A 316.5nA Quiescent Current of DC–DC Converter with 92.8% Peak Efficiency for a IoT Application

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***Abstract*—** This paper proposes a structure that generates a very low Quiescent Current of DC-DC Converter for use in IoT (Internet of Things) applications, achieves high efficiency, and describes the circuits and algorithm associated therewith. The quiescent current result is approximately 316.5 nA using the method of sensing input voltage, turning off unnecessary blocks, and converting to stand-by mode based on the comparator, and peak efficiency is approximately 92.8% through the proposed DC-DC Converter structure in this paper. The circuit is designed with a Samsung 130nm of BCD(Bipolar CMOS DMOS) process that produces an output voltage of 1.8V ~ 4.2V by DC-DC Converter using a standard supply voltage of 1.8V ~ 4.2V.

Keywords— Comparator, DC-DC Converter, Energy Harvester, IoT Application, Quiescent Current

I. INTRODUCTION

Recently, as electronic devices used in IoT applications[1] are miniaturized and diversified, the complexity of IoT system is increasing. In order to implement the corresponding system, it is essential to supply power to drive the electronic device. It may be a common method to select a method for wired charging and power supply for an electronic device used in an IoT system.

However, as the complexity of the system increased, other method was needed due to the limitations of wired power supply, and as an alternative, Energy Harvester-based power transmission was proposed. Energy Harverster-based power supply systems are the right way to power environmentally friendly and compact small IoT electronic devices. However, depending on IoT device surroundings, there are timezone or places where it can't be powered. When power cannot be supplied under these conditions, we need to minimize the power consumption of the devices that supply power to minimize the power discharge of the batteries or other power storage devices used in IoT systems.

This paper will describe how DC-DC Converter, one of the power supplies used in the IoT system, recognizes no incoming power from Energy Harvester and minimizes power consumption.

The rest of this paper is organized as follows. Section II describes the building blocks of the proposed boost converter. Section III introduces the proposed circuit and a simple algorithm, Section IV presents the simulation results of the proposed converter, and last section (section V) concludes the paper.

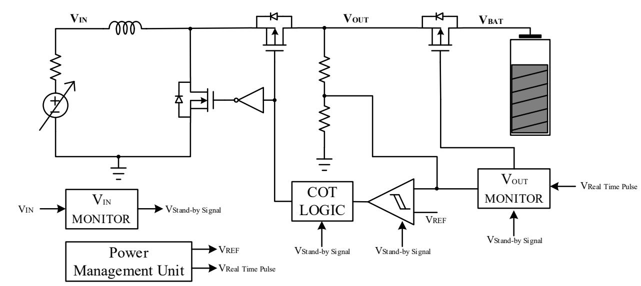

Fig. 1. Block diagram of Proposed CoT DC-DC Converter

II. STRUCTURE OF DC-DC BOOST CONVERTER

Fig. 1 is the structure of Proposed DC-DC Converter type of Constant on Time(CoT) operation.

The COT LOGIC block is a controller of the High Side and Low Side Power MOSFET through signals generated by comparing the reference voltage and output voltage based on the comparator. The VOUT MONITOR block is a controller that generates a signal connecting the output voltage node with the battery. The block monitors the power voltage every certain period based on the real time based pulse voltage and connects to the battery when the power voltage is under certain conditions to induce a charging operation. The Power Management Unit (PMU) is a generator of various signals including the reference voltage and real time pulse required by Sub-Block. The VIN MONITOR block proposed in this paper is a generator to implement a method to lower the Quiescent Current, which generates a signal to switch the Converter to stand-by mode when no power is applied by sensing the incoming voltage from the input.

Due to the advantages of the DC-DC Converter of the CoT type, this structure is a simple structure that uses very little power while operating, and frequency compensation does not need to be considered to operate based on a comparator. In addition, the proposed method can significantly reduce the Quiescent Current, which has the advantage of maintaining battery power for a very long time.

III. PROPOSED OF INPUT MONITORING BLOCK AND ALGORITHM

This part explains a method of reducing the quiescent current of DC-DC converters for use in IoT applications through Input Monitoring block and explains the method by dividing it into circuits and algorithm part.

A. Input Monitoring Block

This block (Fig. 2) is a simple circuit that compares reference voltage and input voltage based on a hysteresis comparator. As the DC-DC Converter may operate and cause ripple of input voltage (Because of regulation operation), RC filters have been added to nodes receiving input voltage to minimize the ripple.

The block operates after the output voltage of the Bandgap reference (BGR) block configured in the PMU block is ready. And the block monitors the incoming input in real time and turns off all blocks except for the BGR block of the PMU block and the reference block that generates the reference voltage when the input voltage is lower than the reference voltage by comparator circuit and the operation mode is convert of stand-by mode (Fig. 3).

In addition, if the output monitoring block converts the DC-DC Converter to stand-by mode with the output node connected to the battery, the output monitoring block remains inoperative(can't disconnect of battery with output node), there is a risk that the battery will eventually drain completely. Therefore, this paper added logic to force the output node to separate the battery regardless of the output monitoring block when the operating with stand-by mode condition and 'BGR block is ready' signal turns off. Additionally, the signal of 'BGR block is ready' turns on when the output voltage of the BGR reaches the desired voltage and turns off when the opposite conditions occur. The condition for OFF of the signal is that when the output voltage of the converter becomes less than about 1.5V so that the proposal about forced disconnecting with battery was designed in combination with this block.

B. Algorithm of converting with stand-by mode

This part shows the algorithm of how to operate converting with stand-by mode and re-operation of regulation mode.

Along with the aforementioned operations of the circuits, I wrote this part to organize and propose the conversion and recovery conditions of the overall converter's operational mode and the order in which the blocks are turned on and operated.

First of all, starting with the condition that the converter is performing a regulation operation, if the input voltage is higher than the reference voltage through the real-time operation of the input monitoring block, the regulation operation continues. If the input voltage is lower than the reference voltage, all unnecessary blocks are turned off according to the operation of the circuit described above, and regulation of the dc-dc converter stops while operating in stand-by mode. After that, if the input voltage is higher than the reference voltage, the block forming the real time pulse operates first, and the converter performs regulation again after a certain period of time based on the count of the pulse. (Fig. 4)

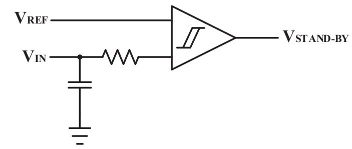

Fig. 2. Input Monitoring Block

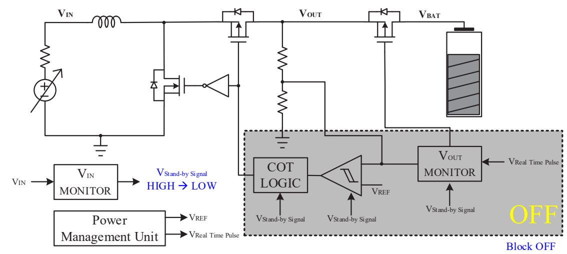

Fig. 3. Stand-by mode with Signal off of output signal of input voltage monitor

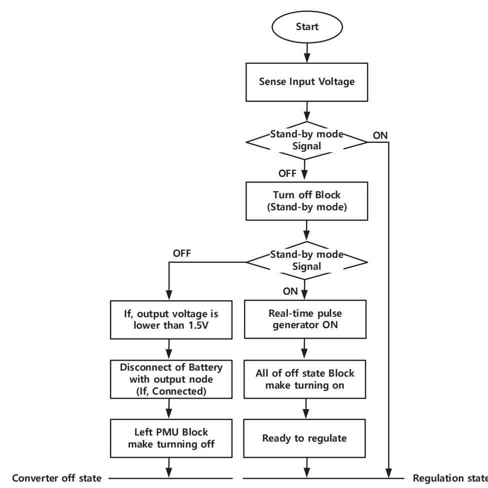

Fig. 4. Algorithm of converting operation mode

IV. EXPERMENTAL RESULT

Fig. 5 shows the DC-DC Converter full operation simulation result with stand-by mode operation state. The figure shows a boosting operation of output voltage due to regulation, a discharging operation of output voltage (with battery voltage) due to stand-by mode operation, and a boosting operation of output voltage due to regulation starting again.

Fig. 6 shows detailed operation of the process of switching to stand-by mode. We can see through the simulation result that the out

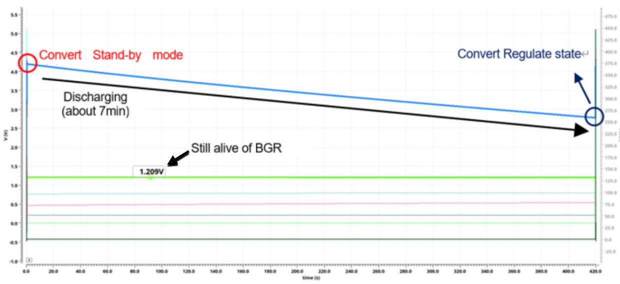

Fig. 5. Full operation of DC-DC Converter with Stand-by mode state

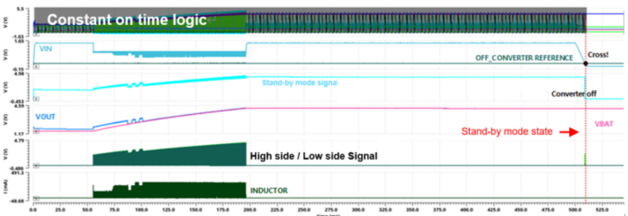

Fig. 6. Detail operation of Regulation state to Stand-by mode state

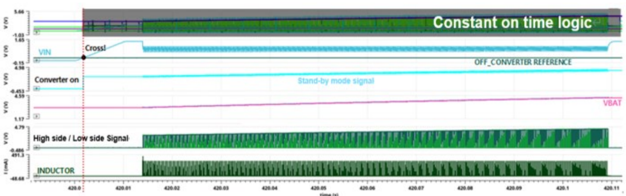

Fig. 7. Detail operation of Stand-by mode state to Regulation state

-put voltage connected to the battery is slowly discharged as the unnecessary COT LOGIC-related blocks are turned off while being lower than the reference voltage according to the input voltage.

Fig. 7 shows the simulation results of the process of changing from stand-by mode to regulation state. As the input voltage is higher than the reference voltage, the real time pulse is preferentially output, and after a predetermined time, the COT LOGIC is operated again and the output voltage is boosted according to the regulation operation.

Fig. 8 shows the top layout of DC-DC Boost Converter. The top layout is designed in the Samsung 130nm CMOS process. The area of the DC-DC Boost converter is 1688.62μm × 915.86μm. And the area of the DC-DC Boost Converter including pad is 1932.32μm × 1009.35μm.

Table 1 shows the results of quiescent current ratio with blocks and total current. By using this method, we can achieve the ultra-low quiescent current result and it can make discharging of battery voltage slower when the IoT device can't be charged by input power (No Input condition).

Table 2 shows the results of quiescent current comparison table that we achieved the lower quiescent current than the other paper.

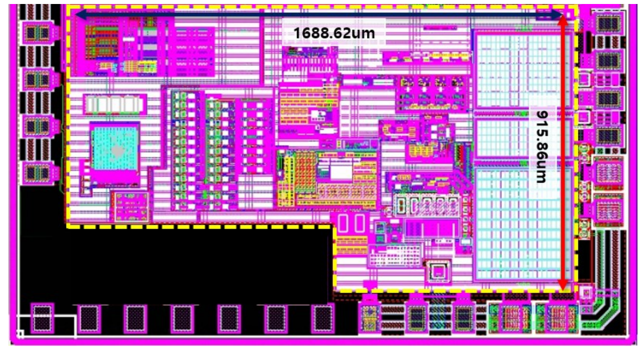

Fig. 8. Layout of DC-DC Converter

TABLE 1. QUIESCENT CURRENT TABLE

Block	Current (nA)
PMU & input monitor	256.6
COT Logic	57.005
Output voltage monitor	2.895
Total	**316.5**

TABLE 2. COMPARISION TABLE

	QUIESCENT CURRENT	Peak Efficiency	MPPT	Application
[2]	490nA	92.1%	X	IoT Application
[3]	470nA	92.7%	X	IoT Application
[4]	494nA	72%	X	Wireless sensor network
[5]	420nA	96.7%	X	Energy Harvesting
THIS WORK	316.5nA	92.8%	O	IoT Application & Energy Harvesting

V. Conclusion

This paper proposes a method to achieve very low quiescent current in DC-DC Converter for power supply used in IoT applications.

Based on the block called INPUT MONITOR, the input voltage is sensed according to the behavior of the comparator, a signal is generated to convert to stand-by mode, and the quiescent current is lowered by turning off unnecessary blocks, resulting in 92.8% peak efficiency and the low quiescent current of about 316.5 nA.

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