

INTERNAL POWER SUPPLY CIRCUIT**BACKGROUND OF THE INVENTION****1. Field of the Invention**

The present invention relates to a power supply circuit, more particularly relates to a booster circuit generating a voltage higher than an external power supply voltage by raising the voltage from the external power supply voltage or a down converter or other DC (direct current)-DC converter generating a voltage lower than the external power supply voltage by lowering the voltage from the external power supply voltage.

2. Description of the Related Art

In recent years, the practice in EEPROMs, flash memories, and other read only memories which can be electrically rewritten has been to supply only a single low power supply voltage from the outside, generate inside the chip an internal voltage higher than the voltage supplied from the outside, and write data into the memory by the high voltage inside the chip.

However, the voltage of the external power supply is being reduced as a general trend and the

boosting efficiency drops the lower the voltage. Therefore, it has not been possible to generate an internal boosted voltage having a sufficient power.

On the other hand, the external power supply used is usually a 5V single power supply, but it has become necessary to operate semiconductor devices at a lower internal voltage due to the desire to deal with the deterioration of the voltage resistance of semiconductor devices accompanying higher integration and the desire to reduce the power consumption.

However, the loss caused by the operation of a power supply circuit in the chip is large and obstructs the reduction of the power consumption.

SUMMARY OF THE INVENTION

An object of the present invention is to provide a power supply circuit able to decrease the number of charge pumping circuits used for obtaining a desired high voltage by increasing the efficiency of raising or lowering the voltage and to give a stable output voltage with a low power loss.

According to one aspect of the present invention, there is provided an internal power supply circuit comprising a plurality of charge accumulating means, a first power supply terminal, a second power supply

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terminal, a first switching means for connecting the plurality of charge accumulating means in parallel to each other in a first state, and a second switching means for connecting the plurality of charge accumulating means in series with each other in a second state, and a control means for energizing the first switching means or the second switching means in response to the first state or the second state to connect the plurality of charge accumulating means between the first power supply terminal and the second power supply terminal, and for deenergizing the first switching means or the second switching means in response to the first state or the second state to disconnect the plurality of charge accumulating means between the first power supply terminal and the second power supply terminal, the control means repeating the energizing and the deenergizing.

Preferably, the charge accumulating means are constituted by capacitors; the first switching means is constituted by a third switching means and a fourth switching means; and a partial booster circuit is comprised by a capacitor connected between a first node and a second node, the third switching means connected between the first node and the first power supply terminal, and the fourth switching means connected

between the second node and the second power supply terminal; a plurality of the partial booster circuits is provided; the second switching means holds in a non-conductive state the first node of a front partial booster circuit and the second node of a rear partial booster circuit in the first state and holds them in a conductive state in the second state; the first switching means comprised of the third switching means and the fourth switching means being held in the conductive state and the second switching means being held in a non-conductive state in the first state; and the first switching means comprised of the third switching means and the fourth switching means being held in the non-conductive state and the second switching means being held in a conductive state in the second state so as to raise the voltage between the first power supply terminal and the second power supply terminal.

The internal power supply circuit of the present invention further comprises a biasing means connected to the second node of the initial stage partial booster circuit for holding the second node at a constant potential and a rectifying means connected between the first node of the final stage partial booster circuit and a boosted voltage output terminal.

Preferably, the biasing means is constituted by a

switching means set in the conductive state when the first switching means comprised of the third and fourth switching means is non-conductive.

Preferably, the first power supply terminal is a positive power supply terminal and the second power supply terminal is a negative power supply terminal, the constant potential is the potential of the first power supply terminal, the biasing means is a rectification element connected so that a direction from the first power supply toward the second node of the initial stage partial booster circuit becomes a forward direction, and the rectification element is connected so that a direction from the first node of the final stage partial booster circuit toward the output terminal becomes the forward direction and supplies the positive boosted voltage to the output terminal.

Alternatively, the first power supply terminal is a negative power supply terminal and the second power supply terminal is a positive power supply terminal, the constant potential is the potential of the second power supply terminal, the biasing means is a rectification element connected so that a direction from the second node of the first stage partial booster circuit toward the first power supply terminal becomes the forward direction, and the rectification element is connected so

that a direction from the output terminal to the first node of the final stage partial booster circuit becomes the forward direction and supplies the negative boosted voltage to the output terminal.

Preferably, the third switching means is constituted by a first conductivity type insulation gate type field effect transistor with a gate electrode connected to an input terminal of a first clock, with one diffusion layer connected to the first power supply, and with another diffusion layer connected to the first node of the partial booster circuit; the fourth switching means is constituted by a first conductivity type insulation gate type field effect transistor with a gate electrode connected to an input terminal of a second clock, with one diffusion layer connected to the second power supply, and with another diffusion layer connected to the second node of the partial booster circuit; and the second switching means is constituted by a second conductivity type insulation gate type field effect transistor with a gate electrode connected to the input terminal of a third clock.

Preferably, the biasing means is constituted by a second conductivity type insulation gate type field effect transistor with a gate electrode connected to the input terminal of a third clock.

Preferably, an amplitude of the first clock is set larger than a potential difference between the first power supply terminal and the second power supply terminal.

Preferably, the first power supply terminal is a positive power supply terminal and the first conductivity type insulation gate type field effect transistor is an n-channel type transistor and is held at a higher level than the first power supply terminal voltage in a high level section of the first clock.

Alternatively, the first power supply is a negative power supply terminal and the first conductivity type insulation gate type field effect transistor is a p-channel type transistor and is held at a lower level than the second power supply terminal voltage in a low level section of the first clock.

Preferably, the second conductivity type insulation gate type field effect transistor constituting the second switching means is formed in an independent well.

Preferably, the biasing means is a second conductivity type insulation gate type field effect transistor formed in the same well as that for the second conductivity type insulator gate type field effect transistors constituting part of the peripheral logic circuit.

According to a second aspect of the present invention, there is provided an internal power supply circuit comprising a first power supply terminal, a second power supply terminal, a first node, a second node, a capacitor connected between the first node and the second node, a first switching means connected between the first node and the first power supply terminal, a second switching means connected between the second node and the second power supply terminal, a biasing means connected to the second node and biasing the node at a constant potential, and a rectifying means connected between the first node and the boosted voltage output terminal, the first and second switching means being repeatedly set in the conductive state and the non-conductive state to be overlapped thereby to output a boosted voltage to an output terminal.

Preferably, the biasing means is a rectification element connected so that a direction from the first power supply toward the second node becomes a forward direction, and the rectifying means is connected so that a direction from the first node toward the boosted voltage output terminal becomes the forward direction.

Preferably, the biasing means is a rectification element connected so that a direction from the second node toward the first power supply becomes a forward

direction, and the rectifying means is connected so that a direction from the boosted voltage output terminal toward the first node becomes the forward direction.

Preferably, the charge accumulating means are constituted by capacitors; the capacitors are connected in series between the first and second power supply terminals and then are charged in the second state; and the capacitors are connected in parallel between the second power supply terminal and a down voltage output terminal in the first state to thereby obtain a voltage between the first and second power supply terminal.

Preferably, further there is provided a switching means connecting to an external power supply between the voltage of the first power supply terminal and the voltage of the second power supply terminal, having at least one sub-power supply of a potential lower than the external power supply, and operationally connects the external power supply and the sub-power supply and of a means for sequentially switching the connection and nonconnection state from the switching means connected to the external power supply to cause charging and discharging of the capacitors.

Preferably further there is provided a means for sequentially switching the connection and nonconnection state from the switching means connected to the sub-

power supply to cause charging and discharging of the capacitors.

Preferably further there is provided at least two arrangements of a plurality of capacitors which are switched between the serial connection and parallel connection based on a clock signal and clock signals having inverse phases are supplied to the above at least two arrangements.

Preferably, the capacitors are composed of ferroelectric capacitors, high dielectric capacitors, MIM (metal-insulator-metal) configuration capacitors, DRAM trench and stack capacitors, planar capacitors, external capacitors, or MIS (metal-insulator-semiconductor) gate capacitors.

According to the present invention, by setting the first and second switching means in the conductive state and setting the third switching means in the nonconductive state, the capacitance element of each booster stage is charged to the differential voltage level between the first power supply and the second power supply, then the first and second switching means are changed over to the nonconductive state and the third switching means is changed over to the conductive state, whereby the charged capacitance elements are connected in series between the constant potential and the output

terminal of the power supply circuit and a positive or negative boosted voltage is output to the output terminal of the power supply circuit.

For this reason, the loss of the boosted voltage becomes only the voltage drop of the rectification element connected between the final stage and the output terminal, the reduction of the boosting efficiency accompanying the rise of the threshold voltage due to the substrate biasing effect can be avoided, and a reduction of the number of the booster stages for obtaining a desired high voltage and a shortening of the rising time of the boosted voltage can be achieved.

Further, according to the present invention, the value of the external power supply voltage is detected by a detecting circuit and the number of connections of the plurality of capacitance elements is switched in accordance with this detected voltage.

Then, the number of the capacitance elements set in accordance with the detected voltage are connected in series between the external power supply and the reference power supply and next connected in parallel and, at the same time, the connection and nonconnection states sequentially switched from the switching means connected to the external power supply to perform charging and discharging, thus an output voltage of a

value between the external ¹² power supply voltage and the reference power supply voltage is obtained.

Also, the switching between the serial connection and parallel connection of the capacitance elements is carried out based on the clock signal. Further, two systems of the plurality of capacitance elements are respectively driven by clock signals having inverse phases to each other. By this, the ripple accompanying the load current can be lowered.

Also, the capacitance element is comprised by an element having a high relative dielectric constant such as a ferroelectric capacitance, whereby the power loss is reduced.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other objects and features of the present invention will become more apparent from the following description of the preferred embodiments made with reference to the drawings, in which:

Fig. 1 is a circuit diagram of an example of an inner power supply circuit;

Fig. 2 is a circuit diagram of a first embodiment of an inner power supply circuit according to the present invention;

Fig. 3 is a circuit diagram of the configuration of

a booster stage of the first embodiment shown in Fig. 2;

Figs. 4A to 4J are timing charts of the power supply circuit of the first embodiment shown in Fig. 2;

Fig. 5 is a circuit diagram of an example of a clock generating circuit supplying a clock signal to the power supply circuit of the first embodiment shown in Fig. 2;

Fig. 6 is a circuit diagram of a boosting clock generator used in Fig. 5;

Figs. 7A to 7H are timing charts of an operation of the clock generating circuit shown in Fig. 5;

Fig. 8 is a circuit diagram of a second embodiment of the power supply circuit according to the present invention;

Fig. 9 is a circuit diagram of the configuration of the booster stage of a second embodiment shown in Fig. 8;

Figs. 10A to 10J are timing charts of the power supply circuit of the second embodiment shown in Fig. 8;

Fig. 11 is a circuit diagram of a boosting clock generator used in Fig. 8;

Figs. 12A to 12E are timing charts of an operation of the clock generating circuit shown in Fig. 8;

Fig. 13 is a circuit diagram of a fundamental configuration of a series regulator as a down converter used as an internal low voltage power supply circuit;

Fig. 14 is a circuit diagram of an example of the configuration of a capacitor switching type down converter;

Fig. 15 is a circuit diagram of a third embodiment of the down converter according to the present invention;

Figs. 16A to 16J are timing charts of an operation of the third embodiment shown in Fig. 15;

Fig. 17 is a circuit diagram of an example of the configuration of a power supply circuit for $0.25 V_{cc}$ according to the present invention; and

Fig. 18 is a circuit diagram of a fourth embodiment of a down converter according to the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Erasing or writing an electrically erasable and programmable read only memory such as an EEPROM or flash memory requires a voltage higher than the supplied voltage. Therefore, various power supply circuits have been devised. Figure 1 is a circuit diagram of a representative example of a conventional power supply circuit constituted by a booster circuit.

Note that, in Fig. 1, M1 to M4 are n-channel type MOS transistors, and C_L is a load capacitor.

As illustrated, the power supply circuit of Fig. 1 is constituted by connecting a plurality of stages of

partial circuits (booster stages) each comprising one capacitor, for example, C2, and one nMOS transistor, for example, M2, in series.

One of the electrodes of each of the capacitors C2, C3, C4 constituting a booster stage are connected to a common connecting point of the gate electrodes and drain diffusion layers of the nMOS transistors M2, M3, M4. The other electrodes of the capacitors C2, C3, C4 are alternately connected to either of supply lines of the clocks $\phi 1$ and $\phi 2$. The common connecting point of the gate electrodes and drain diffusion layers of the diode-connected n-channel type MOS transistors constituting the booster stages is connected to the source diffusion layer of the n-channel type MOS transistor of the booster stage of the front stage, while the source diffusion layer is connected to the common connecting point of the gate electrodes and the drain diffusion layers of the diode-connected n-channel type MOS transistors of the next stage.

Further, the order of connection of the clocks $\phi 1$ and $\phi 2$ is one where the odd number stages of the booster stages are connected to the clock $\phi 1$ and the even number stages are connected to the clock $\phi 2$.

The above power supply circuit constituted in this way attracts the charges from a semiconductor substrate

on which a power supply voltage V_{cc} and the present circuit are formed by giving the clocks $\phi 1$ and $\phi 2$ by inverse phases and supplies a boosted voltage V_{out} to an output terminal T_{out} .

In above-described power supply circuit, a large number of stages of the diode-connected transistors are needed for obtaining a desired high voltage since a forward direction voltage drop corresponding to the threshold voltage V_{th} of the nMOS transistor is caused. Particularly, the nearer to the output terminal T_{out} of the power supply circuit, the larger the reverse direction potential difference between the source and the substrate, so the larger the substrate biasing effect and the more the threshold voltage V_{th} of the transistor rises. Therefore, there is a disadvantage that the boosting efficiency is conspicuously lowered even if the number of stages is increased.

Preferred embodiments of the present invention will now be explained in further detail with reference to the drawings.

Figure 2 is a circuit diagram of a first embodiment of the power supply circuit according to the present invention.

In Fig. 2, CLK_1 , CLK_2 , and CLK_3 denote clock signals, T_{CLK1} , T_{CLK2} , and T_{CLK3} denote clock signal input

terminals, PT_1 denotes a p-channel type (pMOS) ¹⁷
 transistor serving as a biasing means, PT_2 and PT_3
 denote pMOS transistors serving as the third switching
 means, PT_4 denotes diode-connected pMOS transistor, NU_1 ,
 NU_2 , and NU_3 denote n-channel MOS (nMOS) transistors
 serving as the first switching means, NL_1 , NL_2 , and NL_3
 denote nMOS transistors serving as the second switching
 means, K_1 , K_2 , K_3 , L_1 , L_2 , and L_3 denote nodes of the
 booster stages, C_1 , C_2 , and C_3 denote capacitance
 elements (capacitors) for boosting, C_L denotes a
 parasitic capacitance of the load, and T_{out} denotes an
 output terminal of the boosted voltage V_{out} .

Note that the power supply circuit shown in Fig. 2
 is constituted by the booster stages shown in Fig. 3.

Here, an explanation will be given of the
 configuration assuming that the booster stage shown in
 Fig. 3 is a booster stage of the i -th stage. As
 illustrated, the booster stage of i -th stage is
 constituted by a capacitor C_i , nodes K_i and L_i , and nMOS
 transistors NU_i and NL_i .

The capacitor C_i is connected between the node K_i
 and the node L_i .

The gate electrode of the nMOS transistor NU_i is
 connected to the input terminal of the clock signal CLK_i ,
 one diffusion layer is connected to the supply line of

the power supply voltage V_{cc} , and the other diffusion layer is connected to the node L_1 .

The gate electrode of the nMOS transistor NL_1 is connected to the input terminal of the clock signal CLK_2 , one diffusion layer is connected to the node K_1 , and the other diffusion layer is connected to the ground line.

The power supply circuit shown in Fig. 2 is configured with three stages of the booster stages shown in Fig. 3 connected in series.

As illustrated, the node K_1 of the booster stage of first stage is connected via the pMOS transistor PT_1 to the supply line of the power supply voltage V_{cc} . Namely, the source electrode of the pMOS transistor PT_1 is connected to the supply line of the power supply voltage V_{cc} , and the drain electrode is connected to the node K_1 . The gate electrode of the pMOS transistor PT_1 is connected to the input terminal T_{CLK_3} of the clock signal CLK_3 .

The node L_1 of the booster stage of the first stage is connected via the pMOS transistor PT_2 to the node K_2 of the booster stage of the second stage. Namely, the source electrode of the pMOS transistor PT_2 is connected to the node L_1 of the booster stage of the first stage, and the drain electrode is connected to the node K_2 of the booster stage of the second stage.

The gate electrode of the pMOS transistor PT_2 is connected to the input terminal T_{CLK_2} of the clock signal CLK_2 .

The node L_2 of the booster stage of the second stage is connected via the pMOS transistor PT_2 to the node K_2 of the booster stage of the third stage. Namely, the source electrode of the pMOS transistor PT_2 is connected to the node L_2 of the booster stage of the second stage, and the drain electrode is connected to the node K_2 of the booster stage of the third stage.

The gate electrode of the pMOS transistor PT_3 is connected to the input terminal T_{CLK_3} of the clock signal CLK_3 .

The node L_3 of the booster stage of the third stage is connected via the pMOS transistor PT_3 to the output terminal T_{OUT} of the power supply circuit. Namely, the source electrode of the pMOS transistor PT_3 is connected to the node L_3 of the booster stage of the third stage, and the drain electrode is connected to the output terminal T_{OUT} of the power supply circuit.

The gate electrode of the pMOS transistor PT_4 is connected to the output terminal T_{OUT} commonly with the drain electrode. Namely, the pMOS transistors PT_4 are diode-connected.

Further, the output terminal T_{OUT} is grounded via

the load capacitor C_L .

Note that, in the power supply circuit shown in Fig. 2, the pMOS transistor PT_1 serving as the biasing means is for example formed in the same well as that of the other transistors constituting the peripheral circuits of the power supply circuit. pMOS transistors PT_2 and PT_3 are formed in each independent well as the third switching means.

Below, an explanation will be made of the boosting operation of the power supply circuit having the above configuration referring to the timing chart of Figs. 4A to 4J.

At the time of the boosting operation, a clock signal CLK_1 is supplied to the gate electrodes of the nMOS transistors NU_1 , NU_2 , and NU_3 constituting the booster stages. As shown in Fig. 4A, the high-level of the clock signal CLK_1 is held at a higher level than the power supply voltage V_{cc} , for example, a potential of $(V_{cc} + V_{TH})$. Note that, here, V_{TH} is a threshold voltage of the nMOS transistors NU_1 , NU_2 , and NU_3 .

For this reason, when the clock signal CLK_1 is held at a high level, a voltage higher than the power supply voltage V_{cc} , for example, a voltage of $(V_{cc} + V_{TH})$, is supplied to the gate electrodes of the nMOS transistors NU_1 , NU_2 , and NU_3 constituting the booster stages. The

drain electrodes of these transistors are held at a potential of the same level as that of the power supply voltage V_{cc} .

The clock signal CLK_1 , supplied to the gate electrodes of the nMOS transistors NL_1 , NL_2 , and NL_3 , constituting the booster stages is held at a high level and low level in synchronization with the clock signal CLK_1 . Note that, the high level of the clock signal CLK_1 is held at for example the power supply voltage V_{cc} level.

When both of the clock signal CLK_1 and clock signal CLK_2 are held at the high level, all of the nMOS transistors NU_1 , NU_2 , and NU_3 and NL_1 , NL_2 , and NL_3 , constituting the booster stages are set in the conductive state, and the clock signal CLK_2 , supplied to the gate electrodes of the pMOS transistors PT_1 , PT_2 , and PT_3 , connected between the booster stages is held at a high level, for example, the power supply voltage V_{cc} level. therefore all of these pMOS transistors PT_1 , PT_2 , and PT_3 are held in the nonconductive state.

Due to this, during the period from a time t_0 to a time t_1 shown in Figs. 4A and 4B, the clock signal CLK_1 and the clock signal CLK_2 are held at a high level, and the capacitors C_1 , C_2 , and C_3 existing in the booster stages are charged to for example the power supply

voltage V_{cc} level.

At the time t_1 , both of the clock signal CLK_1 and clock signal CLK_2 are switched to the low level, therefore the nMOS transistors NU_1 , NU_2 , and NU_3 and NL_1 , NL_2 , and NL_3 constituting the booster stages are set in the nonconductive state at the time t_1 .

Next, at the time t_2 , the clock signal CLK_1 is switched from the high level to the low level, for example, the ground potential GND. In accordance with this, all of the pMOS transistors PT_1 , PT_2 , and PT_3 are switched to the conductive state.

Due to this, the capacitors C_1 , C_2 , and C_3 all charged to the power supply voltages V_{cc} level are connected in series between the node K_1 of the first stage and the output terminal T_{out} of the power supply circuit, and a voltage obtained by multiplying the power supply voltage by (number of booster stages + 1) is obtained at one end of the capacitor of the final stage.

Here, when the number of the booster stages of the power supply circuit is defined as n and the threshold voltage of the pMOS transistors PT_i diode-connected between the node L_n of the booster stage of the final stage and the output terminal T_{out} is defined as V_{th} , the boosted voltage V_{out} obtained by the power supply circuit

$$V_{out} = (n+1) \times V_{cc} - V_{TP} \quad 23 \quad \dots (1)$$

As shown in Figs. 4D to 4J, after the PMOS transistors PT_1 , PT_2 , and PT_3 are all switched to the conductive state, the node K_1 of the booster stage of the first stage is held at the power supply voltage V_{cc} level, and the node L_1 is held at the $2V_{cc}$ level.

The node K_2 of the second stage is held at $2V_{cc}$ in the same way as the node L_1 of the first stage, and the node L_2 of the second stage is held at $3V_{cc}$.

The node K_3 of the third stage is held at $3V_{cc}$ in the same way as the node L_2 of the second stage, and the node L_3 of the third stage is held at $4V_{cc}$.

The PMOS transistors PT_i are diode-connected. The connection is made so that the direction from the node L_3 of the third stage toward the output terminal T_{out} becomes the forward direction, therefore the voltage of the node L_3 is output to the output terminal T_{out} . By this, the capacitor C_L is charged, and a boosted voltage V_{out} of substantially $4V_{cc}$ is output to the output terminal T_{out} .

Figure 5 is a circuit diagram of a clock generating circuit showing an example of the circuit for generating the clock signals CLK_1 , CLK_2 , and CLK_3 shown in Fig. 2.

As illustrated, the clock generating circuit of the present example is constituted by RS flip-flops RFF_1 ,

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RFF_1 , RFF_2 , RFF_3 , RFF_4 , and RFF_5 , a clock generator 10, and delay circuits DLY_1 and DLY_2 .

An example of the configuration of the clock generator 10 is shown in Fig. 6.

As illustrated, the clock generator 10 is constituted by the nMOS transistors NA, NB, NC, and ND and a capacitor C_{cx} .

One diffusion layer of the nMOS transistor NB is connected to the supply line of the power supply voltage V_{cc} , the other diffusion layer is connected to the node ND_1 , and the gate electrode is connected to the input terminal of the clock signal B.

One diffusion layer of the nMOS transistor NA is connected to the node ND_1 , the other diffusion layer is grounded, and the gate electrode is connected to the input terminal of the clock signal A.

One diffusion layer of the nMOS transistor ND is connected to the supply line of the power supply voltage V_{cc} , the other diffusion layer is connected to the node ND_2 , and the gate electrode is connected to the input terminal of the clock signal D.

One diffusion layer of the nMOS transistor NC is connected to the node ND_2 , the other diffusion layer is grounded, and the gate electrode is connected to the input terminal of the clock signal C.

A capacitor C_{ck} is connected between the node ND_1 and the node ND_2 , and the node ND_2 is connected to the output terminal T_1 of the clock signal CLK_1 .

At the time of the boosting operation, the clock signals A , B , C , and D shown in Figs. 7A to 7D are input to the clock generator 10.

Upon receipt of this, the clock generator 10 generates a clock signal CLK_1 held at a higher level than that of the power supply voltage V_{cc} at the time of a high level.

As shown in Fig. 5, the set signal input terminal S of the RS flip-flop RFF_1 is connected to the inverted output terminal of the RS flip-flop RFF_2 , and a reset signal input terminal R is connected to the inverted output terminal of the RS flip-flop RFF_1 .

The output terminal of the RS flip-flop RFF_1 is connected to the set signal input terminal S of the RS flip-flop RFF_2 , and the inverted output terminal is connected to the reset signal input terminal R of the RS flip-flop RFF_2 .

Further, the inverted output signal of the RS flip-flop RFF_1 is output as the clock signal C to the clock generator 10.

The reset signal input terminal R of the RS flip-flop RFF_2 is connected to the inverted output terminal of

the RS flip-flop RFF₂, and the output terminal is connected to the set signal input terminal S of the RS flip-flop RFF₃.

Further, the output signal of the RS flip-flop RFF₂ is supplied to the clock generator 10 as the clock signal D.

The reset signal input terminal R of the RS flip-flop RFF₃ is connected to the inverted output terminal of the RS flip-flop RFF₂, and the output terminal is connected to the set signal input terminal S of the RS flip-flop RFF₄.

Further, the inverted output signal of the RS flip-flop RFF₃ is supplied to the clock generator 10 as the clock signal A.

The reset signal input terminal R of the RS flip-flop RFF₄ is connected to the inverted output terminal of the RS flip-flop RFF₃, and the output terminal is connected to the set signal input terminal S of the RS flip-flop RFF₅ via the delay circuit DLY₁.

Further, the output signal of the RS flip-flop RFF₄ is supplied to the clock generator 10 as the clock signal B.

The reset signal input terminal R of the RS flip-flop RFF₅ is connected to the output terminal of the RS flip-flop RFF₄, and the inverted output terminal is

connected to the output terminal ²⁷T₂ of the clock signal CLK₂.

The reset signal input terminal R of the RS flip-flop RFF₁ is connected to the inverted output terminal of the RS flip-flop RFF₁, the set signal input terminal S is connected to the output terminal of the delay circuit DLY₂, and the input terminal of the delay circuit DLY₂ is connected to the inverted output terminal of the RS flip-flop RFF₁.

The output terminal of the RS flip-flop RFF₁ is connected to the output terminal T₂ of the clock signal CLK₂.

Below, referring to the timing chart shown in Figs. 7A to 7H, the operation of the clock generating circuit having the above configuration will be explained.

The clock generating circuit shown in Fig. 5 generates the clock signals A, B, C, and D shown in Figs. 7A to 7H and the clock signals CLK₁, CLK₂, and CLK₃.

Note that, the clock signals A, B, C, and D are clock signals alternately taking a high level, for example, the power supply voltage V_{cc} level, and a low level, for example, the ground potential GND level.

Similarly, the clock signals CLK₂ and CLK₃ are clock signals alternately taking a high level, for example, the power supply voltage V_{cc} level, and a low level, for

example, the ground potential GND level.

The clock signals A, B, C, and D are input to the clock generator 10. The clock generator 10 generates a clock signal CLK_1 which is held at a level of more than the power supply voltage V_{cc} at the time of the high level and is held at for example the ground potential GND level at the time of the low level.

As shown in Fig. 6, when both of the clock signal D and the clock signal A are held at the high level and both of the clock signal B and the clock signal C are held at the low level, the nMOS transistors NA and ND are held in the conductive state, and the nMOS transistors NB and NC are held in the nonconductive state.

By this, the node ND_1 is held at the ground potential GND level, and the node ND_2 side is held at a voltage reduced from the power supply voltage V_{cc} by exactly the threshold voltage V_{th} of the nMOS transistor ND , therefore the capacitor C_{cx} is charged to $(V_{cc} - V_{th})$.

Further, at this time, the voltage of $(V_{cc} - V_{th})$ level is output to the output terminal T_1 of the clock signal CLK_1 .

Then, at the time t_0 , shown in Figs. 7A to 7H, the clock signal B is switched from the low level to the high level. Also, at this time, both of the clock A and clock C are held at the low level, and the nMOS transistors NA

and NC are set in the nonconductive state.

In accordance with this, the nMOS transistor NB is switched to the conductive state, and the node ND₁ is held at a voltage reduced from the power supply voltage V_{cc} by exactly the threshold voltage V_{TN} of the nMOS transistor NB, that is, $(V_{cc} - V_{TN})$. By this, the node ND₂ is held at $2(V_{cc} - V_{TN})$. At this time, as shown in Fig. 7F, the voltage of the output terminal T₁ of the clock signal CLK₁ rises by one stage and becomes $2(V_{cc} - V_{TN})$, that is, is held at a higher level than that of the power supply voltage V_{cc} .

Subsequently, at the time t_0' , the clock signal B is switched from the high level to the low level, and the clock signal A is switched from the low level to the high level in accordance with this. Further, in accordance with this, the clock signal C is switched to the high level, and the clock signal D is switched to the low level.

For this reason, at the time t_1 , the potentials of the nodes ND₁ and ND₂ are switched to the ground potential, and the output terminal T₁ of the clock signal CLK₁ is held at the ground potential. Then, at the time t_2 , the clock signal CLK₂ is switched from the high level to the low level.

At the time t_3 , the clock signal CLK₃ and the clock

signal CLK_1 , are switched from the low level to the high level. In accordance with this, the clock signal C is switched to the low level and the clock signal D is switched to the high level, therefore, the capacitor C_{CK} is charged to $(V_{CC} - V_{TH})$ again.

In this way, the clock generating circuit shown in Fig. 5 generates the clock signal CLK_1 , which is held at $2(V_{CC} - V_{TH})$ level at the time of the high level and held at the ground potential at the time of the low level and the clock signal CLK_2 and the clock signal CLK_3 , which are held at the power supply voltage V_{CC} level at the time of the high level and held at the ground potential at the time of the low level and supplies them to the power supply circuit shown in Fig. 2.

As explained above, according to the present embodiment, the clock signal CLK_1 , held at a higher level than the power supply voltage V_{CC} at the time of the high level is supplied to the gate electrodes of the nMOS transistors NU_1 , NU_2 , and NU_3 , constituting the booster stages, the clock signal CLK_2 is supplied to the gate electrodes of the nMOS transistors NL_1 , NL_2 , and NL_3 , the clock signal CLK_3 is supplied to the gate electrodes of the pMOS transistors PT_1 , PT_2 , and PT_3 , connected between the booster stages, the clock signals CLK_1 and CLK_2 are held at the high level, and the

capacitors C_1 , C_2 , and C_3 of the booster stages are charged to the power supply voltage V_{cc} level, then the clock signals CLK_1 and CLK_2 are switched to the low level, the clock signal CLK_3 is switched to the high level, and the boosted voltage V_{out} is supplied to the output terminal T_{out} of the power supply circuit, therefore there is no loss of the boosted voltage due to the substrate biasing effect at the time of boosting, the number of stages necessary for obtaining the desired high voltage can be decreased, the output current per chip area can be made larger, and the rising time can be shortened.

Figure 8 is a circuit diagram of a second embodiment of the power supply circuit according to the present invention.

As illustrated, Fig. 8 is a circuit diagram of the power supply circuit showing an example of the negative booster circuit for generating a negative boosted voltage compared with the power supply voltage V_{cc} . The power supply circuit can be used for biasing for example a structure of a semiconductor circuit such as a dynamic random access memory.

In Fig. 8, CLK_{n2} and CLK_{n3} are inverted signals of the clock signals CLK_2 and CLK_3 shown in Fig. 1, and CLK_{n1} is a clock signal which is held at the power supply

voltage V_{cc} level at the time of the high level in synchronization with the clock signal CLK_{B2} and held at a level lower than the ground potential GND, that is, a negative potential at the time of the low level.

T_{CLKB1} , T_{CLKB2} , and T_{CLKB3} denote input terminals of the clock signals CLK_{B1} , CLK_{B2} , and CLK_{B3} . NT_1 denotes an nMOS transistor serving as the biasing means, NT_2 and NT_3 denote nMOS transistors serving as the third switching means, NT_4 denotes diode-connected nMOS transistor, PL_1 , PL_2 , and PL_3 denote pMOS transistors serving as the first switching means, PU_1 , PU_2 , and PU_3 denote pMOS transistors serving as the second switching means, KB_1 , KB_2 , KB_3 , LB_1 , LB_2 , and LB_3 denote nodes of booster stages, C_1 , C_2 , and C_3 denote capacitors for boosting, C_L denotes a parasitic capacitance of the load, and T_{OUTB} denotes an output terminal of the negative boosted voltage V_{OUTB} .

As illustrated, the power supply circuit of the present example was constituted by three booster stages constituted by pMOS transistors PU_1 , PU_2 , PU_3 , PL_1 , PL_2 , and PL_3 and capacitors C_1 , C_2 , and C_3 .

Here, an explanation will be made of the configuration of the 1-th stage of the booster stage constituted by the pMOS transistors PU_1 and PL_1 and the capacitor C_1 referring to Fig. 9 without losing generality.

As shown in Fig. 9, the gate electrode of the pMOS transistor PU_1 is connected to the input terminal of the clock signal CLK_{n2} , the source electrode is connected to the supply line of the power supply voltage V_{cc} , and the drain electrode is connected to the node KB_1 of the booster stage.

The gate electrode of the pMOS transistor PL_1 is connected to the input terminal of the clock signal CLK_{n1} , the source electrode is connected to the node LB_1 , and the drain electrode is grounded.

One electrode of the capacitor C_1 is connected to the node KB_1 , and the other electrode is connected to the node LB_1 .

Figure 10A to 10J are waveform diagrams of the clock signals CLK_{n1} , CLK_{n2} , and CLK_{n3} , the voltages of the boosting nodes KB_1 , LB_1 , KB_2 , LB_2 , KB_3 , and LB_3 , and the output voltage V_{out} .

As shown in Figs. 10A and 10C, the clock signal CLK_{n1} and the clock signal CLK_{n2} are synchronous. The clock signal CLK_{n1} is held at the power supply voltage V_{cc} level at the time of the high level and is held at the level lower than the ground potential GND, that is, a negative potential, at the time of the low level. The clock signal CLK_{n2} is held at the power supply voltage V_{cc} level at the time of the high level and is held at the

ground potential GND level at the time of the low level.

Below, an explanation will be made of the operation of the negative booster circuit of the present invention referring to the waveform diagram shown in Figs. 10A to 10J.

As shown in Fig. 10A, at the time t_0 , the clock signals CLK_{n1} and CLK_{n2} are switched from the high level to the low level. The clock signal CLK_{n1} is held at the negative potential and the clock signal CLK_{n2} is held at the ground potential GND level.

During the period where the clock signal CLK_{n1} and the clock signal CLK_{n2} are held at the low level, the pMOS transistors PU_1 , PU_2 , and PU_3 and the pMOS transistors PL_1 , PL_2 , and PL_3 are held in the conductive state, and the capacitors C_1 , C_2 , and C_3 are charged.

For this reason, at the booster stages, the nodes LB_1 , LB_2 , and LB_3 are held at the ground potential GND level, the nodes KB_1 , KB_2 , and KB_3 are held at the power supply voltage V_{cc} level, and the capacitors C_1 , C_2 , and C_3 are charged to the power supply voltage V_{cc} level.

At the time t_1 , the clock signals CLK_{n1} and CLK_{n2} are switched from the low level to the high level, and the pMOS transistors PU_1 , PU_2 , and PU_3 and the pMOS transistors PL_1 , PL_2 , and PL_3 are switched to the nonconductive state.

Further, at the time t_2 , the clock signal CLK_2 is switched from the low level to the high level, and the nMOS transistors NT_1 , NT_2 , and NT_3 are switched to the conductive state in accordance with this.

According to this, at the booster stage of initial stage, the node KB_1 is held at the ground potential GND level, and the node LB_1 is held at the $-V_{cc}$ level.

In the booster stage of the second stage, the node KB_2 is held at the $-V_{cc}$ level in the same way as the node LB_1 , and the node KB_1 is held at the $-2V_{cc}$ level.

In the booster stage of the third stage, the node KB_3 is held at the $-2V_{cc}$ level in the same way as the node LB_2 , and the node KB_2 is held at the $-3V_{cc}$ level.

The potential of the node LB_3 is output to the output terminal T_{OUTB} via the diode-connected nMOS transistors NT_4 . Here, when defining the threshold voltage of the nMOS transistor NT_4 as V_{TH} , the negative boosted voltage V_{OUTB} output to the output terminal T_{OUTB} becomes $-(3V_{cc} - V_{TH})$.

In general, the boosted voltage V_{OUTB} obtaining by the negative booster circuit constituted by n number of stages of booster stages is found by the following equation:

$$V_{OUTB} = - (n \times V_{cc} - V_{TH}) \quad \dots (2)$$

In this way, the voltage loss of the boosted voltage V_{out2} obtained by the negative booster circuit shown in Fig. 8 is only the voltage drop in the diode-connected between the final stage and the output terminal T_{out2} , and an improvement of the efficiency of the power supply circuit can be achieved.

Note that, in the negative booster circuit of the present embodiment, in the same way as the positive booster circuit shown in Fig. 2, the nMOS transistor NT_1 is formed in the same well as that for the other transistors constituting the peripheral circuit of for example the negative booster circuit, and nMOS transistors NT_1 and NT_2 are formed in the individually independent wells.

Figure 11 is a circuit diagram of an example of the generator 10a of the clock signal CLK_{A1} in the second embodiment.

As illustrated, the clock generator 10a is constituted by the nMOS transistors NA_2 , NB_2 , NC_2 , and ND_2 and the capacitor C_{cx} .

One diffusion layer of the nMOS transistor NB_2 is connected to the supply line of the power supply voltage V_{cc} , the other diffusion layer is connected to the node ND_1 , and the gate electrode is connected to the input terminal of the clock signal B_2 .

One diffusion layer of the nMOS transistor NA_p is connected to the node ND_1 , the other diffusion layer is grounded, and the gate electrode is connected to the input terminal of the clock signal A_p .

One diffusion layer of the nMOS transistor ND_p is connected to the supply line of the power supply voltage V_{cc} , the other diffusion layer is connected to the node ND_1 , and the gate electrode is connected to the input terminal of the clock signal D_p .

One diffusion layer of the nMOS transistor NC_p is connected to the node ND_1 , the other diffusion layer is grounded, and the gate electrode is connected to the input terminal of the clock signal C_p .

A capacitor C_{CK} is connected between the node ND_1 and the node ND_2 , and the node ND_2 is connected to the output terminal T_{n1} of the clock signal CLK_{n1} .

At the time of the boosting operation, the clock signals A_p , B_p , C_p , and D_p shown in Figs. 12A to 12D are input to the clock generator 10a.

Upon receipt of these clock signals, the clock generator 10a generates a clock signal CLK_{n1} which is held at the power supply voltage V_{cc} at the time of the high level and is held at a lower level than the ground potential GND at the time of the low level.

Below, an explanation will be made of the operation

of the generator 10a of the clock signal CLK_{n1} shown in Fig. 11 referring to the waveform diagram of the clock signals A_n , B_n , C_n , and D_n and the clock signal CLK_{n1} shown in Figs. 12A to 12E.

As shown in Figs. 12A to 12D, at the time t_0' , the clock signals B_n and C_n are switched to the high level, for example, the power supply voltage V_{cc} level. Note that, at this time, both of the clock signals A_n and D_n are held at the low level, for example, the ground potential GND.

In accordance with this, in the clock generator 10a, the nMOS transistors NA_n and ND_n are set in the nonconductive state, and both of the nMOS transistors NB_n and NC_n are set in the conductive state.

For this reason, the capacitor C_{cn} is charged, and the node ND_n is held at a voltage which becomes lower than the power supply voltage V_{cc} by exactly the threshold voltage V_{th} of the nMOS transistor NB_n , that is, $(V_{cc} - V_{th})$.

Then, at the time t_0 , the clock signals B_n and C_n are switched to the low level, and the clock signal A_n is raised to the high level, for example, the power supply voltage V_{cc} level. Note that, at this time, the clock signal D_n is held at the low level as it is.

In accordance with this, both of the nMOS

transistors NB_1 and NC_1 are switched to the nonconductive state, and the nMOS transistor NA_1 is switched to the conductive state. Further, the nMOS transistor ND_1 is held in the nonconductive state as it is. For this reason, the node ND_1 is held at the ground potential GND, and the node ND_2 is held at the negative potential, for example $-(V_{cc} - V_{TN})$.

Subsequently, at the time t_1 , the clock signal A_1 is switched to the low level, and the clock signal D_1 is raised to the high level, for example, the power supply voltage V_{cc} . In accordance with this, the nMOS transistor NA_1 is switched to the nonconductive state, and the nMOS transistor ND_1 is switched to the conductive state.

Note that, at this time, the clock signals B_1 and C_1 are held at the low level, and both of the nMOS transistors NB_1 and NC_1 are held in the nonconductive state, therefore the node ND_2 is held at the power supply voltage V_{cc} level.

Then, at the time t_2 , the clock signal D_1 is switched to the low level, and both of the clock signals B_1 and C_1 are raised to the high level, therefore both of the nMOS transistors NB_1 and NC_1 are set in the conductive state, and the capacitor C_{cx} is charged and the node ND_1 is held at the $(V_{cc} - V_{TN})$ level.

The above operation is repeatedly carried out,

therefore the clock generator 10a shown in Fig. 11 generates a clock signal CLK_{B1} which is held at a level lower than the ground potential GND during the low level section and is held at the power supply voltage V_{cc} level in the high level section and outputs the same from the output terminal T_{B1} . Then, this clock signal CLK_{B1} is supplied to the negative booster circuit shown in Fig. 8, and the negative boosted voltage V_{OUTB} is generated.

As explained above, according to the present embodiment, the clock signal CLK_{B2} is applied to the gate electrodes of the pMOS transistors PU_1 , PU_2 , and PU_3 constituting the booster stages, the clock signal CLK_{B1} which is held at the power supply voltage V_{cc} level at the time of the high level and is held at the negative potential at the time of the low level is supplied to the gate electrodes of the pMOS transistors PL_1 , PL_2 , and PL_3 , the clock signal CLK_{B2} is supplied to the gate electrodes of the nMOS transistors NT_1 , NT_2 , and NT_3 connected between the booster stages, the clock signals CLK_{B1} and CLK_{B2} are held at the low level, and the capacitors C_1 , C_2 , and C_3 of the booster stages are charged to the power supply voltage V_{cc} level, then the clock signals CLK_{B1} and CLK_{B2} are switched to the high level, the clock signal CLK_{B2} is switched to the high level, and the negative boosted voltage V_{OUTB} is output to the output

terminal T_{out}^{41} , therefore there is no loss of the boosted voltage due to the substrate biasing effect at the time of boosting, the number of stages necessary for obtaining the desired high voltage can be decreased, the output current per chip area can be made larger, and the rising time can be shortened.

Also, in recent years, there have been growing demands for a low voltage (for example V_{cc}/m) source independent from the power supply voltage V_{cc} inside an LSI, for example, for a small amplitude transfer between chips and inside a chip.

As this type of inner low voltage supply, a series regulator as shown in Fig. 13 is generally used.

This series regulator is constituted by, as shown in Fig. 13, an operational amplifier 11 with an inverted input (-) connected to the supply line of a constant voltage V_L , and a pMOS transistor 12 with a gate connected to the output of the operational amplifier 11, with a source connected to the supply line of the power supply voltage V_{cc} , and with a drain connected to a noninverted input (+) of the operational amplifier 1 and supplies a low voltage V_L from a node N_1 to a circuit block 13.

When considering the power loss of the series regulator, there is a loss P_{Ls} due to the pMOS transistor

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12 indicated by the following equation:

$$P_{LS} = (V_{cc} - V_L) \cdot I_L \quad \dots (3)$$

Then, when $V_L < (V_{cc}/2)$, the loss becomes 50 percent or more, which becomes a major obstacle to reduction of the power consumption of the LSI.

Particularly, where a lithium ion battery is used as the V_{cc} use external power supply, the fluctuation of the V_{cc} is large and there arises a problem of the power loss thereof.

Therefore, a DC-DC converter which does not use an MOS transistor as a driver and is constituted only by capacitance elements and switches and with which a desired low voltage power supply potential can be obtained has been proposed.

Figure 14 is a circuit diagram of an example of the configuration of this DC-DC converter.

As shown in Fig. 14, this DC-DC converter 20 is constituted by switch circuits 21 to 23 and capacitors 31 to 33. Note that, the switch circuits 21 to 23 are constituted by for example MOS type transistors. Also, as the capacitors 31 and 32, those having the same capacitance are used.

An operational contact a of the switch circuit 21 is connected to the supply line of the power supply voltage V_{cc} , an operational contact b is connected to an

output node ND_{out} , and a fixed contact g is connected to one electrode of the capacitor 31.

The operational contact a of the switch circuit 22 is connected to the operational contact a of the switch circuit 23, the operational contact b is grounded, and the fixed contact g is connected to the other electrode of the capacitor 31.

The operational contact b of the switch circuit 23 is connected to the output node ND_{out} , and the fixed contact g is connected to one electrode of the capacitor 32. Then, the other electrode of the capacitor 32 is grounded.

Also, the capacitor 33 is a stabilizing capacitor which is connected between the output node ND_{out} and the ground line for suppressing the voltage drop of the output node ND_{out} by a load current I_L and stabilizing the same. Note that, it is not necessary to provide this stabilizing capacitor 33 where the parasitic capacitance of the output power supply line is large.

The switch circuits 21, 22, and 23 connect their fixed contacts g to the operational contact a when the clock signal ϕ is at the V_{cc} level (high level) and connect their fixed contacts g to the operational contact b when the clock signal ϕ is at the ground level (low level).

In such a configuration, when the clock signal ϕ is at a high level, two capacitors 31 and 32 are connected in series between the supply line of the power supply voltage V_{cc} and the ground line to charge the capacitors 31 and 32.

When the clock signal ϕ is at a low level, two capacitors 31 and 32 are connected in parallel to discharge the same.

Next, since the capacitors 31 and 32 are constituted by elements having the same capacitance, due to the above charge and discharge function, the output voltage V_a appearing at the output node ND_{out} becomes $V_{cc}/2$, which is supplied to a circuit block 40 operating at this low voltage $V_{cc}/2$.

In the down converter shown in Fig. 14, when the nodes $ND1$ and $ND2$ are discharged from the power supply voltage V_{cc} and $0.5 V_{cc}$ to $0.5 V_{cc}$ and $0V$, respectively, a power P_d indicated by the following equation is consumed:

$$P_d = (1/2) \cdot (Cs1 + Cs2) \cdot (V_{cc}/2)^2 \cdot (1/\tau) \quad \dots (4)$$

Here, $Cs1$ and $Cs2$ are parasitic capacitances of the nodes $ND1$ and $ND2$.

Similarly, at the time of charging as well, the same amount of power is consumed and, as a result, a power P indicated by the following equation is consumed

in total:

$$P = (1/4) \cdot (Cs1+Cs2) \cdot (V_{cc}/t)^2 \quad \dots (5)$$

With the power consumption shown by equation (5), however, the demand for reduction of the power consumption of the LSI is not sufficiently satisfied, thus realization of a DC-DC converter with which a stable output voltage can be obtained with a further lower power loss has been desired.

Figure 15 is a circuit diagram of a third embodiment of the DC-DC converter according to the present invention. Also, Figs. 16A to 16J are timing charts of the circuit of Fig. 15.

As shown in Fig. 15, this DC-DC converter 20a is constituted by switch circuits 21a to 23a, capacitors 31a, 32a, and 33a, an external power supply 50 of the power supply voltage V_{cc} , a power supply 60 for $0.25 V_{cc}$, and a timing generating circuit 70 generating the clock signals $\phi 1$ to $\phi 7$ at a timing shown in Figs. 16A to 16F.

In the switch circuit 21a, fixed contacts c1 and c2 of two on-off switches 111 and 112 are connected in parallel to one electrode of the capacitor 31a, the operational contact a1 of the switch 111 is connected to the external power supply 50, and the operational contact a2 of the switch 112 is connected to the output node ND_{out} .

Then, the switch 111 is controlled on or off by the clock signal ϕ_1 , and the switch 112 is controlled on or off by the clock signal ϕ_5 .

More specifically, the switches 111 and 112 become the on state when the clock signal is at a high level and become the off state when it is at a low level. These on and off controls are complementarily carried out.

In the switch circuit 22a, the fixed contacts c1, c2, and c3 of the three on-off switches 121, 122, and 123 are connected in parallel to the other electrode of the capacitor 31a, and the operational contact a1 of the switch 121 is connected to the operational contact a1 of the switch 131 of the switch circuit 23a. The operational contact a2 of the switch 122 is connected to the power supply 60 for $0.25 V_{cc}$, and the operational contact a3 of the switch 123 is grounded.

Then, the switch 121 is controlled on or off by the clock signal ϕ_2 , the switch 122 is controlled on or off by the clock signal ϕ_6 , and the switch 123 is controlled on or off by the clock signal ϕ_7 .

More specifically, the switches 121, 122, and 123 become the on state when the clock signal is at a high level and become the off state when it is at a low level. The on-off control of these switches 121, 122, and 123 is sequentially carried out.

In the switch circuit 23a, the fixed contacts c1 and c2 of the two on-off switches 131 and 132 are connected in parallel to one electrode of the capacitor 32a, and the operational contact a2 of the switch 132 is connected to the output node ND_{out} .

Then, the switch 131 is controlled on or off by the clock signal $\phi 3$, and the switch 132 is controlled on or off by the clock signal $\phi 4$.

More specifically, the switches 131 and 132 become the ON state when the clock signal is at a high level and become the off state when it is at a low level. These on and off controls are complementarily carried out.

Also, the other electrode of the capacitor 32a is grounded.

Note that, the switch circuits 21a to 23a are constituted by for example MOS system transistors.

Also, a stabilizing capacitor 33a for suppressing the voltage drop of the output node ND_{out} by the load current I_L is connected between the output node ND_{out} and the ground line.

Note that, it is not necessary to provide this stabilizing capacitor 33a when the parasitic capacitance of the output power supply line is large.

Also, as the capacitors 31a and 32a, those having the same capacitance are used.

Figure 17 is a circuit diagram of an example of the configuration of the power supply 60 for $0.25 V_{cc}$.

This $0.25 V_{cc}$ use power supply 60 is constituted by switch circuits 511 to 517 and capacitors 521 to 525 as shown in Fig. 17. Note that, the switch circuits 511 to 517 are constituted by for example MOS system transistors. Also, as the capacitors 521 to 524, those having the same capacitance are used.

The operational contact a of the switch circuit 511 is connected to the supply line of the power supply voltage V_{cc} , the operational contact b is connected to the output node ND_{out} , and the fixed contact g is connected to one electrode of the capacitor 521.

The operational contact a of the switch circuit 512 is connected to the operational contact a of the switch circuit 513, the operational contact b is grounded, and the fixed contact g is connected to the other electrode of the capacitor 521.

The operational contact b of the switch circuit 513 is connected to the output node ND_{out} , and the fixed contact g is connected to one electrode of the capacitor 522.

The operational contact a of the switch circuit 514 is connected to the operational contact a of the switch circuit 515, the operational contact b is grounded, and

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the fixed contact g is connected to the other electrode of the capacitor 522.

The operational contact b of the switch circuit 515 is connected to the output node ND_{out} , and the fixed contact g is connected to one electrode of the capacitor 523.

The operational contact a of the switch circuit 516 is connected to the operational contact a of the switch circuit 517, the operational contact b is connected to the output node ND_{out} , and the fixed contact c is connected to one electrode of the capacitor 524.

Further, the other electrode of the capacitor 524 is grounded.

Further, the capacitor 525 is a stabilizing capacitor which is connected between the output node ND_{out} and the ground line for suppressing the voltage drop of the output node ND_{out} by a load current I_L and stabilizing the same. Note that, it is not necessary to provide this stabilizing capacitor 525 when the parasitic capacitance of the output power supply line is large.

The switch circuits 511 to 517 connect their fixed contacts g to the operational contact a when the clock signal ϕ_{10} is at the V_{cc} level (high level) and connect their fixed contacts g to the operational contact b when

the clock signal ϕ_{s0} is at the ground level (low level).⁵⁰

In the power supply 60 having such a configuration, when the clock signal ϕ_{s0} is at a high level, the four capacitors 521, 522, 523, and 524 are connected in series between the supply line of the power supply voltage V_{cc} and the ground line and the capacitors 521 to 524 are charged.

When the clock signal ϕ_{s0} is at a low level, the four capacitors 421 to 424 are connected in parallel so the discharging is carried out.

The capacitors 521 to 524 are constituted by ones having the same capacitance, therefore, due to the above charge and discharge function, the output voltage V_a appearing at the output node ND_{out} becomes $V_{cc}/4 = 0.25 V_{cc}$ which is supplied to the operational contact a2 of the switch 122 of the switch circuit 12a in the circuit of Fig. 15.

The timing generating circuit 70 first sets the clock signals $\phi 1$ to $\phi 3$ at a high level as shown in Fig. 16, holds the switches 111, 121, and 131 in the on state, connects two capacitors 31a and 32a in series between the external power supply 50 and the ground line, and makes them perform the charging with respect to the capacitors 31a and 32a.

Subsequently, at a time t_1 , the clock signals $\phi 1$ to

Ø3 are switched to the low level, the clock signals Ø4 and Ø6 are set at a high level, the node ND2 is connected to the $0.25 V_{cc}$ use power supply 60, and the charges of the capacitor 31a on the side connected to the node ND2 are discharged to the power supply 50.

Then, at a time t_2 after an elapse of a predetermined time, the clock signal Ø6 is switched to the low level, the clock signal Ø7 is set at a high level, the node ND2 is connected to the ground line, and the capacitor 31a is discharged so that the node ND1 exhibits $0.5 V_{cc}$ and node ND2 exhibits 0V.

Next, at a time t_3 , the clock signal Ø5 is set at a high level, the node ND1 is connected to the output node ND_{out} , and $0.5 V_{cc}$ ($V_{cc}/2$) is supplied to the output node ND_{out} .

Further, at a time t_4 , the clock signals Ø5 and Ø7 are switched to the low level, the clock signal Ø6 is set at a high level, the node ND2 is connected to $0.25 V_{cc}$ use power supply 60, and the capacitor 31a is charged so that the potential of the node ND1 changes from $0.5 V_{cc}$ to $0.75 V_{cc}$ and the potential of the node ND2 changes from 0V to 0.25.

Next, at a time t_5 , the clock signal Ø6 is switched to the low level, the clock signal Ø1 is set at a high level, the node ND1 is connected to the external power

supply 50, and the capacitor 31a is charged so that the potential of the node ND1 becomes V_{cc} and the potential of the node ND2 becomes $0.5 V_{cc}$.

Next, the operation by the above configuration will be explained by referring to the timing chart of Fig. 16.

First, the clock signals $\phi 1$, $\phi 2$, and $\phi 3$ among the clock signals $\phi 1$ to $\phi 7$ are set at a high level at the timing generating circuit 70, and the clock signal $\phi 1$ is supplied to the switch 111 of the switch circuit 21a, the clock signal $\phi 2$ is supplied to the switch 121 of the switch circuit 22a, and the clock signal $\phi 3$ is supplied to the switch circuit 131, respectively.

By this, the switches 111, 121, and 131 become the on state, the two capacitors 31a and 32a are connected in series between the external power supply 50 and the ground line, and the capacitors 31a and 32a are charged.

Next, at a time t_1 , the clock signals $\phi 1$ to $\phi 3$ are switched to the low level at the timing generating circuit 70, the clock signals $\phi 4$ and $\phi 6$ are set at a high level, the clock signal $\phi 4$ is supplied to the switch 132 of the switch circuit 23a, and the clock signal $\phi 6$ is supplied to the switch 122 of the switch circuit 22a, respectively.

By this, the switches 111, 121, and 131 become the off state, the switches 132 and 122 become the on state,

and the supply of $V_{oo}/2$ to the capacitor 33a and the circuit block 40 is started.

Along with the switch 122 becoming the on state, the node ND2 is connected to the $0.25 V_{oo}$ use power supply 60, and the charges of the capacitor 31a on the side connected to the node ND2 are discharged to the power supply 60. Here, via the switch 122, a charge of $0.25 V_{oo} (Cs1 + Cs2)$ flows into the power supply 50. The level of the node ND1 at this time is $0.75 V_{oo}$.

In this case, at the switch 122, the power consumption shown by the following equation occurs.

$$P_{111} = (1/2) \cdot (Cs1 + Cs2) \cdot (V_{oo}/4)^2 \cdot (1/\tau) \quad \dots (6)$$

Here, Cs1 and Cs2 are parasitic capacitances of the nodes ND1 and ND2. The relationship with respect to the capacitance C_{21} of the capacitor 31a is set as $C_{21} \gg Cs1, Cs2$.

Next, at a time $t2$, the clock signal $\phi6$ is switched to the low level at the timing generating circuit 70, the clock signal $\phi7$ is set at a high level, and the clock signal $\phi7$ is supplied to the switch 123 of the switch circuit 22a.

By this, the switch 122 becomes the off state, and the switch 123 becomes the on state.

Along with the change of the switch 123 to the on

state, the node ND2 is connected to the ground line. As a result, the capacitor 31a is discharged so that the node ND1 exhibits $0.5 V_{cc}$ and the node ND2 exhibits 0 V.

In this case, at the switch 123, a power equivalent to the power indicated by the above equation (6) is consumed.

Then, at a time t_3 , the clock signal ϕ_5 is set at a high level at the timing generating circuit 70 and is supplied to the switch 112 of the switch circuit 21a.

By this, the switch 112 becomes the off state, and $0.5 V_{cc}$ ($V_{cc}/2$) is supplied to the output node ND_{out}.

Also, at a time t_4 , the clock signals ϕ_5 and ϕ_7 are switched to the low level at the timing generating circuit 70, the clock signal ϕ_6 is set at a high level, and the clock signal ϕ_6 is supplied to the switch 122 of the switch circuit 22a.

By this, the switches 122 and 123 become the off state, and the switch 122 becomes the on state.

Along with the change of the switch 122 to the on state, the node ND2 is connected to the $0.25 V_{cc}$ use power supply 60. As a result, the capacitor 31a is charged so that the potential of the node ND1 changes from $0.5 V_{cc}$ to $0.75 V_{cc}$, and the potential of the node ND2 changes from 0V to $0.25 V_{cc}$.

In this case, at the switch 122, a power equivalent

to the power indicated by the above equation (6) is consumed.

Here, charges of $0.25 V_{cc} (Cs1+Cs2)$ flow out the power supply 60 via the switch 122. In this way, at the $0.25 V_{cc}$ use power supply 60, an inflow and outflow of $0.25 V_{cc} (Cs1+Cs2)$ occur by the charging and discharging, and the charges are recycled. For this reason, the frequency of the clock signal ϕ_{50} for the power supply 50 may be low, and there is almost no power loss due to the circuit of Fig. 15.

Next, at a time $t5$, the clock signal $\phi6$ is switched to the low level at the timing generating circuit 70, the clock signal $\phi1$ is set at a high level, and the clock signal $\phi1$ is supplied to the switch 111 of the switch circuit 21a.

By this, the switch 122 becomes the off state, and the switch 111 becomes the on state.

Along with the switch 111 becoming the on state, the node ND1 is connected to the external power supply 40. As a result, the capacitor 31a is charged so that the potential of the node ND1 becomes V_{cc} and the potential of the node ND2 becomes $0.5 V_{cc}$.

In this case, at the switch 111, a power equivalent to the power indicated by the above equation (6) is consumed.

The power P_T consumed by a series of discharging and charging operations is given by the following equation:

$$\begin{aligned} P_T &= 4 \times (1/2) \cdot (C_{s1} + C_{s2}) \cdot (V_{\infty}/4)^2 \cdot (1/\tau) \\ &= 4 \times (1/8) \cdot (C_{s1} + C_{s2}) \cdot V_{\infty}^2 \cdot (1/\tau) \end{aligned}$$

... (7)

This power consumption is $1/2$ of the power consumption $P = (1/4) \cdot (C_{s1} + C_{s2}) \cdot (V_{\infty}/\tau)^2$ of the conventional circuit.

As explained above, according to the first embodiment, in a DC-DC converter wherein two capacitors 31a and 32a are connected in series between the external power supply and the reference power supply (ground) to be charged and are connected in parallel to give an output voltage V_a of a value between the external power supply voltage and the reference power supply voltage by the clock signals $\phi 1$ to $\phi 3$, provision is made of a power supply 50 for potential lower than the external power supply 50 and the ground voltage source and provision is made of switches 121, 122, and 123 respectively operationally connecting the external power supply 50 and the power supply 60 for low potential with the capacitors 31a and a circuit 60 for sequentially switching the connection and nonconnection state from the switch side connected to the external

power supply to charge and discharge the capacitors 31a and sequentially switching the connection and nonconnection state from the switch side connected to the ground voltage source side to discharge the capacitors 31a and thereby perform a heat insulating charging, therefore there is the advantage that a low voltage source with which a stable output voltage V_a can be obtained with a low power loss can be realized.

Note that, in the present embodiment, a so-called two-step charging method was used, but by adopting an n number step charging method in which the number of switches of the switch circuit 22a is further increased to n , the power loss can be reduced to $1/n$ of that of the conventional method.

Note that, needless to say the number of connections of the capacitors is not limited to that of the present example, and a variety of modifications are possible.

Also, the switch circuit can be constituted by for example a transmission gate of the CMOS type, but desirably a p-channel MOS transistor and n-channel MOS transistor are selected and used corresponding to the transmission potential.

Also, so as to reduce the power loss, as the capacitor, desirably use is made of an external

capacitance, high dielectric capacitance, MIM (metal-insulator-metal) configuration capacitance, DRAM trench or stack capacitance, planar capacitance, ferroelectric capacitance, or the like.

Particularly, a ferroelectric such as PZT has a relative dielectric constant larger than SiO_2 by two figures or more, and the parasitic capacitance can be sufficiently reduced.

Figure 18 is a circuit diagram of a fourth embodiment of the DC-DC converter according to the present invention.

The difference of the present first embodiment from the above third embodiment resides in that the switch circuits and capacitor columns of the system A and system B are connected in parallel, and they are respectively driven by the clock signals $\phi 1$ to $\phi 7$ and $\overline{\phi 1}$ to $\overline{\phi 7}$ having inverse phases to each other (deviated by $\pi/2$ phase).

Note that, the fundamental operation of the circuit per se is similar to that of the third embodiment, and therefore an explanation thereof is omitted here.

In such a configuration, in the circuit of the system A, when for example the nodes ND1A and ND2A are discharged to the $0.25 V_{cc}$ use power supply 60a via the switch 122A from V_{cc} and $0.5 V_{cc}$ to $0.75 V_{cc}$ and $0.25 V_{cc}$, respectively, in the circuit of the system B, the

charging operation is conversely carried out only by the same charge amount, therefore the both are cancelled.

Accordingly, the supply of the charges from the $0.25 V_{cc}$ use power supply 60a is 0, and there is an advantage that the $0.25 V_{cc}$ use power supply 60a becomes very stable.

The ripple of the output node ND_{out} accompanied with the load current I_L can be lowered.

Many widely different embodiments of the present invention may be constructed without departing from the spirit and scope of the present invention. It should be understood that the present invention is not restricted to the specific embodiments described above.



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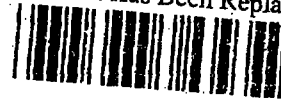
What is claimed is:

1. An internal power supply circuit, comprising;
a plurality of charge accumulating means,
a first power supply terminal,
a second power supply terminal,
a first switching means for connecting the
plurality of charge accumulating means in parallel to
each other in a first state, and
a second switching means for connecting the
plurality of charge accumulating means in series with
each other in a second state, and
a control means for energizing the first switching
means or the second switching means in response to the
first state or the second state to connect the plurality
of charge accumulating means between the first power
supply terminal and the second power supply terminal,
and for deenergizing the first switching means or the
second switching means in response to the first state or
the second state to disconnect the plurality of charge
accumulating means between the first power supply
terminal and the second power supply terminal,
the control means repeating the energizing and the
deenergizing.
2. An internal power supply circuit according to
claim 1, wherein

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the charge accumulating means are constituted by capacitors;

the first switching means is constituted by a third switching means and a fourth switching means; and

a partial booster circuit is comprised by a capacitor connected between a first node and a second node, the third switching means connected between the first node and the first power supply terminal, and the fourth switching means connected between the second node and the second power supply terminal;

a plurality of the partial booster circuits is provided;

the second switching means holds in a non-conductive state the first node of a front partial booster circuit and the second node of a rear partial booster circuit in the first state and holds them in a conductive state in the second state;

the first switching means comprised of the third switching means and the fourth switching means being held in the conductive state and the second switching means being held in a non-conductive state in the first state; and

the first switching means comprised of the third switching means and the fourth switching means being held in the non-conductive state and the second

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switching means being held in a conductive state in the second state so as to raise the voltage between the first power supply terminal and the second power supply terminal.

3. An internal power supply circuit according to claim 1, further comprising;

a biasing means connected to the second node of the initial stage partial booster circuit for holding the second node at a constant potential and

a rectifying means connected between the first node of the final stage partial booster circuit and a boosted voltage output terminal.

4. An internal power supply circuit according to claim 3, wherein the biasing means is constituted by a switching means set in the conductive state when the first switching means comprised of the third and fourth switching means is non-conductive.

5. An internal power supply circuit according to claim 3, wherein:

the first power supply terminal is a positive power supply terminal and the second power supply terminal is a negative power supply terminal,

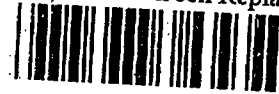
the constant potential is the potential of the first power supply terminal,

the biasing means is a rectification element

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connected so that a direction from the first power supply toward the second node of the initial stage partial booster circuit becomes a forward direction, and

the rectification element is connected so that a direction from the first node of the final stage partial booster circuit toward the output terminal becomes the forward direction and supplies the positive boosted voltage to the output terminal.

6. An internal power supply circuit according to claim 3, wherein:

the first power supply terminal is a negative power supply terminal and the second power supply terminal is a positive power supply terminal,

the constant potential is the potential of the second power supply terminal,

the biasing means is a rectification element connected so that a direction from the second node of the first stage partial booster circuit toward the first power supply terminal becomes the forward direction, and

the rectification element is connected so that a direction from the output terminal to the first node of the final stage partial booster circuit becomes the forward direction and supplies the negative boosted voltage to the output terminal.

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7. An internal power supply circuit according to claim 3, wherein;

the third switching means is constituted by a first conductivity type insulation gate type field effect transistor with a gate electrode connected to an input terminal of a first clock, with one diffusion layer connected to the first power supply, and with another diffusion layer connected to the first node of the partial booster circuit;

the fourth switching means is constituted by a first conductivity type insulation gate type field effect transistor with a gate electrode connected to an input terminal of a second clock, with one diffusion layer connected to the second power supply, and with another diffusion layer connected to the second node of the partial booster circuit; and

the second switching means is constituted by a second conductivity type insulation gate type field effect transistor with a gate electrode connected to the input terminal of a third clock.

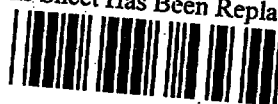
8. An internal power supply circuit according to claim 3, wherein

the biasing means is constituted by a second conductivity type insulation gate type field effect transistor with a gate electrode connected to the input

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terminal of a third clock.

9. An internal power supply circuit according to claim 7, wherein an amplitude of the first clock is set larger than a potential difference between the first power supply terminal and the second power supply terminal.

10. An internal power supply circuit according to claim 7, wherein the first power supply terminal is a positive power supply terminal and the first conductivity type insulation gate type field effect transistor is an n-channel type transistor and is held at a higher level than the first power supply terminal voltage in a high level section of the first clock.

11. An internal power supply circuit according to claim 7, wherein the first power supply is a negative power supply terminal and the first conductivity type insulation gate type field effect transistor is a p-channel type transistor and is held at a lower level than the second power supply terminal voltage in a low level section of the first clock.

12. An internal power supply circuit according to claim 7, wherein the second conductivity type insulation gate type field effect transistor constituting the second switching means is formed in an independent well.

13. An internal power supply circuit according to

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claim 8, wherein the biasing means is a second conductivity type insulation gate type field effect transistor formed in the same well as that for the second conductivity type insulator gate type field effect transistors constituting part of the peripheral logic circuit.

14. An internal power supply circuit, comprising:

a first power supply terminal,

a second power supply terminal,

a first node,

a second node,

a capacitor connected between the first node and the second node,

a first switching means connected between the first node and the first power supply terminal,

a second switching means connected between the second node and the second power supply terminal,

a biasing means connected to the second node and biasing the node at a constant potential, and

a rectifying means connected between the first node and the boosted voltage output terminal,

the first and second switching means being repeatedly set in the conductive state and the non-conductive state to be overlapped thereby to output a boosted voltage to an output terminal.

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15. An internal power supply circuit according to claim 14, wherein

the biasing means is a rectification element connected so that a direction from the first power supply toward the second node becomes a forward direction and

the rectifying means is connected so that a direction from the first node toward the boosted voltage output terminal becomes the forward direction.

16. An internal power supply circuit according to claim 14, wherein

the biasing means is a rectification element connected so that a direction from the second node toward the first power supply becomes a forward direction and

the rectifying means is connected so that a direction from the boosted voltage output terminal toward the first node becomes the forward direction.

17. An internal power supply circuit according to claim 1, wherein

the charge accumulating means are constituted by capacitors;

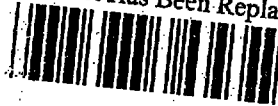
the capacitors are connected in series between the first and second power supply terminals and then are charged in the second state; and

the capacitors are connected in parallel between the second power supply terminal and a down voltage

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output terminal in the first state to thereby obtain a voltage between the first and second power supply terminal.

18. An internal power supply circuit according to claim 17, further comprising;

a switching means connecting to an external power supply between the voltage of the first power supply terminal and the voltage of the second power supply terminal, having at least one sub-power supply of a potential lower than the external power supply, and operationally connects the external power supply and the sub-power supply and

a means for sequentially switching the connection and nonconnection state from the switching means connected to the external power supply to cause charging and discharging of the capacitors.

19. An internal power supply circuit according to claim 8, further comprising a means for sequentially switching the connection and nonconnection state from the switching means connected to the sub-power supply to cause charging and discharging of the capacitors.

20. An internal power supply circuit according to claim 18, wherein

at least two arrangements of a plurality of capacitors which are switched between the serial,

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connection and parallel connection based on a clock
signal and

clock signals having inverse phases are supplied
to the above at least two arrangements.

21. An internal power supply circuit according to
claim 17, wherein the capacitors are composed of
capacitors selected from ferroelectric capacitors, high
dielectric capacitors, MIM (metal-insulator-metal)
configuration capacitors, DRAM trench and stack
capacitors, planar capacitors, external capacitors, and
MIS (metal-insulator-semiconductor) gate capacitors.

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