Abstract

Wireless Sensor Network (WSN) is one of the supporting technologies to materialize the Internet of Things (IoT). However, a large scale deployment of the WSN faces multifarious challenges. WSN node size and maintenance cost incurred by periodic energy source replacement are among them. From the perspectives of energy sources, these two challenges can be better addressed by Wireless Power Transfer (WPT) technologies in comparison with energy scavengers or traditional energy storages. Omnidirectional Electro-magnetic Radiation WPT technology appears to be a viable choice. Hence, this work proposed various circuit design techniques in developing the dedicated Power Management Integrated Circuit (PMIC) structures to support implementation of such WPT technology.

In detail, this thesis lists (i) a new trimming circuit structure for a sub-1-volt CMOS Voltage Reference (VR), (ii) a controllable Negative Source Degenerating Resistance (NSDR), and (iii) a compensator-less analogue controller for a Pulse Width Modulation (PWM) Discontinuous Current Mode (DCM) Boost DC-DC Converter. To elaborate, the trimming effort aims at minimizing unwanted temperature coefficient due to the finite resistance of the trimming switches so as to improve the overall Temperature Coefficient (TC) of a CMOS Voltage Reference (VR). Moreover, the negative resistance designed is dependent on the load current of an Output Capacitor-Less (OCL) Low Drop-Out Voltage Regulator (LDO). It is made to boost the gain of the LDO by improving the current efficiency. Lastly, the compensator-less controller is meant to minimize power and area concern brought by the compensator in switching DC-DC converter.

Subsequently, structures of three key PMIC building blocks, such as a VR, an OCL LDO and a boost DC-DC switching converter, are proposed based on the aforementioned circuit design techniques. A trimming circuit is proposed for a sub-1-volt CMOS voltage reference based on threshold voltage difference (ΔV_{th}) approach. Implemented in 180 μm CMOS technology, the trimmed CMOS VR consumes 0.941 μA under supply input of 0.8 V with a TC of 26.6 ppm/°C and a Power Supply Rejection (PSR) larger than 60 dB at 1 MHz. The

trimmed VR is functional under supply input from 0.7 V to 1.5 V.

Furthermore, a fast-transient OCL LDO that is based on a load-dependent NSDR at the input stage of its Error Amplifier (EA) is proposed. By having the resistance of the NSDR varies with respect to the load current of the OCL LDO, no compensation capacitor is needed for frequency compensation to ensure stability. In this manner, the overall OCL LDO is implemented in 180 μm CMOS process. It achieves a fast load transient response of 3 μs in a load step up and down between 0 mA to 100 mA in 100 ns. The OCL LDO functions under supply input from 0.8 V to 1.5V, across which, it consumes quiescent current of no more than 20 μA in zero load condition.

In addition, a compensator-less PWM DCM Boost DC-DC converter based on a Square-Root Voltage Mode (SRVM) controller is also proposed. The SRVM controller achieve voltage regulation by implementing analog signal processing unit to sense the load current and convert it into a PWM voltage control signals to drive the power switches. The block level design of the proposed Boost DC-DC converter is simulated in MATLAB. It achieves output ripples of 0.42% of its steady-state output of 3 V. Output overshoots of 3 mV with 4 μs recovery time are observed during step-down load transients between 40 and 0 mA in 100 ns. Correspondingly, output undershoots during step-up load transients are less than 10.8 mV with a recovery time of 8.9 μs. The boost converter can start up from its 0.9-V input autonomously based on a proposed two-phase start-up control scheme. On top of this, a novel signal boosting technique is presented to ensure gate driving voltages for MOSFET switches as high as attainable to minimize the conduction losses. At the steady state, the boost converter operates with a fixed 1-MHz switching frequency with a 1 μH inductor and a 10 μF capacitor with the maximum load current of 40 mA.

Overall, all proposed designs achieve supply and load independence as well as power and area efficiency in addressing the unique PMIC design challenges dedicated to the Omnidirectional EM Radiation WPT.