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A HIGH EFFICIENCY CHARGE PUMP FOR LOW VOLTAGE DEVICES

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Abstract: A charge pump is a kind of DC to DC converter that uses capacitors as energy storage elements to create a higher or lower voltage power source. Charge pumps make use of switching devices for controlling the connection of voltage to the capacitor. Charge pumps have been used in the nonvolatile memories, such as EEPROM and Flash memories, for the programming of the floating-gate devices. They can also be used in the low-supply-voltage switched-capacitor systems that require high voltage to drive the analog switched. This paper includes voltage analysis of different charge pumps. On the basis of voltage analysis a new charge pump is proposed.

1. INTRODUCTION

Power consumption is one of the most crucial considerations in VLSI designing. Generally, the most common and capable method to reduce the power consumption in a digital system is to reduce the supply voltage. However, a low supply voltage can considerably reduce the quality of the circuit function. In fact, it causes a reduction in speed and noise margins in digital circuits, a reduction dynamic range of analog circuits and some difficulties in read and write operation in some types of memories such as EEPROM and Flash types.

Charge pumps are used in applications where low or high voltage than power supply are required. Charge pumps make use of capacitors as energy storage element and pump charges towards the output stage using switches to convert lower DC voltage level at the input into higher DC level voltage at the output[1]. These circuits can find application in nonvolatile memories, such as EEPROM and Flash memories, for programming of the floating gate devices.

Many of the systems- such as EEPROMS, Flash memories, power management blocks, audio and video codes, image sensor circuits and displays- require internal voltage higher than supply voltage. This internal high voltage needs to be generated on chip or in-system. The traditional approach of switch-capacitor circuit or inductor based linear regulators consumes too much power and silicon area, to justify today's shrinkage needs. An on-chip charge pump provides an excellent solution and eliminates the need for an inductor.

The implementation of DC-DC convertor in CMOS is desirable. CMOS is currently the technology of choice in low power design. The popularity of CMOS is largely due to ease in designing circuits with minimal static power dissipation [2]. A CMOS charge pump circuit, which uses both NMOS switches and PMOS switches to eliminate the body effect, has been designed. A novel CTS control scheme which combines the backward

control scheme and the forward control scheme is to obtain high voltage gain.

The charge pump solution eliminates the need of DC/DC boost convertors and expensive low profile inductors that are required to meet the size limitations of handheld devices and cell phones.

The paper is organized as follows: Basic concept of charge pump is given in section 2. Analysis of Dickson charge pump is presented in section 3. Analysis of Static charge pump is given in section 4. Analysis of Dynamic charge pump is explained in section 5. At the end the conclusion is given in section 6.

2. BASIC CONCEPTS

A charge pump circuit provides a voltage that is higher than the voltage of the power supply or a voltage of reverse polarity. In many applications such as Power IC, continuous time filters, and EEPROM, voltages higher than the power supplies are frequently required. Increased voltage levels are obtained in a charge pump as a result of transferring charges to a capacitive load and do not involve amplifiers or transformers.[2] It is for this reason that charge pump is a device of choice in semiconductor technology where normal range of operating voltages is limited. To generate a higher voltage, the first stage involves the capacitor being connected across a voltage and charged up. The second stage includes the capacitor being disconnected from the original charging voltage and reconnected with its negative terminal to the original positive charging voltage. Because the capacitor retains the voltage across it (ignoring leakage effects) the positive terminal voltage is added to the original, effectively doubling the voltage. The output capacitor smooth's the pulsing nature of the higher voltage output . Charge pumps usually operate at high frequency level in order to increase their output power within a reasonable size of total capacitance used for charge transfer. This operating frequency may be adjusted by compensating for changes in the power requirements and saving the energy delivered to the charge pump.

3. DICKSON CHARGE PUMP

John F Dickson proposed a voltage multiplier circuit. The MOST's in Dickson charge pump function as diodes, so that the charges can be pushed only in one direction. However the nodes of the diode chain are coupled to the inputs via capacitors in parallel so that the capacitors have to withstand the full voltage developed along the chain[3]. Two pumping clocks are used. The two pumping clocks Clk1 and Clk2 are out of phase and have a voltage amplitude V which is equal to input voltage . The value of input voltage is equal to VDD. Two clocks push the charge voltage upward through the transistors through the coupling capacitors C1-C4,. Cs is the parasitic capacitance assosiated with each pumping node, f is the frequency of the pumping clocks and is the output current loading.

When CLk1 goes from low to high and Clk2 goes from high to low, the voltage at node 1 is settled to and the voltage at node 2 is settled to , where and are defined as steady-state lower volatge at node 1 and node 2. Charges are being pushed from node 1 to node 2 through MD2, MD1 and MD2 are reverse biased. The final voltage difference between node 1 and node 2 is the threshold voltage MD2[1]. The necessary condition for the charge pump to function is that must be larger than the MOST's threshold voltage , i.e . The voltage pumping gain for the second pumping stage is defined as the voltage difference between and .

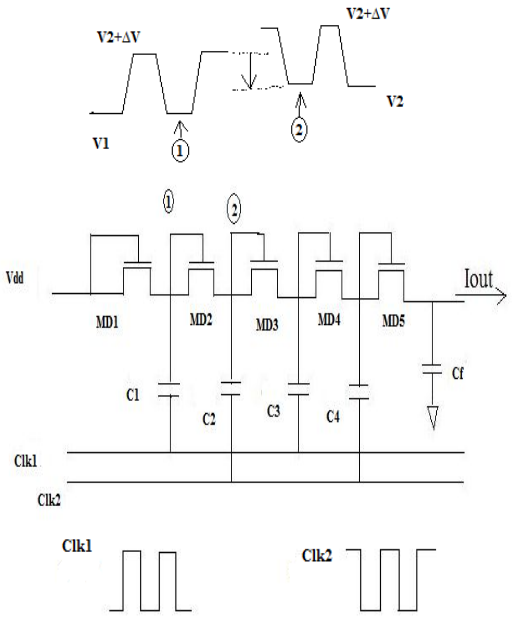

Figure 1. A four-stage dickson charge pump.[1]

The drawback of Dickson charge pump is that the boosting ratio is 3 degraded by the threshold drop across the diodes. The body effect makes this problem even worst at high voltages[4].

4. STATIC CHARGE PUMP

MOST switches with proper on/off cycles are reffered to as CTS's. They have been used in place of diodes and show better voltage pumping gain than the diodes. MD1-MD4 are diodes for setting up the initial voltage at each pumping node[1]. They are not involved in the pumping operation. MS1-MS4 are the CTS's. If the switches can be on/off at the designated clock pulses, they can allow the charge to be pushed only in one direction. Then for each pumping stage upper voltage of each input is equal to the lower voltage of the output. In Fig.2 when Clk1 is high and Clk2 is low , the voltage at node1 is pushed to from and voltage at node 3 is pushed to . MS2 switch must be turned on by the voltage at node 3. Therefore voltage at node 3 must be higher than the threshold voltage of MS2. The gate to source volatge of MS2 is , i.e. .

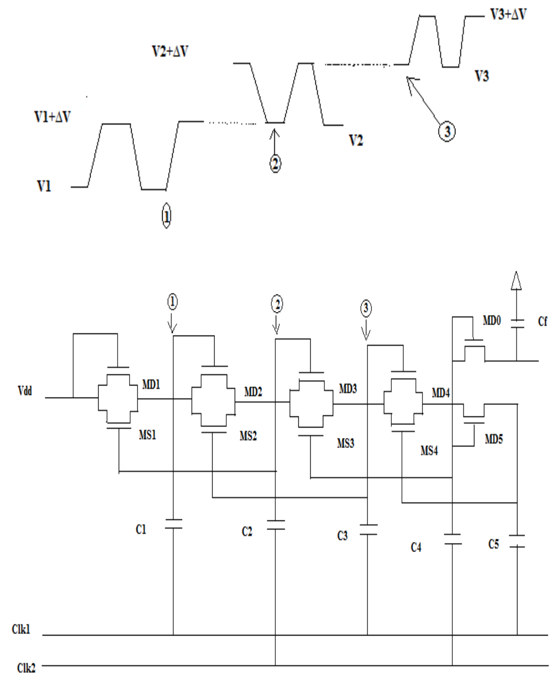

Figure 2. A four stage charge pump using static CTS's.[1]

On the other hand when the opposite condition arises the voltage at node 1 is and voltage at node 3 is . For ideal operation MS2 has to be turned off. Therefore gate to source voltage of MS2 must be smaller than the threshold voltage i.e.

These two conditons have to be satisfied. Therefore MS2 can never be turned off completely and reverse charge sharing between node 1 and node 2 occurs. Thereby reducing the output of the charge pump.

The drawback of this circuit is that charge transfer switches can not be completely turned off, leading to reverse charge sharing which leads to reducing in voltage gain[4].

5. DYNAMIC CHARGE PUMP

To overcome the drawback of static charge pump dynamic charge pump is designed. In dynamic charge pump each CTS's is accompanied with p-mos and n-mos pair, so that CTS's can be turned on and off completely.

When Clk1 is high node 1 and node 2 have volatge and voltage at node 3 is + . If the voltage is 2 above , then MP2 is turned on, causing Ms2 being turned on by the voltage at node 3[1]. On the other hand , when Clk1 is low and Clk2 is high, the voltage at node 1 is and both the voltages at node 2 and node 3 is 2 . If 2 > and 2 >), where is the threshold voltage of pMOST's , then MP2 is turned on , causing MS2 being turned off.

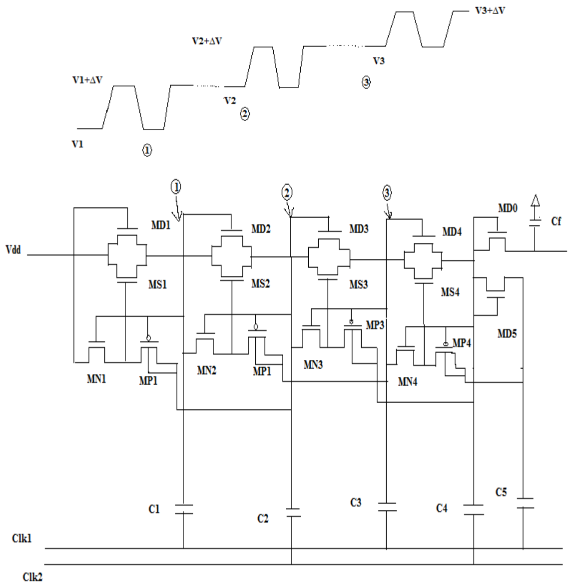

Figure 3. A four stage charge pump using dynamic CTS's[1].

6. RESULTS

In this paper volatge analysis for different charge pumps has been performed. Results have been simulated in Cadence Virtuoso and the results are shown in the form of input vs output voltage plot.

6.1 Dickson Charge Pump

Voltage analysis of the Dickson charge pump. On varying the input voltage change is observed in output voltage. Output voltage increases with increase in input voltage.Input voltage is varied from 1V to 5V. Period of the input pulse is kept constant at 10ns.

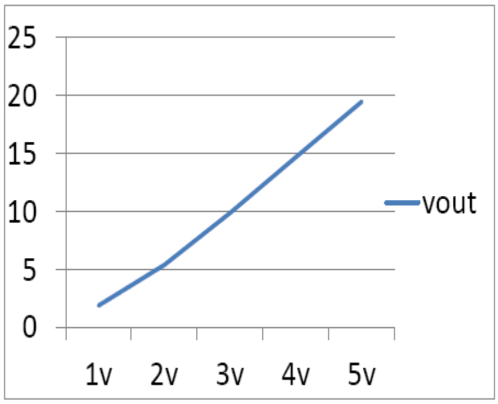

Figure 4. Voltage analysis of Dickson charge pump

6.2 Static Charge Pump

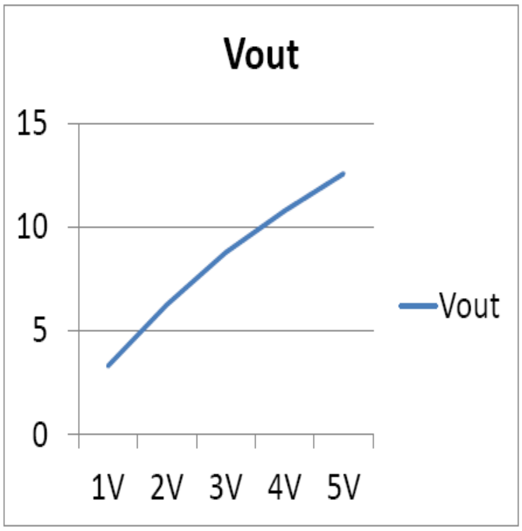

Figure 5. Voltage analysis of static charge pump

Voltage analysis of the Static charge pump. On varying the input voltage change is observed in output voltage. Output voltage increases with increase in input voltage. But the increase in output voltage is less in comparison to Dickson charge pump. The output voltage is less because of reverse charge sharing effect. To overcome this problem Dynamic charge pump was designed. Input voltage is varied from 1V to 5V. Period of the input pulse is kept constant at 10ns. Voltage of input pulse is also varied fromm 1V to 5V.

6.3 Dynamic Charge Pump

Voltage analysis of the Dynamic charge pump. On varying the input voltage change is observed in output voltage. Output voltage increases with increase in input voltage. Input voltage is varied from 1V to 5V. Period of the input pulse is kept constant at 10ns. Voltage of input pulse is also varied from 1V to 5V.

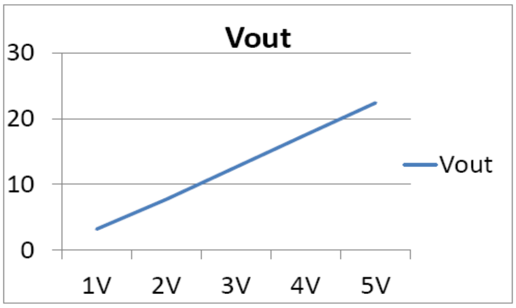

Figure 6. Voltage analysis of Dynamic charge pump

7. PROPOSED CHARGE PUMP

A MOS switch when is completely ON can pass charge from its drain to its source similar to a forward biased diode. It has the advantage that almost no voltage drop occurs between its drain and source terminal. Replace the diode connected NMOS transistors of a classical Dickson charge pump with PMOS switches. If these switches are turned ON and OFF at proper clock phases, they can allow the charge to be pushed in only one direction. In order to control the ON/OFF operation of each switch, a dynamic inverter is inserted in each stage.

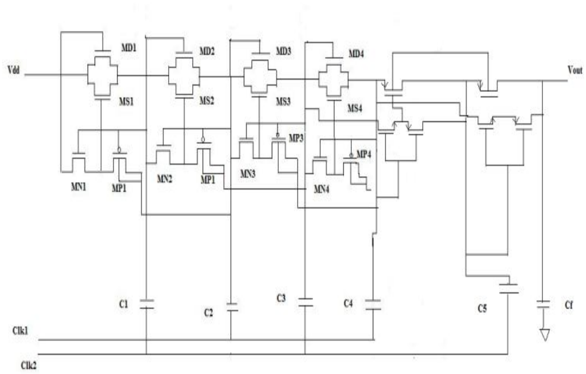

Figure 7. Proposed charge pump

As a result, the output voltage obtained is 25.07V.

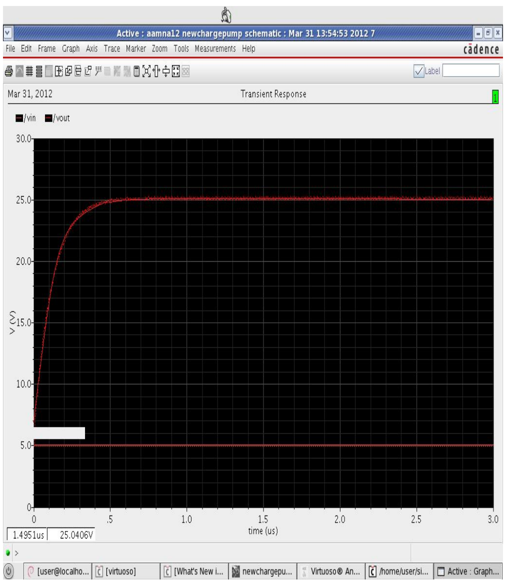

Figure 8. Output waveform of proposed charge pump

8. COMPARISON BETWEEN DICKSON, STATIC AND DYNAMIC CHARGE PUMPS

Comparison between Proposed, Dickson ,Static and Dynamic Charge Pump on the basis of variation of input voltage and output voltage obtained.

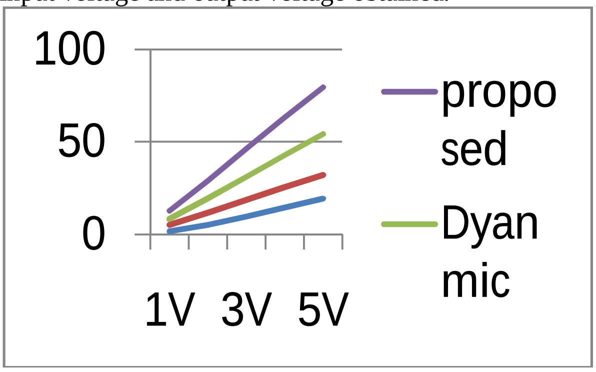

Figure 9. Comparison on the basis of voltage variation

9. CONCLUSION

As we can see that based on voltage analysis of the charge pumps , the output gain of Proposed charge pump is the highest. On the basis of voltage analysis of three different charge pumps-Dickson, Static and Dynamic, a new charge pump is proposed for improving the output voltage gain by making changes at the output stages of the charge pump.

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