A Fully-Integrated Switched-Capacitor Voltage Converter with higher Efficiency at Low Power

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ABSTRACT

DC-DC converters are also known as switching voltage regulators, are one of the main component of a power management unit. Their main role is to provide a constant, smooth output voltage to power the electronic devices. Switching mode DC-DC converters are critical building blocks in portable devices and hence their efficiency and power are a major issue. This paper describes design techniques to maximize the efficiency of fully integrated switched-capacitor (SC) DC-DC converters. The measured performance of switched capacitor converter implemented on tanner EDA tool at 45 nm and 90nm CMOS technology with 2V input voltage to support output voltages of .5 and .7 and achieves 94% and 98% efficiency at an output power 86.9uW and 0.175mW .

Keywords- DC-DC conversion, switched-capacitor, switching converter

1. INTRODUCTION

Every Electronic circuit is assumed to operate some supply voltage which is usually assumed to be constant in nature. A voltage regulator is a power electronic circuit that maintains a constant output voltage irrespective of change in load current or line voltage. Many different types of voltage regulators with a variety of control schemes are used. With the increase in circuit complexity and improved technology a more severe requirement for accurate and fast regulation is desired. This has led to need for newer and more reliable design of dc-dc converters. The dc-dc converter inputs an unregulated dc voltage input and outputs a constant or regulated voltage. The regulators can be mainly classified into linear and switching regulators shown in fig-1. All regulators have a power transfer stage and a control circuitry to sense the output voltage and adjust the power transfer stage to maintain the constant output voltage. A DC-DC converter is a device that accepts a DC input voltage and produces a DC output voltage. Typically, the output produced is at a different voltage level than input. Portable electronic devices, such as cell phones, PDAs, pagers and laptops, are usually powered by batteries. After the battery has been used for a period of time, the battery voltage drops depending on the types of batteries and devices. This voltage variation may cause some problems in the operation of the electronic device powered by the batteries. So, DC-DC converters are often used to provide a stable and constant power supply voltage for these portable electronic devices. According to the components used for storing and transferring energy, there are two main kinds of topologies in DC/DC converters: inductive converters and switched capacitor converters. The inductive converter using inductor as energy storing and transferring component has been a power supply solution in all kinds of applications for many years. It is still a good way to deliver a high load current over 500mA. But in recent years, since the size of portable electronic device is getting smaller and smaller, and the load current and supply voltage are getting lower and lower, the inductor less converters based on switched capacitor are more and more popular in the space constrained applications with 10mA to 500mA load current. Such converters avoid the use of bulky and noisy magnetic components, inductors.

2. TYPES OF DC-DC CONVERTER

DC-DC converter are a kind of converters which convert unregulated DC power to regulated DC power. The basic configuration of DC-DC converters are-

- Buck Converter- Buck converter is made of voltage source, voltage controlled switch, flywheel diode, inductor, capacitor and load . A control circuit is connected between the base of MOSFET and one of the plates of capacitor. It is called the buck converter because the voltage across the inductor bucks or opposes supply voltage. In this converter the output voltage is normally less than the input voltage.[1,2]

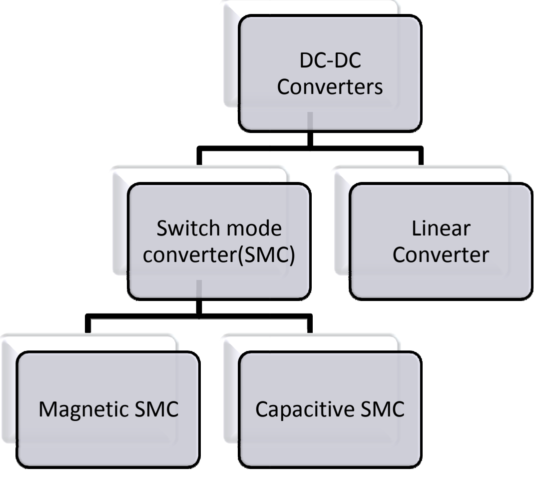


Fig1-Classification of converters

Boost Converter-The boost converter has similar structure as the buck converter, but has components arranged in different manner. It is called boost converter because the voltage across inductor adds to the input supply voltage to boost the voltage above input voltage. The output of boost is always greater than input voltage[1,2].

- Buck-Boost Converter-The components in buck-boost converter are MOSFET, diode, inductor and capacitor similar to buck and boost converter. The components are arranged in different way to provide step up as well as step down with polarity reversal or inversion as well[1,2].
- Cuk Converter-The buck, boost and buck-boost converters all transfer energy between input and output using the inductor, thus building the voltage across the inductor. The cuk converter transfers energy through the capacitor thus the analysis is based on current through the capacitor. The output is inverted as in the buck-boost converter whereas the circuit configuration is a combination of buck and boost converters[1,2].
- Switched Capacitor Converter-These converters exclusively comprised of only switches and capacitors to efficiently convert one voltage into another. They have smaller size than inductor based converters[3].

3. SWITCHED CAPACITOR DC-DC CONVERTER

Switched capacitor converters become popular for on-chip power conversion since there is no inductive component present, which on-chip with sufficiently low losses are large and difficult to manufacture, are required. They uses only switches and capacitor. Consider the circuit shown in fig-2, consisting of only switches and capacitors. The switches in the circuit are operated by two distinct non-overlapping clock signal, $\square_1$ and $\square_{2,}$ so that switches turn on when the clock signal is high. During phase 1 ($\square_1$), the charge-transfer capacitors (C_T)get charged from the battery (V_{In}). In the phase2 ($\square_2$) of the clock, they dump the charge gained onto the load (V_L).

This paper presents the design and evaluation of a 2:7 and 2:5 voltage ratio down conversion switched capacitor converter shown in implemented in 45nm and 90nm technology on tanner tool. During the operation of SC topologies 2:7 and 2:5,these topologies switch into the circuit depending upon the load and input voltage requirements shown in fig-3. During the clock signal a=high ,load capacitor C_L is charged from battery voltage, through charge transfer capacitors. Similarly when clock signal b=high ,charge accumulated by charge transfer capacitor is transferred to load capacitor by connecting them together shown in fig-3. Different capacitor arrangement in SC topology results in the unique no-load voltage at the output . During the closed loop operation of SC converter, these topologies will be configured in the main switching matrix based on the input voltage range and output voltage. If the output voltage falls below a certain value for a certain topology, a higher topology is needed to meet up load current requirement.

4. DESIGN AND IMPLEMENTATION

This section discusses the design and implementation of the 2:7 and 2:5 SC converter integrated in a 45nm and 90nm technology. In this work the demonstration of high efficiency voltage conversion is done by using the circuit shown in fig-4. In 2:7 and 2:5 conversion the output voltage is lower than the input voltage . In Phase-1 the capacitors C_1, C_2, C_3,C_4(2:7 conversion) and C_1,C_2,C_3(2:5 conversion)charges and current flows into the V_{out}.

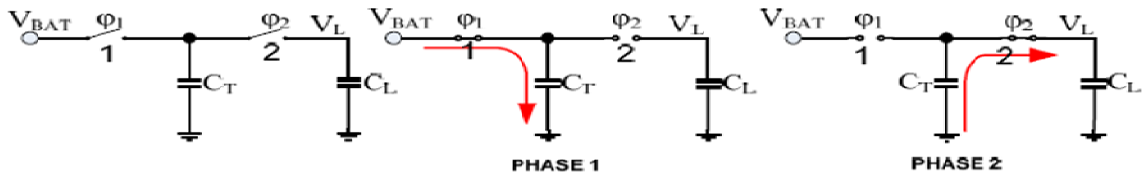
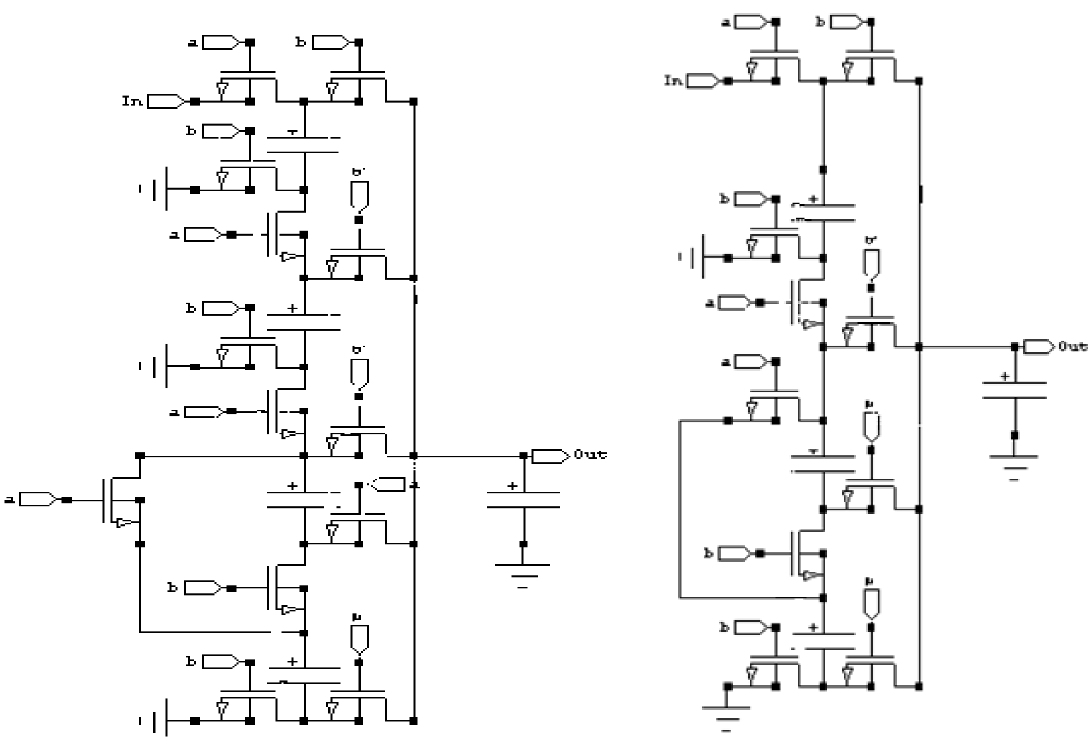


Fig 2:Basic working of SC DC-DC converter

In the Phase-2, the capacitor discharges towards the output voltage. Thus, charge is delivered to the load in each switching cycle. While an inherent output ripple may exist, a multi-phase system with sufficient decoupling capacitance minimizes this effect. In a step-down converter which are intended to generate output voltages near the nominal process voltage, then the breakdown voltage of these switches will most likely to be smaller than the input voltage V_{BAT}, and therefore appropriate switch driving strategies are needed. Therefore a differential ring oscillator is used to meet the requirement of clock generation.



(a) **(b)**

Fig3-(a)2:7 Topology of SC converter (b)2:5 Topology of SC converter

The output of ring oscillator is used to drive two different phases of SC converter topologies. The output of ring oscillator is applied to AND gate with enable. here AND gate is designed because it provides buffering to the clock generator and clock produce with sharper edges, it also provides additional control from outside for enabling/disabling the clock generator .Some transistor in SC stage require different clock voltage to operate . This poses the requirement of level shifter[4] which can shift the voltage level of V_{drive} to GND. here V_{drive} is the optimum value of gate to source voltages at which the efficiency is higher. This circuit for both topologies is simulated for current and power dissipation for different values of frequency on different technologies such as 45nm and 90nm. Simulated figures are depicted from fig-5 to fig-8. Here it is shown that 2:7 topology gives better efficient result on 90nm technology i.e. 94% and 2:5 gives 98% efficiency on 45nm technology each of them at 2v supply. Summary of work is shown in table-1.

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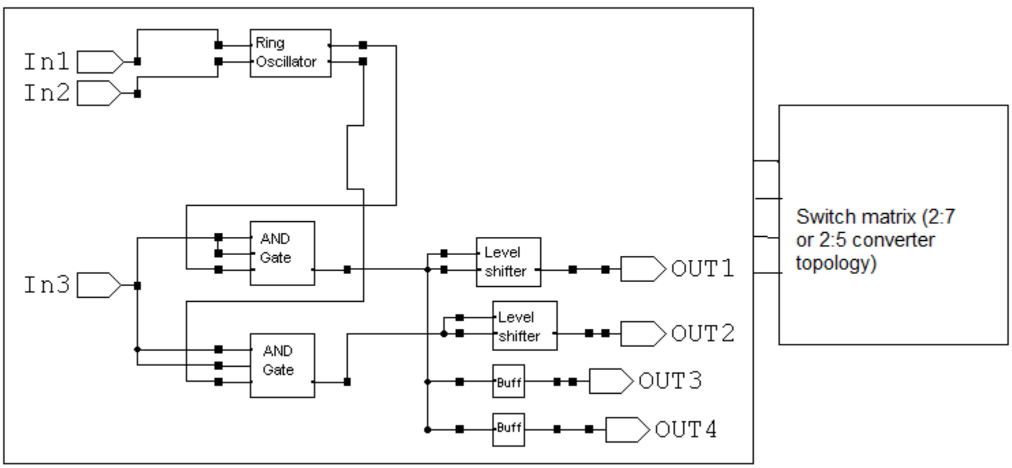
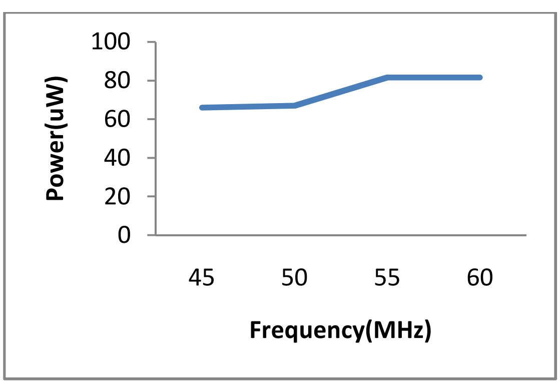
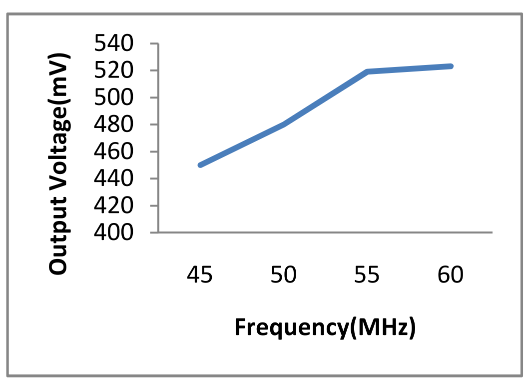
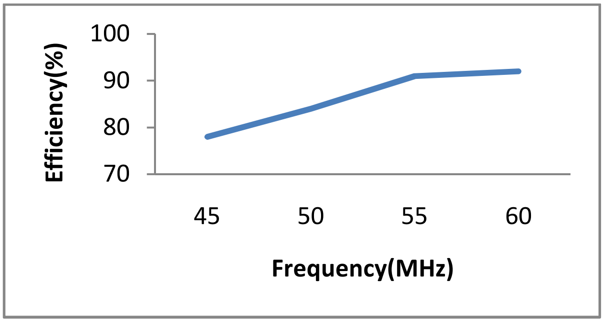


Fig4- Converter power switch control circuit



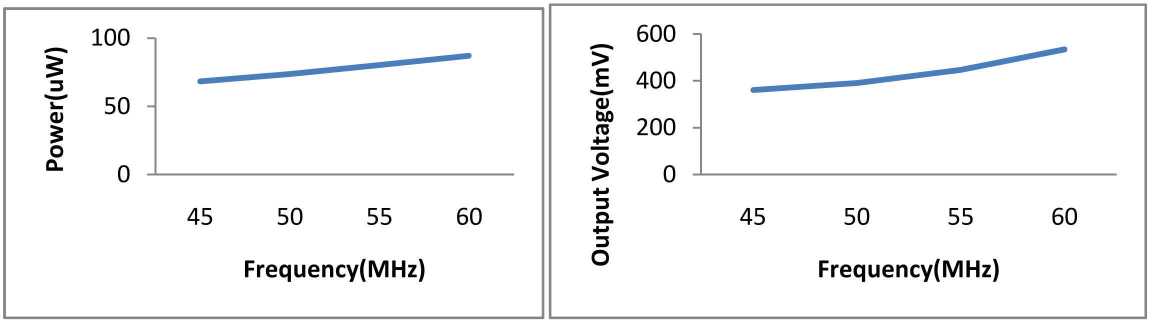


(a) **(b)**

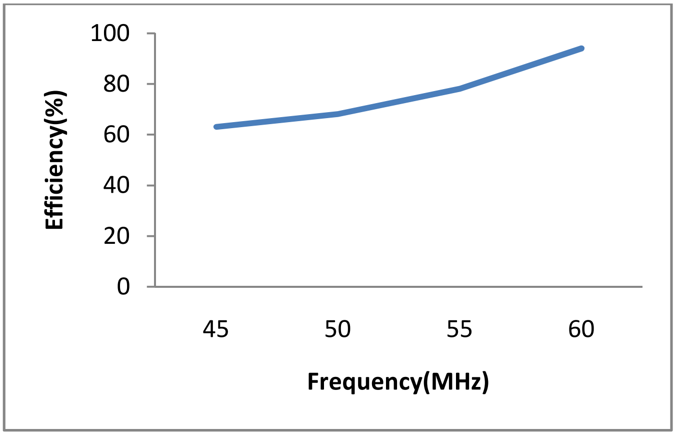


(c)

fig5--(a)Power v/s frequency (b) Output Voltage V/s Frequency (c)Efficiency v/s Frequency on 45nm technology for 2:7 topology

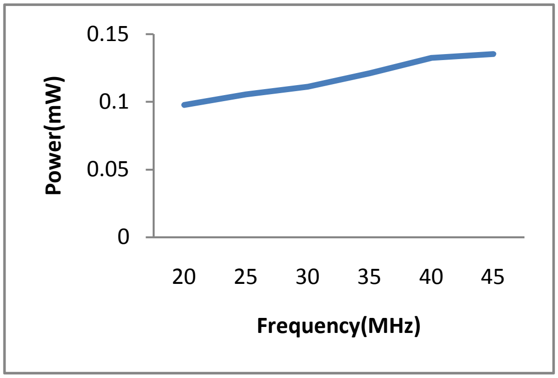


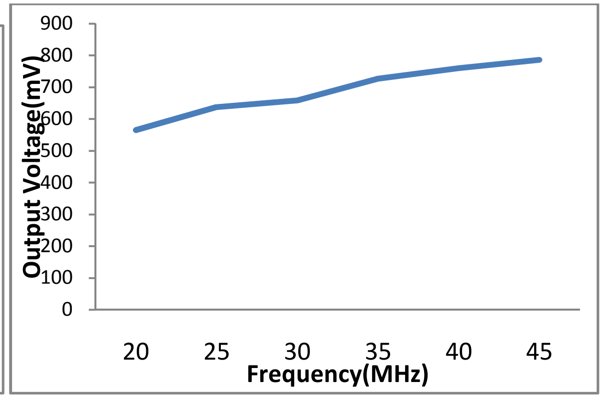
(a) **(b)**



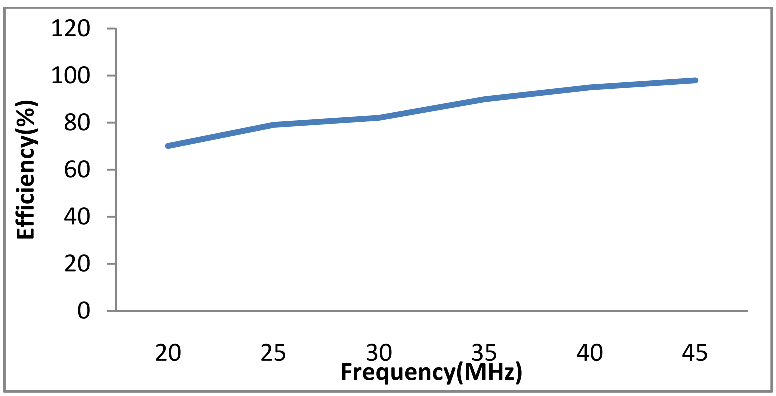
(c)

Fig6-(a)Power v/s frequency (b) Output Voltage V/s Frequency (c)Efficiency v/s Frequency on 90nm technology for 2:7 topology



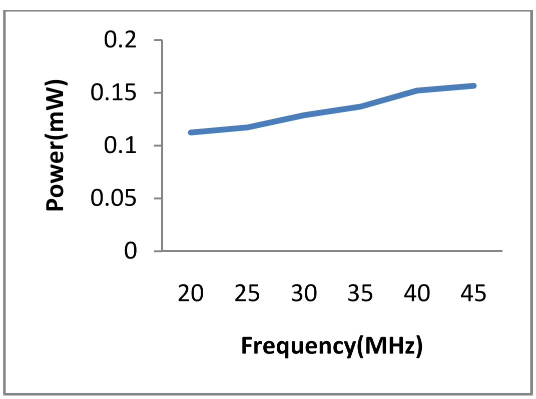


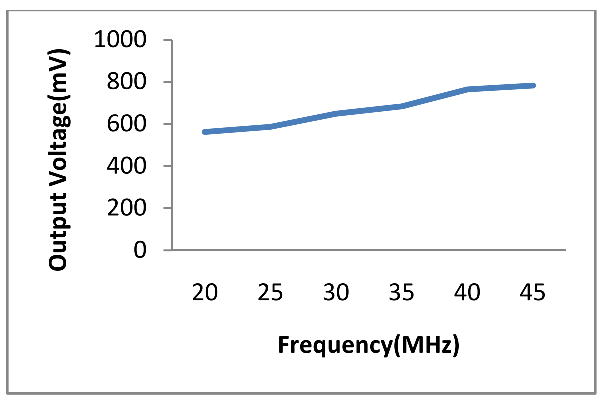
(a) (b)



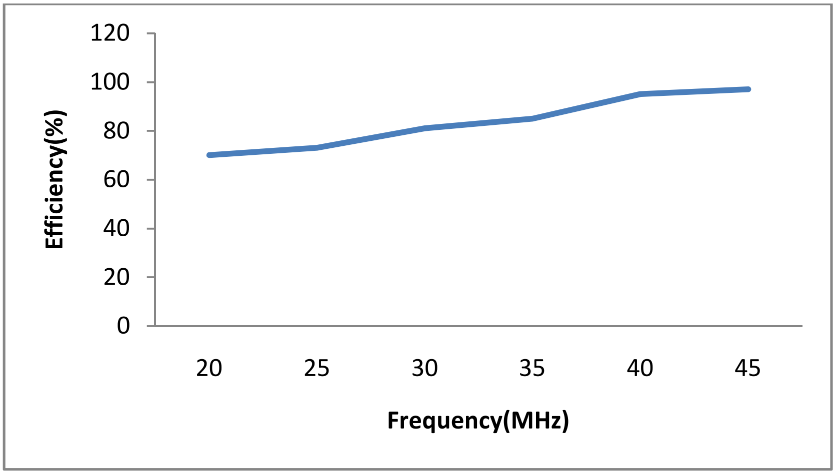
(c)

Fig7--(a)Power v/s frequency (b) Output Voltage V/s Frequency (c)Efficiency v/s Frequency on 45nm technology for 2:5 topology





(a) (b)



(c)

Fig8---(a)Power v/s frequency (b) Output Voltage V/s Frequency (c)Efficiency v/s Frequency on 90nm technology for 2:5 topology

Table1- Summary of the 2:7 and 2:5 Converter

Topology	2:7		2:5	
Process	45nm Tanner Tool	90nm Tanner Tool	45nm Tanner Tool	90nm Tanner Tool
Input Voltage	2v	2v	2v	2v
Output Voltage	0.532v	0.534v	0.786v	0.783v
Power	81.5uW	86.9uW	0.1352mW	0.1565mW
Frequency	60MHz	60MHz	45MHz	45MHz
Efficiency	92%	94%	98%	97%

5. COMPARISON AND RESULT

In Table. 2, the results presented in this paper are compared to previously published results on SC converters focusing on efficiency. This work is implemented on 90nm and 45nm Technology on Tanner EDA Tool and it gives

98% efficiency at low power for 2:5 topology on 45nm.

Table-2 Comparison of the work presented in this paper to previously published work

Reference	[5]	[6]	[This work]
Technology	45nm SOI	90nm BULK	45nm and 90nm Tanner EDA Generic
Topology	2:1	2:1	2:7 and 2:5
Input Voltage	2V	2.4V	2V
Output Voltage	0.95V	1V	0.78(2:5on 45nm)
Power	2.6mV	1650mW	135.2uW(2:5 on 45nm)
Frequency	100MHz	N/A	45MHz(2:5on 45nm)
Efficiency	90%	69%	98%(2:5on 45nm)

6. CONCLUSION

In this paper 2:5 and 2:7 topologies are simulated on 90nm and 45nm technology on Tanner EDA Tool. This work shows the better efficient result on 45nm technology for 2:5 topology when input voltage is 2V at 45MHz frequency which results in 0.78V output voltage,135.2uW power and 98% efficiency .

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