Automotive supply line robustness incorporating hardware-embedded wavelet filters

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***Abstract*—In this paper we present a method to detect variations in the power supply quality of automotive smart-power devices. Automotive micro-electronics which are connected to the vehicles power net have to withstand a broad variety of disturbances on their supply lines. Due to a multitude of topologies, architectures and parasitic effects of the vehicles power net, it is almost impossible to make assumptions about the transient behavior or disturbances on the devices supply lines. Transient disturbances range over a large scale in terms of shapes, frequencies, time scales and amplitudes. These disturbances influence the behavior of the devices or even may lead to application failures.**

To cope with those changes in the power quality we propose a concept to detect and evaluate supply line disturbances by means of real-time and hardware-embedded wavelet filters. Based on the results of the translated signal, a decision can be made to react accordingly (e.g. switch into a fail-safe state).

Keywords: Automotive Power Micro-electronics, Wavelet Transform, Functional Safety, ISO26262

I. Introduction

Automotive smart-power semiconductors are typically directly connected to the vehicles power net. Various effects and architectures, such as the capacitive behavior of the car's battery, wire inductances, an alternator driven in parallel to the main battery or active voltage regulations to improve the energy efficiency cause various complex transients and disturbances on the vehicles power net.

Furthermore, a large number of system components like light bulbs, motors and pumps exhibiting resistive, inductive and capacitive behaviors are connected as loads to the automotive power net. Random switching of all these components in combination with the power net topology [2] leads to a harsh electrical environment for analog and mixed-signal smart-power devices.

With regard to recent standards in the area of functional safety, ISO26262-compliance and quality [1], automotive smart-power devices must be able to react in a safe and secure manner on supply disturbances on the vehicles power net (e.g. by entering a safety state or switching-off its power stages) unless the functionality of the device cannot be guaranteed.

That is why we propose a concept to detect, diagnose and evaluate transient supply line disturbances on the vehicles power net to enable a proper reaction of automotive smart-power devices. The concept is based on wavelet-based signal transforms [3] which are deployed on hardware (e.g. a micro-controller) or fully embedded on the smart-power device. This implementation enables an in-vehicle operation and may adapt the micro-electronics accordingly (e.g. switching into a fail-safe state or adjust internal electrical performances).

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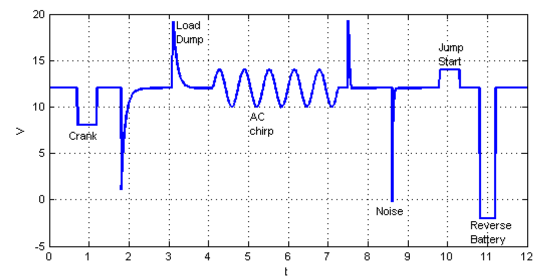


Fig. 1. ISO7637-2 and main surges on automotive power net representing supply line disturbances for analog and mixed-signal power devices

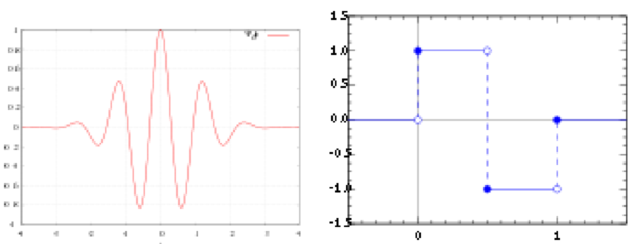
II. Wavelet theory and supply line disturbance correlations

The wavelet transform has been successfully used in applications as distinct as image processing, geo-science and medicine [4]–[6]. With deeper focus on micro-electronics IC design and development, an approach for optimization of power circuits on micro-electronics is proposed in [8]. This research work deals with the optimization of micro-electronics power circuits by determine the worst-case voltage drop on the power circuitry. Therefore, the wavelet approach is successfully applied in simulation-based optimization.

Both the Short-Time Fourier-Transform (STFT), as well as the wavelet transform have been considered as candidate transforms for the detection of transients on power supply lines. For certain types of disturbances on the supply lines with lots of oscillatory or small bandwidth content, the SFFT may serve for detection.

Nevertheless many other types of disturbances on supply lines like steps, spikes are more defined by shape over time, than frequency content, as shown in typical surges from ISO7637-2 depicted in Fig. 1. These kind of profiles are more easy to detect by the wavelet transform than using the STFT. A property of the wavelet transform also observed in other applications [7] are advantages w.r.t. computational and hardware implementation effort. For this reason we follow the rest of the discussion using the wavelet transform and omit the STFT.

In this article we focus on the practical aspects of detecting disturbances on automotive supply lines and less on the mathematical aspects of the transform itself. The principal idea of wavelet based detection is that depending on the physical origin of the disturbance a small time-scale transient with a particular shape is observable and detectable. This transient scales in time extension, but not in general shape. In the wavelet transform the shape is generated by a so-called kernel or wavelet. Two typical kernels, the Morlet and the Haar wavelet are depicted in Fig. 2.



(a) Real-valued Morley wavelet (b) Haar wavelet

Fig. 2. Examples of wavelet types and kernels for practical application in automotive supply line disturbance detection scheme

Recorded typical supply line disturbances and transients on the automotive power net suffering from transient open faults (depicted Fig. 3 and Fig. 4), show considerable similarity to the wavelet kernels in Fig. 2. That is why wavelet or kernel transforms serves as a motivation to apply them for fault and error detection in automotive systems with special focus on the power net quality.

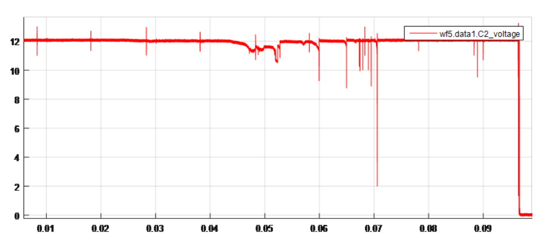


Fig. 3. Recorded time series of supply line disturbances occurring on the automotive board net with transient faults prior to failure

Fig. 4. Detail of short-term transient showing oscillatory shape on the power supply line

As mentioned above different fault mechanisms create transients of different shapes, frequencies and amplitudes. Initial investigations and findings show that the Haar wavelet may be particularly useful to detect longer opens or shorts, while very short transients have more oscillatory components that may be better to detect with Morley or Mexican Hat wavelets. We do not exclude that other wavelets have better detection properties, which is subject to future work in this field of research.

III. Design concept and implementation

Our approach, presented in Fig. 5, proposes a design concept which combines classical analog and mixed-signal power micro-electronics targeting automotive systems with a fault detection and error handling based on embedded wavelet filters.

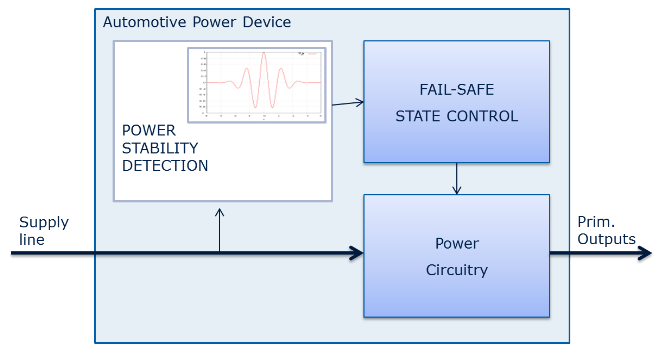


Fig. 5. Concept of automotive smart-power device incorporating embedded wavelet-based detection scheme for supply line disturbance and fault detection

Beside the power circuitry and the embedded wavelet-based detection scheme a fault detection, called *FAIL-SAFE STATE CONTROL* in Fig. 5, needs to be implemented to make decisions on the transposed supply line disturbances. This individual decision how to handle the supply line disturbance is related to the specific system or application, environment and requirements.

We start our proof of concept using a Simulink model of the entire concept. Simulink is a commonly used language for behavioral modelling on application level of analog and mixed-signal power devices [11].

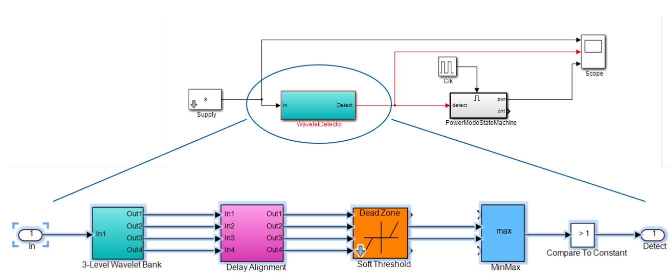


Fig. 6. Example Simulink model of the entire design concept of a power quality aware analog/mixed-signal power device

Our basic wavelet-based detection scheme, depicted in Fig. 6, uses a probe of the supply line (left), wavelet filter, heuristically chosen thres-holding functions and subsequent entry for operation mode (right). A multitude of implementations [12] and toolsets for automated code generation is available for deployment on different hardware platforms such as micro-controllers, FPGAs, etc. Due to this fact, Simulink represents a perfect starting point to transfer the wavelet-based detection scheme on hardware for real-time evaluation of supply line disturbances occurring on automotive power nets.

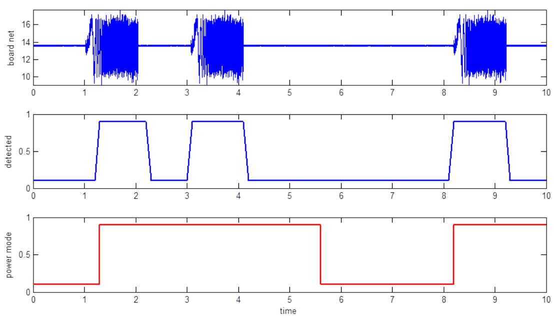


Fig. 7. Simulation results of wavelet-based detection scheme for supply line disturbances (top trace) with power mode reaction (lower trace) using Simulink model

Before deploying the entire model on hardware we use the Simulink model enhanced with an example device under test and apply a disturbed power net signal (upper trace) at the input side. The primary reaction of wavelet-based detector (middle trace) and power mode change of the example device under test (lower trace) are depicted in Fig. 7. The simulation results show that disturbances are detected by the model and the thres-holding function provides a logical signal to the example device under test. The reaction of the device (e.g. switch off power stages) needs to be implemented within an additional controller which is not subject to this article.

Finally, we deploy the wavelet-based detection scheme for supply line disturbances on a low-cost micro-controller and a high performance FPGA having individual advantages and disadvantages in terms of performance and implementation/code deployment:

Micro-controller	**FPGA**
(+) Automated code generation	(+) High computational performance
(+) Low costs	(+) Real-time capability
(−) Low computational performance	(−) High modeling effort
	(−) Manual model transfer

TABLE I
ADVANTAGES AND DISADVANTAGES OF MICRO-CONTROLLER AND FPGA IMPLEMENTATION

IV. VALIDATION ON HARDWARE

In this section we demonstrate how our wavelet-based supply line disturbance detection scheme works on real hardware. Therefore, we determine whether supply line disturbances are detected by the described concept and quantify accuracy as well as performance in case of a real-time signal transpose.

We are using both hardware targets, described in Section III, and deployed the entire model combining wavelet filter and thres-holding functions (see Fig. 6).

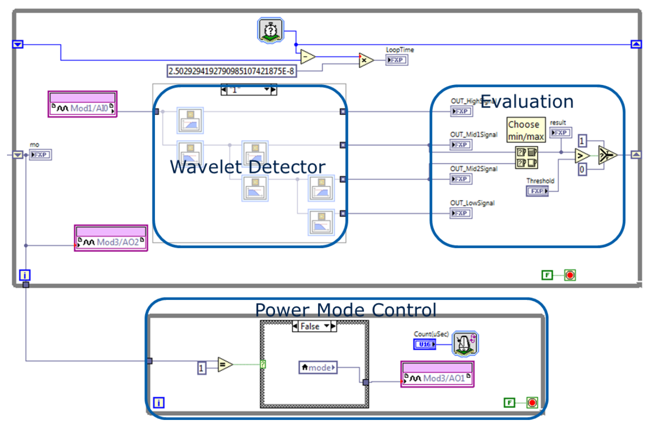


Fig. 8. Wavelet-based detection scheme for automotive supply line disturbances implemented and deployed on a FPGA platform

We apply various pseudo-random signals representing supply line disturbances to the detection scheme. Those pseudo-random signals imply various transients and continuous sequences as shown in Fig. 1. Due to the pseudo-random generation it is possible to vary shape, frequency and amplitude of the individual parts from the whole sequence. This makes it possible to be as close to the real power net measurements and configurable in terms of scalability.

In particular, a variable short-term sinusoidal overlay, similar to Fig. 4, was generated as an example supply line disturbance. We varied the frequency and the amplitude of the applied signal in order to determine the sensitivity and the hardware performance of the detection scheme. The results of the detection scheme based on the wavelet transform implemented on the micro-controller as well as on the FPGA platform are proposed as follows:

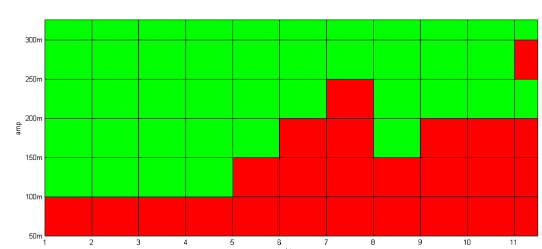


Fig. 9. Hardware performance evaluation on a microcontroller platform for a supply line disturbed by a short-term transient sinusoidal overlay (disturbing signal amplitude (V) versus signal frequency (kHz)

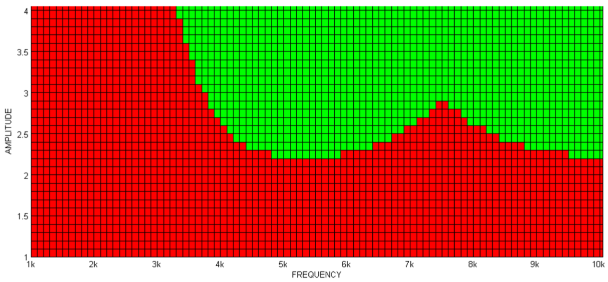


Fig. 10. Hardware performance evaluation on a FPGA platform for a supply line disturbed by a short-term transient sinusoidal overlay (disturbing signal amplitude (V) versus signal frequency (kHz)

The x-axis shows the center frequency of the input signal while the amplitude is visualized on the y-axis. Green fields represent supply line variations which were detected by the concept while red points were not detected, either due to performance or due to the thres-holding functions.

With regard to performance characteristics of the detection scheme, the micro-controller solution suffers from the hardware limitations. The FPGA is able to detect a large number of supply line disturbances w.r.t. amplitude and frequency variations. However, it is possible to state that the wavelet-based detection scheme is also working on hardware, either a micro-controller or a FPGA target.

V. Conclusion and Outlook

In this paper we present a method for power quality aware design concept incorporating wavelet filters which is deployable on hardware. The approach applies wavelet or kernel transformations as detection scheme for supply line disturbances occurring on the automotive power net. This concept improves the robustness of automotive power devices in the context of functional safety or ISO26262 compliance.

Future work within this research field focuses on the evaluation of further wavelet of kernel transformations being applied as detection scheme for automotive supply line disturbances. Further investigations can be the analysis of the transposed signal making decisions on the power quality which takes impact on the power circuitry or foresee transient effects leading to device or system failures.

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