Energy analysis methods and tools for modelling and Optimizing monitoring tyre systems

Energy Analysis Methods and Tools for Modeling and Optimizing Monitoring Tyre Systems

Abstract— **The increasing demand of "safe" vehicles requires continuous design of innovative devices and sensors. This paper presents a methodology for an efficient energy analysis of a self-powered sensor in an ultra-low power automotive application. In order to achieve this goal, new tools have been developed for storing and elaborating data (e.g., power consumption values, operating conditions, etc.) and even for reporting the energy balance, after considering the source (i.e. a scavenger device) that supplies the sensor.**

Index Terms—**Low-power design, wireless sensors, energy scavenging, analysis tools**

I. Introduction

A major challenge in modern transportation systems is the need of increasing the their safety by monitoring driving conditions and by dynamically applying proper adjustments to the vehicle. In the last years, Tyre Pressure Monitoring Systems (TPMS) have been conceived for controlling both temperature and pressure of the tyres and alerting in case of critical situations. Unfortunately, these information are not enough for improving driving controls. To achieve this goal, Pirelli Tyre has conceived a real time monitoring system [1] for tyre status analysis (pressure and temperature) and also for operating conditions analysis (i.e., potential friction) by implanting a self-powered chip (Sensor Node) inside the tyre and an elaboration unit connected to the junction box on the car.

The architecture of the Sensor Node requires, at least, a sensor data acquisition block, a data computing system and a wireless communication device. Obviously, standard batteries cannot supply this chip for a full tyre lifetime, therefore, it is necessary to consider energy harvesting devices that can supply energy to the system during the wheel rotation. Unfortunately, the available energy depends almost on the size of such a scavenging device and mostly on the tyre rotation speed. Hence, an energy balance is mandatory for an accurate analysis of the total energy consumption. The challenge is to reduce the minimum speed for the monitoring system activation in order to acquire the most relevant number of sensor data.

II. Energy Analysis methodology

If we consider the aforementioned application, measuring its energy consumption is extremely important, since the energy balance impacts not only the lifetime of the device, but also its operating limits.

For this reason, it is mandatory to build a consistent energy analysis flow. The entry point of this flow is the definition of the architecture of the design. Once the architecture is defined, every block must be simulated in a realistic manner for validating its behavior and accurately estimating its power dissipation.

Unfortunately, estimating the power consumption of self-powered devices with different working status it is not enough since temporal aspects are not considered. Hence, using power figures for choosing the components that will be optimized and the techniques that will be adopted for reducing the overall power budget, may end up with a non expected energy balance.

Optimization of dynamic power/energy is essential in an industrial design flow for mobile devices but, nowadays, static or stand-by power/energy optimization requires the same attention for deep submicron technologies.

For this particular monitoring system, the functioning of each block (data acquisition, memories, etc.) should be considered during a single wheel round, that is the basic timing unit. Hence, a duty cycle (i.e., active time over idle time in a single wheel round) for each specific component should be defined and used for selecting the best optimization technique to be implemented.

For instance, if we consider a functional block with an high dynamic power and a low leakage power, we normally want to optimize this block for minimizing the dynamic power only. But if we consider also temporal information and the block results having a short duty cycle, it is worth to optimize not only the dynamic power but also the static one since the idle time is significant.

This approach is thus useful to increase the efficiency of the optimization step.

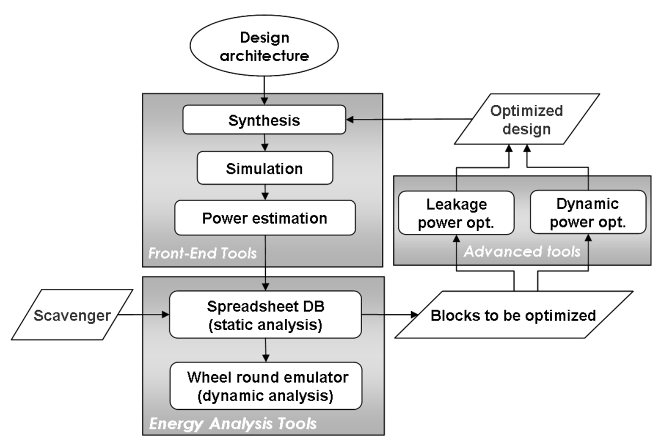

Fig. 1. Energy analysis flow.

Figure 1 shows the main step of the described flow. After estimating the power consumption of a single block, as accurate as possible, such power values are input for an evaluation tool that calculates the contribute in term of energy consumption. After advanced optimizations on single functional blocks, the total power has to be re-estimated in order to evaluate the energy reduction. Finally, it is possible to integrate the model of the energy source with the estimation of total load current and emulate the energy balance for a long timing window. The last step is useful for identifying operating windows of the conceived monitoring system.

Both the dynamic and the static power of this monitoring system are influenced by some parameters. Dynamic power is linked to the operating mode of each block and, generally, to the performance required by the whole system. Static power is mainly linked to the working temperature of the circuit. Even the duty cycle of some functional block (i.e. transmission blocks) can be different for cruising speed variation. In order to control these dependencies and achieve an ultra-low-power circuit, the system designer can develop an energy evaluation platform and thus estimate the energy consumption of different architectures.

A. Analysis tools

For a true analysis of this monitoring system, it is necessary to consider all the parameters that contribute for modifying the expected power consumption of the circuit, such as the operating conditions (i.e., configurations for each functional block), the number of data to be acquired and also working conditions (i.e., temperature and supply voltage) and process variation. Furthermore, the performance of the entire system should be tuned on the amount of energy that can be generated by the scavenger device in such operating conditions. For this reason, it is useful to set an evaluation platform that allows to observe all effects of the aforementioned parameters in the energy balance.

In collaboration with the EDA group of the Politecnico di Torino, tools for estimating and simulating the consumption during the wheel round have been developed. In particular, all data about power estimation of each functional blocks are collected into a dynamic spreadsheet that has to be considered as a complete database for the energy analysis. This spreadsheet also estimates the power and energy consumption of the Sensor Node under different working and operating conditions. The user can even evaluate custom architectures of the chip in order to strike a balance between energy requirement and system performance.

Figure 2 reports the graphical output of the tool and, in particular, the two curves of the energy generated by scavenger device and required by the whole system at different cruising speeds. The break-even point corresponds to the intersection of the two curves and, for lower speeds, there is a deficit of energy. This estimation has to be considered as a snapshot of the energy balance in a wheel round.

In order to evaluate the behavior of the Sensor Node within a long timing window, a realistic model has been developed and integrated with the above mentioned database for emulating the dynamic and static currents of the whole chip. It directly interfaces with the energy profile of the scavenger device for a dynamic comparison between the available energy and the required one. After setting a desired cruising speed profile and Sensor Node configuration, user can evaluate if the monitoring system can be active during all the considered time. Otherwise, some parameters should be modified in order to reach a positive energy balance.

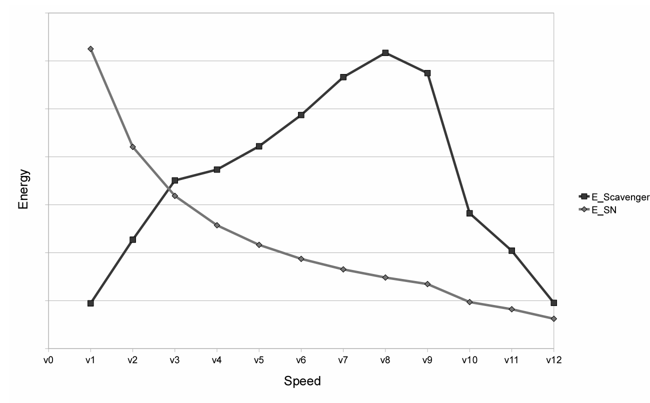

Fig. 2. Graphical representation of the energy balance at different speeds.

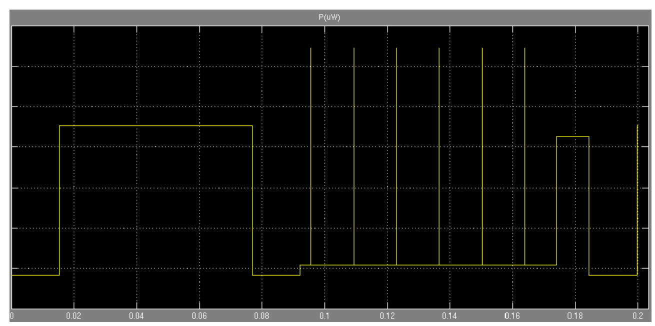

Fig. 3. Instant power consumption of the Sensor Node during a limited timing window.

At the end, these tools can be useful for analysis but also for validation of the chosen architecture from an energetic point of view.

III. Conclusions

This paper describes a methodological approach about energy analysis. The development of self-powered systems is critical for power and energy constraints and the time needed to achieve the expected performance is often too long compared to the time-to-market previously defined.

For this reason, it is strongly suggested to identify what are the functional blocks to be optimized and what are the most effective optimization techniques considering the functioning of the circuit. Tools developed for analyzing the energy consumption related to all the operating and working conditions, are very useful for validating the performance of the system.

References

[1] S.C. Ergen, A. Sangiovanni-Vincentelli, X. Sun, R. Tebano, S. Alalusi, G. Audisio, and M. Sabatini, "The Tire as an Intelligent Sensor", IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems, Vol. 28, No. 7, July 2009, pp. 941-955