterized in comprising, in combination: a MOS gate controlled power semiconductor device having first and second power electrodes and a control electrode; a charge pump circuit having first and second power terminals and an output terminal; a V_{CC} input voltage terminal connected to said first power electrode of said MOS gate controlled power semiconductor device and connectable to a source of power; a load terminal connected to said second power electrode of said MOS gate controlled power semiconductor device and connectable to a grounded load which is energized from said source of power when said MOS gate controlled power semiconductor device is closed; and a ground terminal connectable to said grounded load; said charge pump circuit being operable to produce an output voltage at its said output terminal which is higher than



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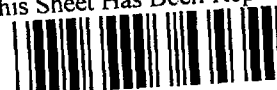
said V_{CC} input voltage; said second power terminal of
said charge pump circuit connected to said ground
terminal, whereby said output terminal of said charge
20 pump circuit is connected to said control electrode of
said MOS gate controlled power semiconductor device for
providing a voltage sufficiently higher than the voltage
of said second terminal to turn on said MOS gate
controlled power semiconductor device; a grounding switch
25 connected to said control electrode of said MOS gated
power device for grounding said control electrode when
said grounding switch is closed; and an auxiliary power
MOSFET having first and second power terminals and a gate
terminal; said first and second power terminals of said
30 auxiliary power MOSFET connected to said first power
terminal of said charge pump circuit and said V_{CC} input
voltage terminal respectively; said gate terminal of said
auxiliary power MOSFET connected to said control
electrode of said MOS gate controlled power semiconductor
35 device so that when said grounding switch is closed, said
gate terminal of said auxiliary power MOSFET is grounded,
thereby turning off said auxiliary power MOSFET to
electrically isolate said charge pump circuit from said
supply voltage.

12. The circuit of claim 11 which is further
characterized in including starter circuit means coupled
between a auxiliary supply voltage source and said charge
pump circuit for starting said charge pump circuit before
5 said auxiliary power MOSFET conducts.

13. The circuit of claim 1 which is further
characterized in that said MOS gate controlled power
semiconductor device, said charge pump circuit, and said



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5 current source are integrated into a monolithic semiconductor chip.

14. The circuit of claim 3 which is further characterized in that said MOS gate controlled power semiconductor device, said charge pump circuit, said first switching means and said current source are
5 integrated into a monolithic semiconductor chip.

15. The circuit of claim 3 which is further characterized in that said MOS gate controlled power semiconductor device, said charge pump circuit, said voltage clamp means and said current source are
5 integrated into a monolithic semiconductor chip.

16. The circuit of claim 9 which is further characterized in that said MOS gate controlled power semiconductor device, said charge pump circuit, said auxiliary power MOSFET and said current source are
5 integrated into a monolithic semiconductor chip.

17. A charge pump circuit for a MOSgated power semiconductor device; said MOSgated power semiconductor device having a V_{CC} input voltage terminal, a ground terminal and a control terminal; said charge pump circuit
5 characterized in comprising, in combination: a square wave oscillator having an output terminal; an inverter buffer connected to said oscillator output terminal; a charge storage capacitor coupled to the output of said inverter buffer; a first coupling circuit means coupling
10 said capacitor to said control electrode of said MOSgated power semiconductor device; a second coupling circuit means for coupling said V_{CC} input voltage terminal to the



node between said capacitor and said first coupling
circuit means whereby, when the output of said inverter
15 buffer is low, said capacitor is charged from the voltage
at said V_{CC} terminal and through said second coupling
means and, when said output of said inverter buffer is
high, the voltage of said capacitor plus the voltage of
said V_{CC} terminal are applied in series through said
20 first coupling means to said control terminal of said
MOSgated power semiconductor device; and wherein said
first coupling means comprises a depletion mode MOSFET
having source and drain terminals connected to said
capacitor and control electrode of said MOSgated power
25 semiconductor device respectively and having its
substrate connected to the output of said inverter
buffer; a resistive circuit means connected from said
capacitor to the gate of said depletion mode MOSFET, and
a second control MOSFET connected from said gate of said
30 depletion mode MOSFET and said ground terminal and having
a gate connected to said oscillator output terminal.

18. The circuit of claim 17 which is further
characterized in that said second coupling means is a
diode.

19. The circuit of claim 34 or 35 which is
further characterized in that said resistive circuit
means comprises a second depletion mode MOSFET having a
gate connected to the gate of said first-mentioned
5 depletion mode MOSFET and a substrate connected to the
substrate of said first-mentioned depletion mode MOSFET.

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20. The circuit of claims 17, 18 or 19 which is further characterized in that wherein said second coupling circuit means includes a control MOSFET.

21. A charge pump circuit for a MOSgated power semiconductor device; said MOSgated power semiconductor device having a V_{CC} input voltage terminal, a ground terminal and a control terminal; said charge pump circuit comprising, in combination: a square wave oscillator having an output terminal; an inverter buffer connected to said oscillator output terminal; a charge storage capacitor coupled to the output of said inverter buffer; a first coupling circuit means coupling said capacitor to said control electrode of said MOSgated power semiconductor device; a second coupling circuit means for coupling said V_{CC} input voltage terminal to the node between said capacitor and said first coupling circuit means whereby, when the output of said inverter buffer is low, said capacitor is charged from the voltage at said V_{CC} terminal and through said second coupling means and, when said output of said inverter buffer is high, the voltage of said capacitor plus the voltage of said V_{CC} terminal are applied in series through said first coupling means to said control terminal of said MOSgated power semiconductor device; and wherein said secondary coupling circuit means includes a control MOSFET.

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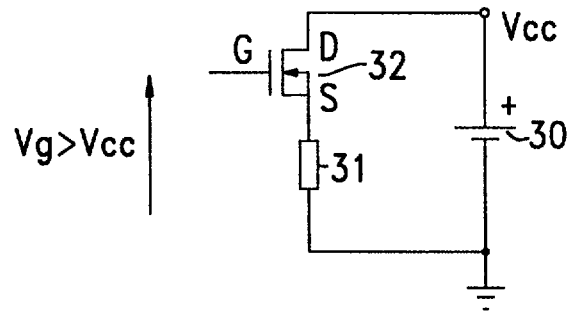


FIG. 1
PRIOR ART

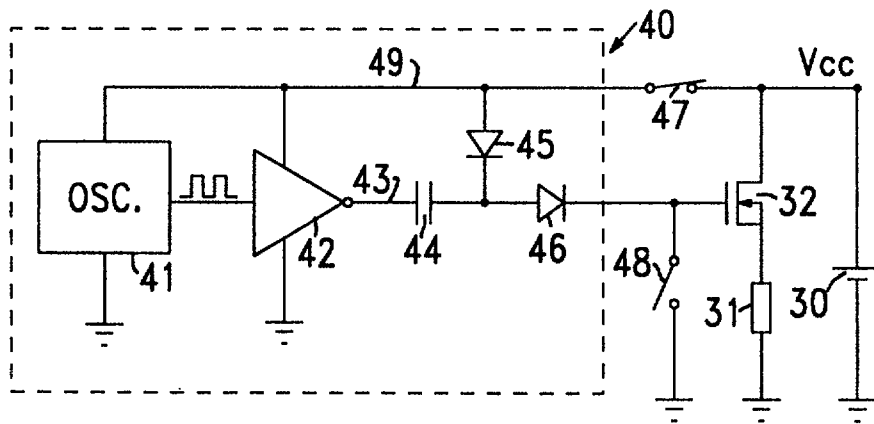


FIG. 2
PRIOR ART

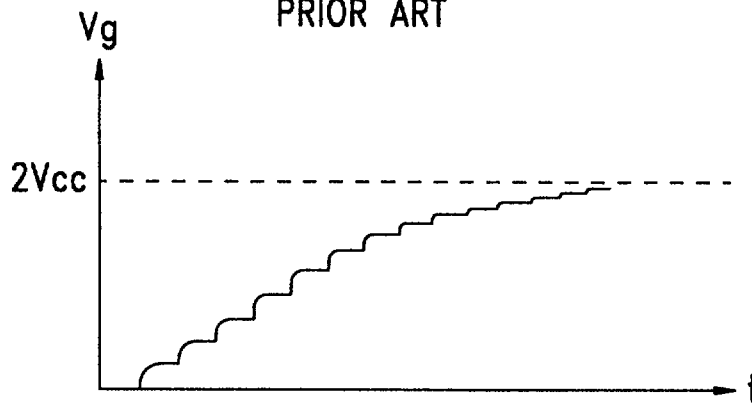


FIG. 3
PRIOR ART

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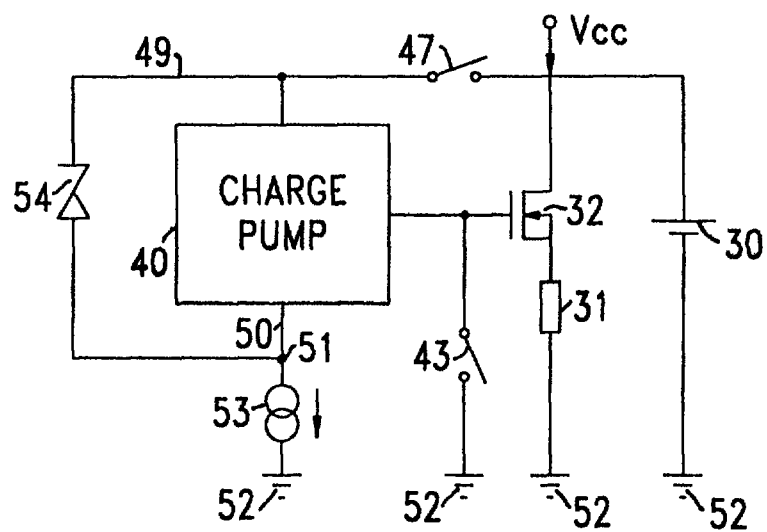


FIG. 4

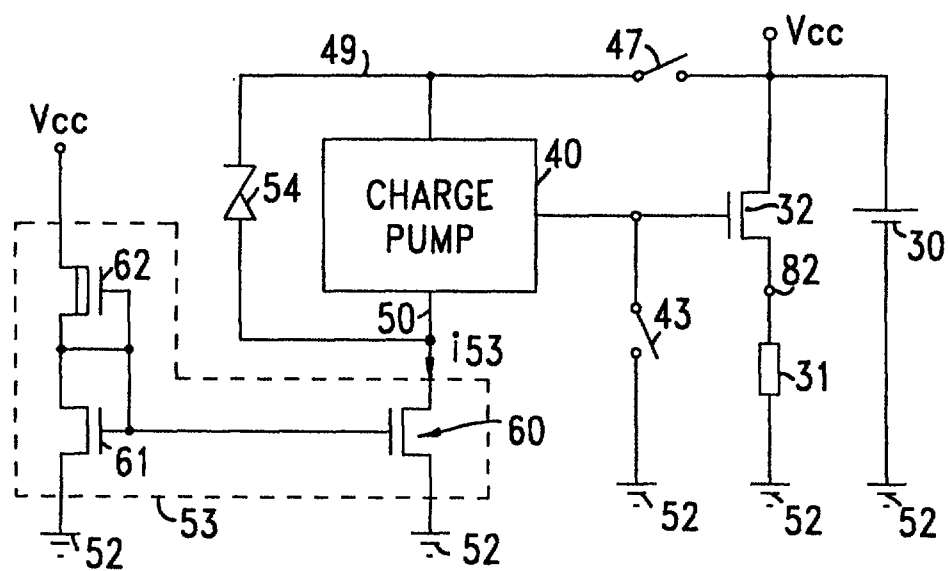


FIG. 4A

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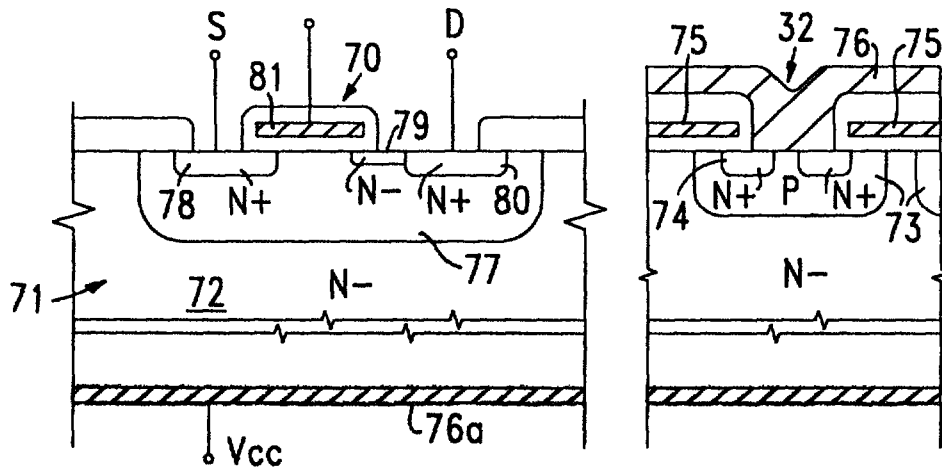


FIG. 5A

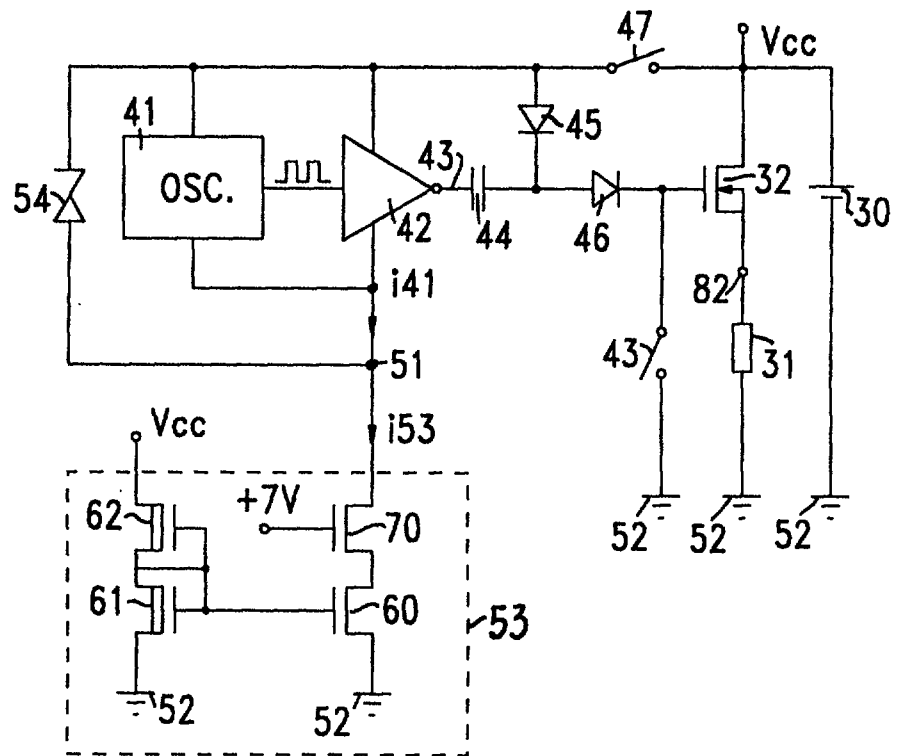


FIG. 5

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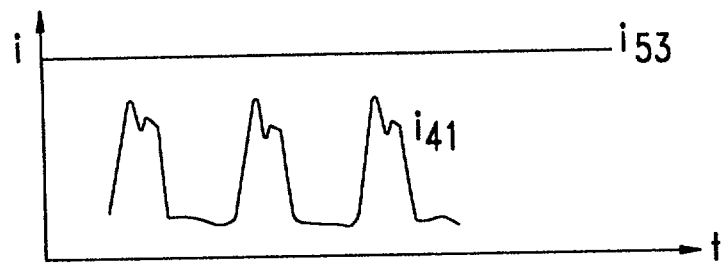


FIG. 6

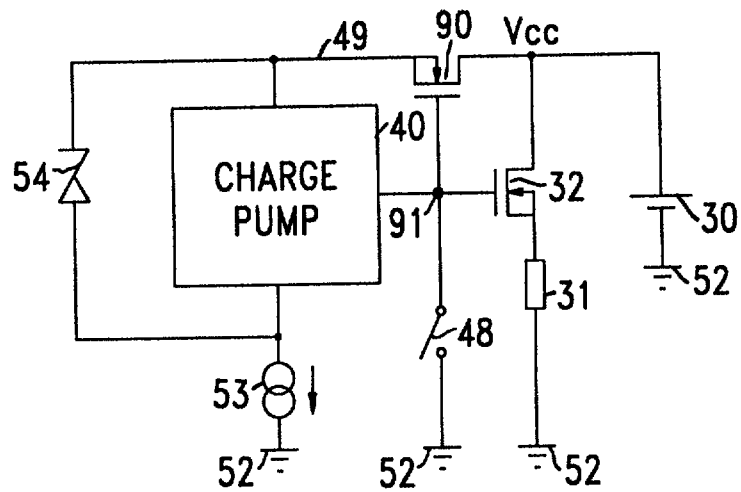


FIG. 7

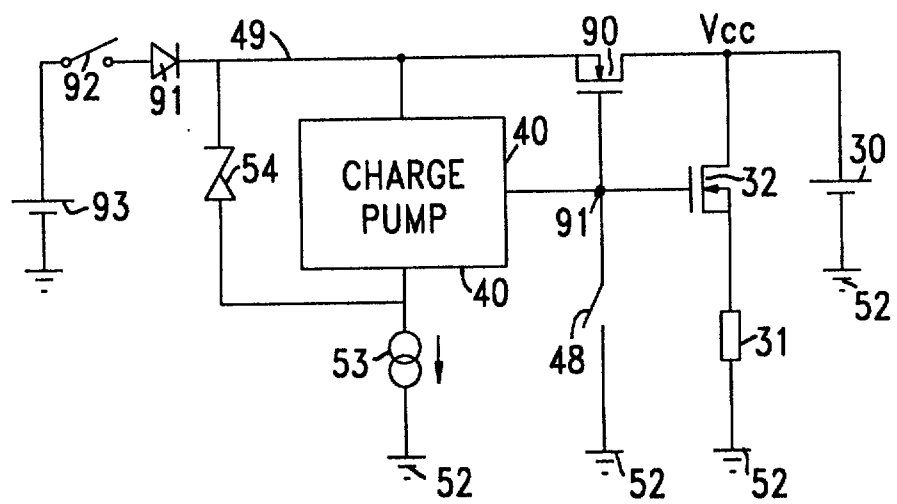


FIG. 8

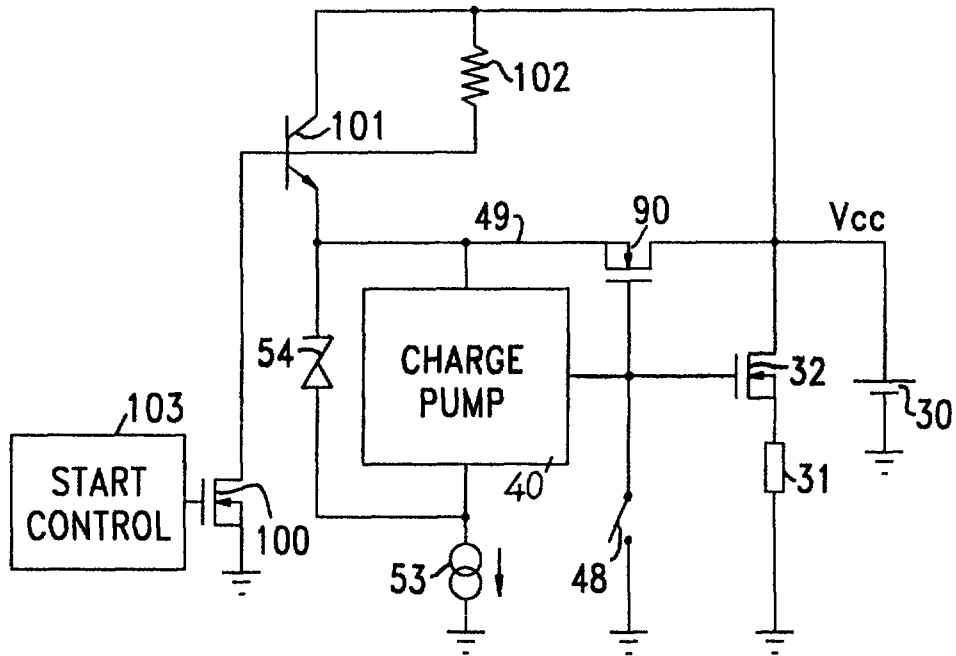


FIG. 9

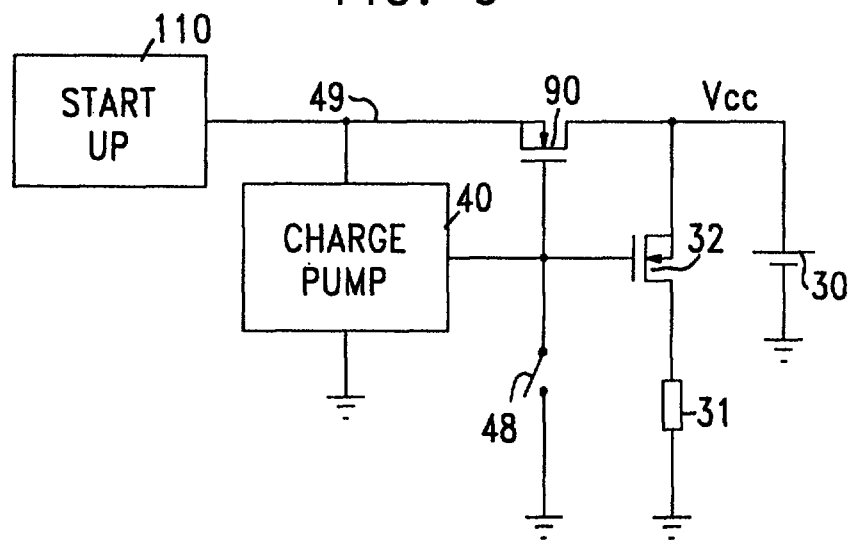


FIG. 10

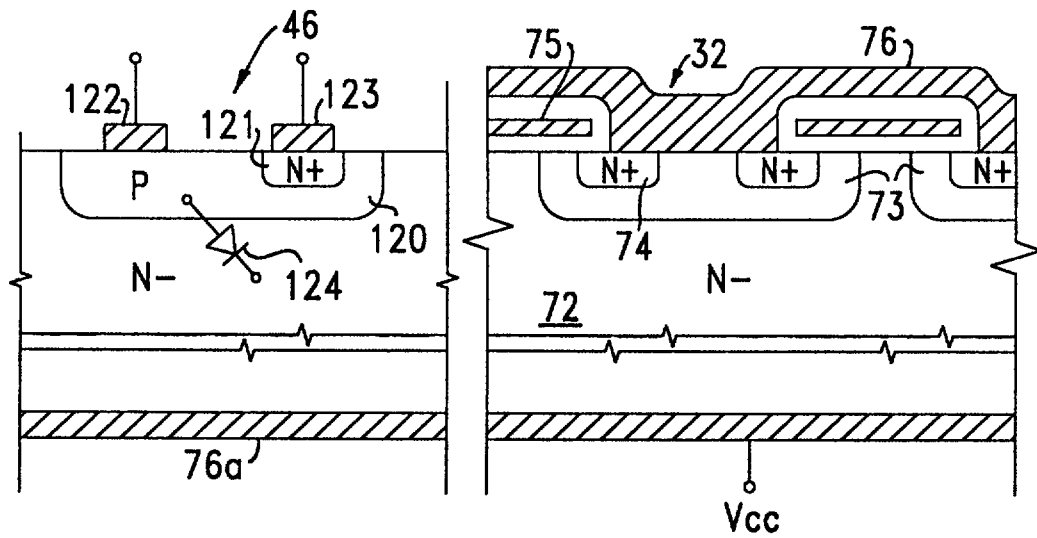


FIG. 11

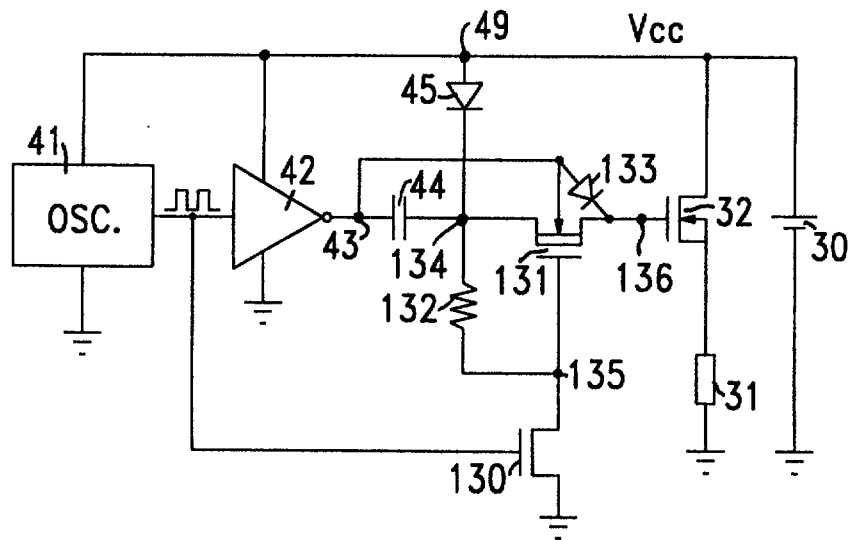


FIG. 12

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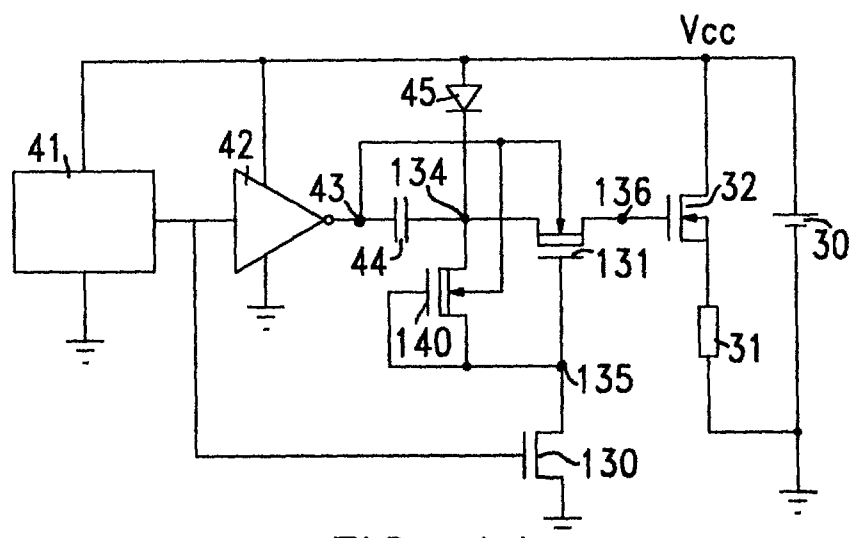


FIG. 14

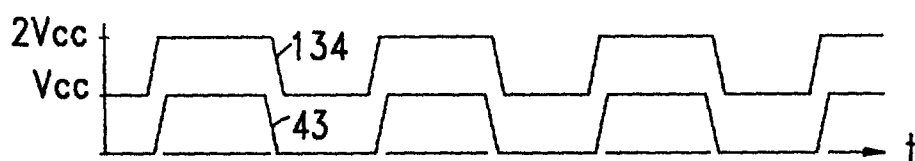


FIG. 13A

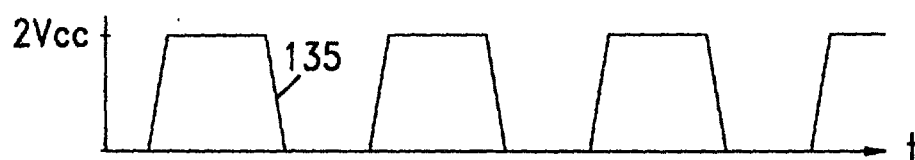


FIG. 13B

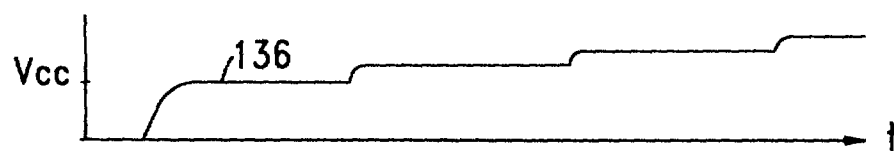


FIG. 13C

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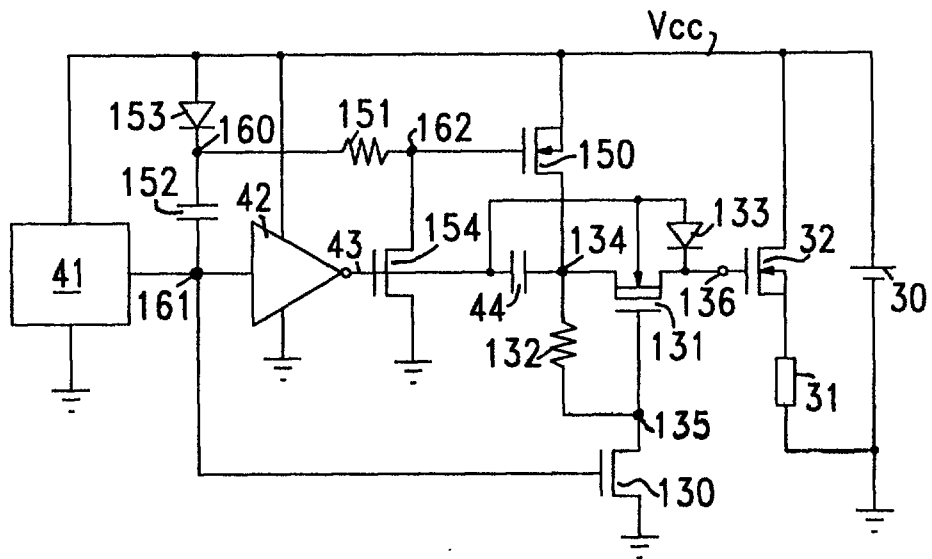


FIG. 15

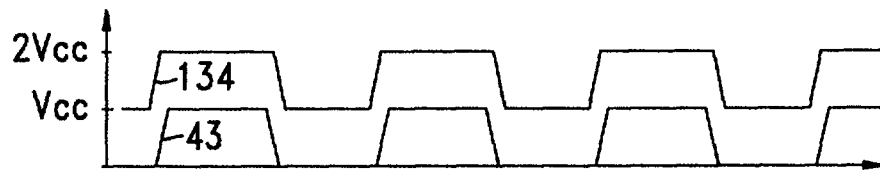


FIG. 16A

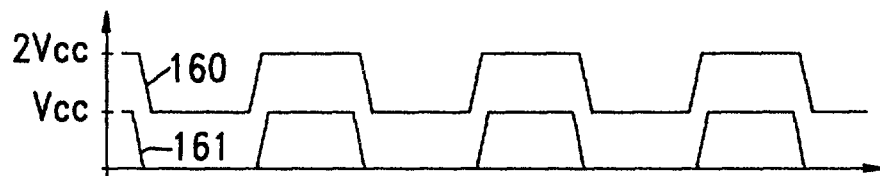


FIG. 16B

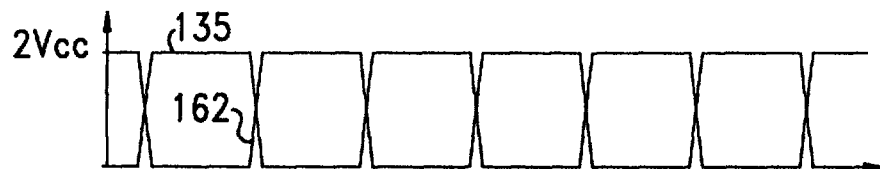


FIG. 16C

FIG. 18D

IMPROVED CHARGE PUMP CIRCUIT FOR HIGH SIDE SWITCH

ABSTRACT OF THE DISCLOSURE

A high side monolithic switching circuit integrated into a silicon chip is described in which the charge pump is connected to the ground terminal by a constant current circuit and floats relative to the ground terminal to reduce noise generation. The charge pump is connected to a V_{CC} terminal by an auxiliary power MOSFET having its gate connected to the charge pump output circuit. The conventional charge pump diodes are implemented as MOSFET devices which can be easily integrated into the common monolithic chip. A clamping circuit across the charge pump permits the use of a low voltage, small area capacitor for a high voltage device.

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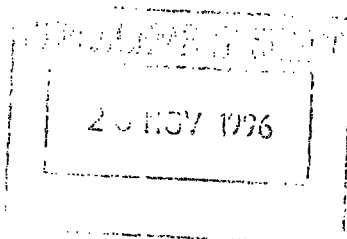


IMPROVED CHARGE PUMP CIRCUIT FOR HIGH SIDE SWITCHABSTRACT OF THE DISCLOSURE

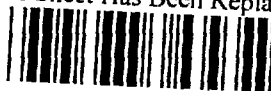
A high side monolithic switching circuit integrated into a silicon chip is described in which the charge pump is connected to the ground terminal by a constant current circuit and floats relative to the ground terminal to reduce noise generation. The charge pump is connected to a V_{CC} terminal by an auxiliary power MOSFET having its gate connected to the charge pump output circuit. The conventional charge pump diodes are implemented as MOSFET devices which can be easily integrated into the common monolithic chip. A clamping circuit across the charge pump permits the use of a low voltage, small area capacitor for a high voltage device.

Fig. 7

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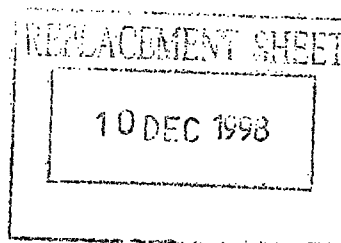
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WHAT IS CLAIMED IS:

1. A high side switch circuit comprising, which is characterized in containing in combination: a MOS gate controlled power semiconductor device having first and second power electrodes and a control electrode; a charge pump circuit having first and second power terminals and an output terminal; a constant current source circuit having input and output terminals; a V_{CC} input voltage terminal connected to said first power electrode of said MOS gate controlled power semiconductor device and connectable to a source of power; a load terminal connected to said second power electrode of said MOS gate controlled power semiconductor device and connectable to a grounded load that is capable of being energized from said source of power when said MOS gate controlled power semiconductor device is closed; and a ground terminal connectable to said grounded load; said charge pump circuit being operable to produce an output voltage at its said output terminal which is higher than said V_{CC} input voltage; said first power terminal of said charge pump circuit being connected with said V_{CC} input voltage terminal; said second power terminal of said charge pump circuit connected to said input terminal of said constant current circuit; said output terminal of said constant current circuit connected to said ground terminal, whereby said second power terminal has a floating potential; said output terminal of said charge pump circuit being connected to said control electrode of said MOS gate controlled power semiconductor device for providing a voltage sufficiently higher than the voltage of said second terminal to turn on said MOS gate controlled power semiconductor device.

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☒	Claim(s) : pages ... to ...	page ...
☐	Drawing(s) : pages ... to ...	page ...
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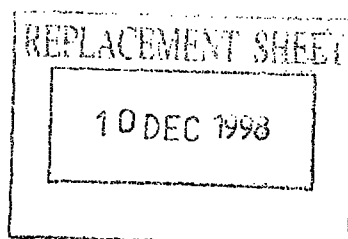
2. The circuit of claim 1 which is further characterized in that said MOS gate controlled power semiconductor device is a power MOSFET.

3. The circuit of claims 1 or 2 which is further characterized in including first switching means operable to connect and disconnect said charge pump first power terminal to said V_{CC} input voltage terminal and second switching means for connecting and disconnecting said control electrode of said MOS gate controlled power device to said ground terminal when said first switching means disconnects and connects said pump first power terminal to said V_{CC} input terminal respectively.

4. The circuit of claims 1, 2 or 3 which is further characterized in including voltage clamp means connected between said first and second power terminals of said charge pump circuit to limit the voltage therebetween.

5. The circuit of claims 1, 2, 3 or 4 which is further characterized in that said voltage clamp means comprises a zener diode.

6. The circuit of claims 1 to 5 which is further characterized in that said charge pump circuit comprises, in combination: a square wave oscillator connected to and operated from said first and second power terminals of said charge pump circuit and having an oscillator output terminal, an inverter buffer connected to said oscillator output terminal, a charge storage capacitor, a first diode and a second diode; said inverter buffer having an output connected in series with

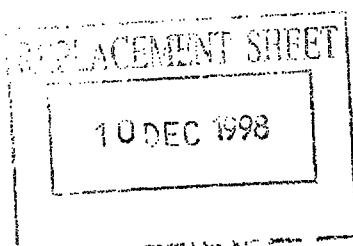




said capacitor and said first diode to said control electrode of said MOS gate controlled power device; said second diode connected from said V_{CC} input voltage terminal to the node between said capacitor and said first diode whereby, when the output of said inverter buffer is low, said capacitor is charged from the voltage at said V_{CC} terminal and through said second diode and, when said output of said inverter buffer is high, the voltage of said capacitor plus the voltage of said V_{CC} terminal are applied in series through said first diode to said control terminal of said MOS gate controlled power device.

7. The circuit of claims 1 to 6 which is further characterized in that said constant current circuit comprises a first control MOSFET having drain and source electrodes connected to said second power terminal of said charge pump circuit and said ground terminal respectively and a cascaded enhancement mode MOSFET and depletion mode MOSFET connected between an auxiliary voltage source and said ground terminal; the node between said enhancement mode and depletion mode MOSFETs connected to their respective gates and to the gate of said first control MOSFET.

8. The circuit of claim 7 which is further characterized in including a second control MOSFET in combination with said first MOSFET to increase the voltage between said second power terminal of said charge pump circuit and said ground terminal without breakdown of said first control MOSFET.

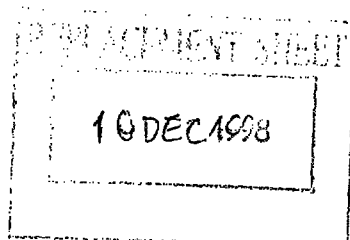




9. The circuit of claims 1 to 8 is further characterized in including an auxiliary power MOSFET having first and second power terminals and a gate terminal; said first and second power terminals of said auxiliary power MOSFET connected to said first power terminal of said charge pump circuit and said V_{cc} input voltage terminal respectively; said gate terminal of said auxiliary power MOSFET connected to said control electrode of said MOS gate controlled power semiconductor device.

10. The circuit of claim 9 which is further characterized in including starter circuit means coupled between a auxiliary supply voltage source and said charge pump circuit for starting said charge pump circuit before said auxiliary power MOSFET conducts.

11. A high side switch circuit characterized in comprising, in combination: a MOS gate controlled power semiconductor device having first and second power electrodes and a control electrode; a charge pump circuit having first and second power terminals and an output terminal; a V_{cc} input voltage terminal connected to said first power electrode of said MOS gate controlled power semiconductor device and connectable to a source of power; a load terminal connected to said second power electrode of said MOS gate controlled power semiconductor device and connectable to a grounded load which is energized from said source of power when said MOS gate controlled power semiconductor device is closed; and a ground terminal connectable to said grounded load; said charge pump circuit being operable to produce an output voltage at its said output terminal which is higher than

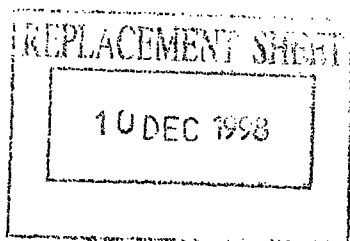




said V_{CC} input voltage; said second power terminal of said charge pump circuit connected to said ground terminal, whereby said output terminal of said charge pump circuit is connected to said control electrode of said MOS gate controlled power semiconductor device for providing a voltage sufficiently higher than the voltage of said second terminal to turn on said MOS gate controlled power semiconductor device; a grounding switch connected to said control electrode of said MOS gated power device for grounding said control electrode when said grounding switch is closed; and an auxiliary power MOSFET having first and second power terminals and a gate terminal; said first and second power terminals of said auxiliary power MOSFET connected to said first power terminal of said charge pump circuit and said V_{CC} input voltage terminal respectively; said gate terminal of said auxiliary power MOSFET connected to said control electrode of said MOS gate controlled power semiconductor device so that when said grounding switch is closed, said gate terminal of said auxiliary power MOSFET is grounded, thereby turning off said auxiliary power MOSFET to electrically isolate said charge pump circuit from said supply voltage.

12. The circuit of claim 11 which is further characterized in including starter circuit means coupled between a auxiliary supply voltage source and said charge pump circuit for starting said charge pump circuit before said auxiliary power MOSFET conducts.

13. The circuit of claim 1 which is further characterized in that said MOS gate controlled power semiconductor device, said charge pump circuit, and said



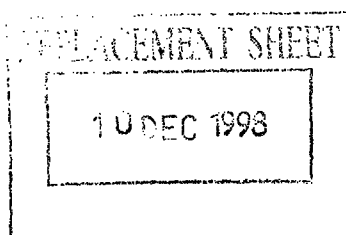


current source are integrated into a monolithic semiconductor chip.

14. The circuit of claim 3 which is further characterized in that said MOS gate controlled power semiconductor device, said charge pump circuit, said first switching means and said current source are integrated into a monolithic semiconductor chip.

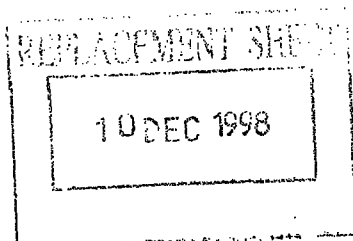
15. The circuit of claim 3 which is further characterized in that said MOS gate controlled power semiconductor device, said charge pump circuit, said voltage clamp means and said current source are integrated into a monolithic semiconductor chip.

16. The circuit of claim 9 which is further characterized in that said MOS gate controlled power semiconductor device, said charge pump circuit, said auxiliary power MOSFET and said current source are integrated into a monolithic semiconductor chip.





17. A high side switch circuit comprising, in combination: a MOS gate controlled power semiconductor device having first and second power electrodes and a control electrode; a charge pump circuit having first and second power terminals and a charge pump output terminal; a V_{CC} input voltage terminal connected to said first power electrode of said MOS gate controlled power semiconductor device and connectable to a source of power; a load terminal connected to said second power electrode of said MOS gate controlled power semiconductor device and connectable to a grounded load which is energized from said source of power when said MOS gate controlled power semiconductor device is closed; and a ground terminal connectable to said grounded load; said charge pump circuit being operable to produce an output voltage at said charge pump output terminal which is higher than said V_{CC} input voltage; said second power terminal of said charge pump circuit connected to said ground terminal, whereby said output terminal of said charge pump circuit is connected to said control electrode of said MOS gate controlled power semiconductor device for providing a voltage sufficiently higher than the voltage of said second terminal to turn on said MOS gate controlled power semiconductor device; said charge pump circuit characterized in comprising, in combination: a square wave oscillator having an oscillator output terminal; an inverter buffer connected to said oscillator output terminal; a charge storage capacitor coupled to the output of said inverter buffer; a first coupling circuit means coupling said capacitor to said control electrode of said MOSgated power semiconductor device; a second coupling circuit means for coupling said V_{CC} input voltage terminal to the node between said capacitor and said first coupling circuit means whereby, when the output of said inverter



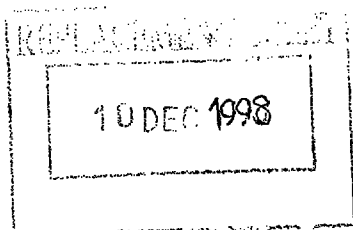


buffer is low, said capacitor is charged from the voltage at said V_{CC} terminal and through said second coupling circuit means and, when said output of said inverter buffer is high, the voltage of said capacitor plus the voltage of said V_{CC} terminal are applied in series through said first coupling circuit means to said control terminal of said MOSgated power semiconductor device; and wherein said first coupling circuit means comprises a depletion mode MOSFET having source and drain terminals connected to said capacitor and control electrode of said MOSgated power semiconductor device respectively and having its substrate connected to the output of said inverter buffer; a resistive circuit means connected from said capacitor to the gate of said depletion mode MOSFET, and a second control MOSFET connected between said gate of said depletion mode MOSFET and said ground terminal and having a gate connected to said oscillator output terminal.

18. The circuit of claim 17 which is further characterized in that said second coupling circuit means is a diode.

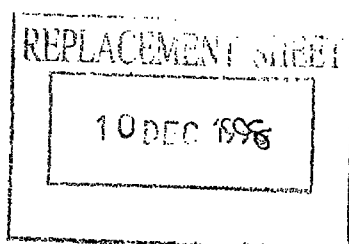
19. The circuit of claim 17 or 18 which is further characterized in that said resistive circuit means comprises a second depletion mode MOSFET having a gate connected to the gate of said first-mentioned depletion mode MOSFET and a substrate connected to the substrate of said first-mentioned depletion mode MOSFET.

20. The circuit of claims 17, 18 or 19 which is further characterized in that wherein said second coupling circuit means includes a control MOSFET.



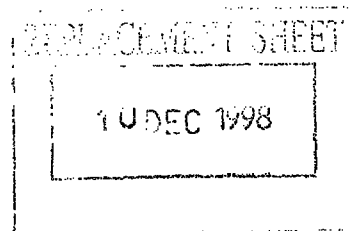


21. A high side switch circuit comprising, in combination: a MOS gate controlled power semiconductor device having first and second power electrodes and a control electrode; a charge pump circuit having first and second power terminals and a charge pump output terminal; a V_{CC} input voltage terminal connected to said first power electrode of said MOS gate controlled power semiconductor device and connectable to a source of power; a load terminal connected to said second power electrode of said MOS gate controlled power semiconductor device and connectable to a grounded load which is energized from said source of power when said MOS gate controlled power semiconductor device is closed; and a ground terminal connectable to said grounded load; said charge pump circuit being operable to produce an output voltage at said charge pump output terminal which is higher than said V_{CC} input voltage; said second power terminal of said charge pump circuit connected to said ground terminal, whereby said output terminal of said charge pump circuit is connected to said control electrode of said MOS gate controlled power semiconductor device for providing a voltage sufficiently higher than the voltage of said second terminal to turn on said MOS gate controlled power semiconductor device; said charge pump circuit characterized in comprising, in combination: a square wave oscillator having an oscillator output terminal; an inverter buffer connected to said oscillator output terminal; a charge storage capacitor coupled to the output of said inverter buffer; a first coupling circuit means for transferring charge stored in said capacitor to said control electrode of said MOSgated power semiconductor device; a second coupling circuit means for coupling said V_{CC} input voltage terminal to the node between said capacitor and said first coupling circuit means whereby, when the output of said inverter buffer is low, said capacitor is charged





from the voltage at said V_{CC} terminal and through said second coupling means and, when said output of said inverter buffer is high, the voltage of said capacitor plus the voltage of said V_{CC} terminal are applied in series through said first coupling circuit means to said control terminal of said MOSgated power semiconductor device; and wherein said second coupling circuit means includes a control MOSFET.



IMPROVED CHARGE PUMP CIRCUIT FOR HIGH SIDE SWITCH

ABSTRACT OF THE DISCLOSURE

A high side monolithic switching circuit integrated into a silicon chip is described in which the charge pump is connected to the ground terminal by a constant current circuit and floats relative to the ground terminal to reduce noise generation. The charge pump is connected to a V_{CC} terminal by an auxiliary power MOSFET having its gate connected to the charge pump output circuit. The conventional charge pump diodes are implemented as MOSFET devices which can be easily integrated into the common monolithic chip. A clamping circuit across the charge pump permits the use of a low voltage, small area capacitor for a high voltage device.

Fig. 7

