

# EFFICIENT POWER MANAGEMENT FOR ENERGY AWARE, SELF-SUFFICIENT WIRELESS SENSORS IN AERONAUTIC APPLICATIONS

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**Abstract:** An efficient power management is a key enabler for self-sufficient operation of wireless sensors from ambient energy sources. In recent years large emphasis has been put on the development of energy generators e.g. for vibration or thermal energy harvesting, however the performance of power conversion and storage circuits still appears to be low. In this paper we present an improved power management circuit that allows passive and active rectification of bipolar input signals, start-up from very low input voltages, digitally controlled, highly efficient energy storage using supercap technology, input/output decoupling and complete energy awareness for adaptive sensor behavior.

**Keywords:** Power Management, DC/DC Conversion, Voltage Booster, Supercapacitor, Energy Storage

## INTRODUCTION

Wireless sensor networks rely on the availability of local energy sources. Especially in difficult-to-access places and in low temperature environments energy harvesting is providing key solutions to overcome the disadvantages of conventional battery technologies like the need for periodic replacement or low-temperature compatible, toxic cell chemistries. The conditioning and storage of energy is one of the main challenges, as the harvester output depends on the environmental conditions and may even cease completely.

Within the German national funded AMETYST project [1] an improved power management circuit has been developed that addresses this problem.

## POWER MANAGEMENT CONCEPT

The principle of the design is shown in Figure 1.

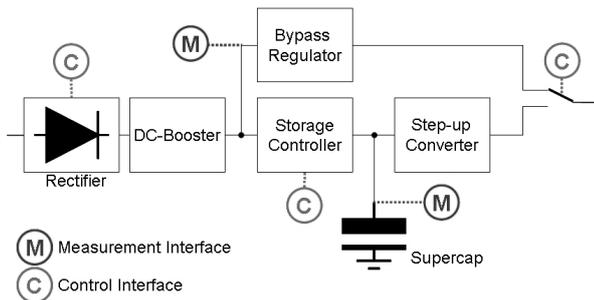


Fig. 1: Block diagram of power management circuit.

After passive rectification using Schottky diodes the DC voltage is stepped up by a DC-Booster to generate an intermediate operating voltage. This voltage is used to power a microcontroller via a bypass regulator. The controller then activates an active rectification using low resistance MOS transistors. Depending on the power input level it initiates the energy storage process by actively controlling a discontinuous buck converter. This buck converter is

used to transfer the energy into a supercap with very high efficiency, thus eliminating one of the major drawbacks of earlier design concepts using a transistor based supercap charge control. Once the charge level reaches an acceptable minimum, the operation can be switched to supercap supply, where a step-up converter provides a stable output voltage.

Continuous monitoring of both harvester input power and charge level on the supercapacitor enables the sensor node to select either the most efficient or the most powerful energy source. This complete power and energy status awareness, allows adaptation of the system behavior to the given environmental conditions.

## GENERATOR SOURCE MODELLING

Thermoelectric power generators are considered for many aeronautic wireless applications. They benefit from the large temperature changes and differences the aircraft experiences during flight and provide an intrinsic robustness, as they have no moveable parts. In general the behavior of a thermoelectric generator (TEG) is described by its Seebeck-coefficient  $\alpha$  (see Eq. 1).

$$U_0 = \alpha \cdot \Delta T \quad (1)$$

Where  $U_0$  is the open loop voltage of the generator and  $\Delta T$  is the temperature difference across the generator element. TEG are considered to exhibit a constant source resistance  $R_i$  and the maximum power output  $P_{max}$  can be described as

$$P_{max} = \frac{\alpha^2 \Delta T^2}{4 \cdot R_i} \quad (2)$$

The Micropelt MPG-D751 exhibits an output impedance of 300  $\Omega$  and a Seebeck-coefficient of 140 mV/K [2].

## DC BOOSTER CIRCUIT

The rectification stage is followed by the DC booster that converts the low input voltage generated by the TEG to a higher intermediate voltage. The circuit applied is a free running, switched mode power converter that is based on a transformer single transistor inverter (Fig. 2) [2].

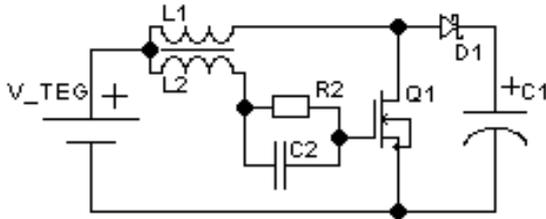


Fig. 2: DC-Booster circuit.

Rising input voltage creates a current through the inductor L2 that charges C2 and finally switches the transistor Q1 into 'ON' state. Now the primary inductor L1 is charged with energy until the feedback current induced in L2 closes Q1. Finally the energy stored in L1 is discharged into capacitor C1.

Depending on the selection and dimensioning of components, very low start-up voltages of around 0.3V and very good efficiencies of up to 85% can be achieved. The circuit performs an impedance conversion of about 1:3.

## STORAGE CONTROLLER

Storing electrical energy for aeronautic wireless sensor applications typically requires supercapacitor (SC) technology [3]. Here the main challenge in addition to low temperatures and self-discharge issues is how to effectively store and recover energy from the SC, as it exhibits a non constant voltage level. When storing energy into a capacitor, the major concerns are resistive losses and the short circuit loading of the source. In order to transfer the energy most efficiently, we apply a switched mode power converter as shown in Figure. 3.

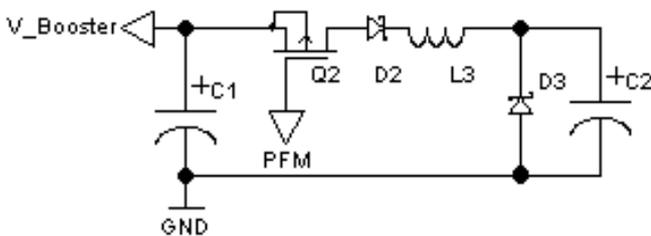


Fig. 3: Storage control circuit.

The energy transfer is controlled by applying a pulse frequency modulated (PFM) signal to Q2 that allows to directly adjust the charge current into the supercapacitor C2. The PFM is also used to stabilize the intermediate voltage on C1, thus giving the power management the capability of maximum power point tracking in combination with the DC-Booster circuit. Measurements show that the typical SC energy intake

efficiencies currently range up to 86%.

After charging, the supercapacitor C2 to a certain value, a commercial step-up converter (e.g. MAX1723) allows to provide energy output for the application with an average efficiency of 84%.

## FLIGHT SIMULATION RESULTS

After circuit optimization, a prototype has been deployed in a hardware-in-the-loop test, where a Micropelt MPG-D751 was exposed to a typical short range flight temperature profile. According to previous measurements and simulations, the maximum temperature occurring across the generator during such an event is 17.8 Kelvin. Figure 5 shows the result of the energy produced by the generator and the resulting energy stored in the supercapacitor.

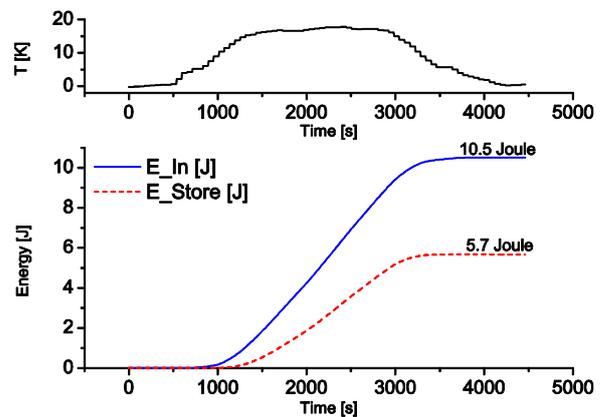


Fig. 5: Flight simulation results.

The overall storage efficiency for the tested short range flight profile was found to be 54.2%. The peak efficiency during cruising condition is 65.5% and corresponds with the previous circuit analysis.

## CONCLUSION

It has been shown that it is possible to efficiently store energy harvested by a thermo-generator during a short range flight. The overall storage efficiency reached was 54.2%. Considering additional output conversion losses, a total efficiency of 45.6% can be achieved for final application. By monitoring energy levels and power intake, it is possible to adapt the wireless sensor behavior to the available energy.

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## REFERENCES

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