LOW POWER INTERFACE IC'S FOR ELECTROSTATIC ENERGY HARVESTING APPLICATIONS

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An Abstract of a Thesis Submitted to the Graduate

Faculty of Rensselaer Polytechnic Institute

in Partial Fulfillment of the

Requirements for the Degree of

DOCTOR OF PHILOSOPHY

Major Subject: ELECTRICAL ENGINEERING

The original of the complete thesis is on file
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December 2011
(For Graduation May 2012)

ABSTRACT

The application of wireless distributed micro-sensor systems ranges from equipment diagnostic and control to real time structural and biomedical monitoring. A major obstacle in developing autonomous micro-sensor networks is the need for local electric power supply, since using a battery is often not a viable solution. This void has sparked significant interest in micro-scale power generators based on electrostatic, piezoelectric and electromagnetic energy conversion that can scavenge ambient energy from the environment. In comparison to existing energy harvesting techniques, electrostatic-based power generation is attractive as it can be integrated using mainstream silicon technologies while providing higher power densities through miniaturization. However the power output of reported electrostatic micro-generators to date does not meet the communication and computation requirements of wireless sensor nodes. The objective of this thesis is to investigate novel CMOS-based energy harvesting circuit (EHC) architectures to increase the level of harvested mechanical energy in electrostatic converters.

The electronic circuits that facilitate mechanical to electrical energy conversion employing variable capacitors can either have synchronous or asynchronous architectures. The later does not require synchronization of electrical events with mechanical motion, which eliminates difficulties in gate clocking and the power consumption associated with complex control circuitry. However, the implementation of the EHC with the converter can be detrimental to system performance when done without concurrent optimization of both elements, an aspect mainly overlooked in the literature. System level analysis is performed to show that there is an optimum value for either the storage capacitor or cycle number for maximum scavenging of ambient energy. The analysis also shows that maximum power is extracted when the system approaches synchronous operation. However, there is a region of interest where the storage capacitor can be optimized to produce almost 70% of the ideal power taken as the power harvested with synchronous converters when neglecting the power consumption associated with synchronizing control circuitry. Theoretical

predictions are confirmed by measurements on an asynchronous EHC implemented with a macro-scale electrostatic converter prototype.

Based on the preceding analysis, the design of a novel ultra low power electrostatic integrated energy harvesting circuit is proposed for efficient harvesting of mechanical energy. The fundamental challenges of designing reliable low power sensing circuits for charge constrained electrostatic energy harvesters with capacity to self power its controller and driver stages are addressed. Experimental results are presented for a controller design implemented in AMI $0.7\mu M$ high voltage CMOS process using a macro-scale electrostatic converter prototype. The EHC produces $1.126\mu W$ for a power investment of $417nW$ with combined conduction and controller losses of $450nW$ which is a 20-30% improvement compared to prior art on electrostatic EHCs operating under charge constrain.

Inherently dual plate variable capacitors harvest energy only during half of the mechanical cycle with the other half unutilized for energy conversion. To harvest mechanical energy over the complete mechanical vibration cycle, a low power energy harvesting circuit (EHC) that performs charge constrained synchronous energy conversion on a tri-plate variable capacitor for maximizing energy conversion is proposed. The tri-plate macro electrostatic generator with capacitor variation of $405pF$ to $1.15nF$ and $405pF$ to $1.07nF$ on two complementary adjacent capacitors is fabricated and used in the characterization of the designed EHC. The integrated circuit fabricated in AMI $0.7\mu M$ high voltage CMOS process, produces a total output power of $497nW$ to a $10\mu F$ reservoir capacitor from a $98Hz$ vibration signal.

In summary, the thesis lays out the theoretical and experimental foundation for overcoming the main challenges associated with the design of charge constrained synchronous EHC's, making electrostatic converters a possible candidate for powering emerging communication transceivers and portable electronics.