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Reliable GPS position on an unreliable hardware

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I. INTRODUCTION

There is continual motivation to reduce power consumption and extend battery life of mobile devices. Power consumption and device lifetime can be improved by operating at minimal supply voltage, which increases the likelihood of hardware errors. These errors can also be produced due to process and temperature variations coupled with increased advancement of CMOS technology [1]. Occurrence of errors can affect the performance of circuits and can change the state of a gate and the output of a system; their presence can generate a system failure if it is not corrected. Therefore, it is increasingly important to deal with hardware errors effects in order to keep devices working properly.

Hardware errors can be classified into three main groups: permanent, transient and timing errors. Permanent errors are defined as an irreversible physical changes: a stuck at the value 0 or 1 of a bit. They can be caused by manufacturing defects or device wear-out. Transient errors are temporal single malfunctions that manifest as a temporary change of the binary value of a bit. The other term used for transient errors is Single Event Upsets (SEU). Environmental changes, such as higher or lower temperature and voltage variation, are the essential sources of the occurrence of these errors. Timing errors result when a input signal arrives too late and misses the reference arrival of the clock.

During the last decades, reliability of circuits has been addressed at the lower design level by proposing resilience techniques to protect particular components. Examples are Razor flip-flops to detect signal delay errors [2], double sampling for combinational circuits [3], error correcting codes used first to protect memories [4], and then applied for interconnect networks [5], and TIMBER techniques for pipeline structures [6]. For higher design level, predictions techniques, such as Algorithmic Noise Tolerance (ANT) technique, propose to increase the reliability of circuit by adding a reduced precision replica to the original function. This reduced precision replica consumes much less power than the original function. The final output is chosen between the original function output and the output of the replica [7]. In extremely critical applications, such as space, avionics and healthy applications, where the system cost is less important than its reliability, Triple modular redundancy (TMR) is proposed on the system level design [8]. The author of [9] propose some resilience techniques for double-iterative Multiple-Input Multiple-Output Bit-Interleaved Coded Modulation (MIMO BICM) receivers. These techniques have been realised on different layers of abstraction in order to have a mutual trade-off of system performance, hardware reliability and implementation complexity.

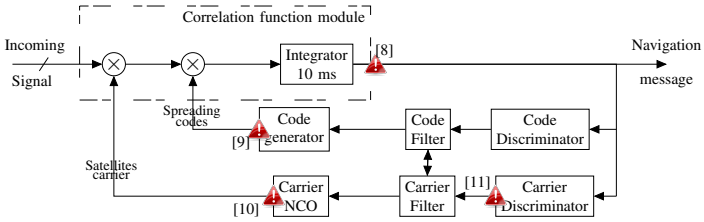

Fig. 1. Top Level of the simplified tracking channel module; Error tolerance has been already studied in components with warning marks at the output. The corresponding proposed techniques are presented and evaluated in papers beside each mark.

Global positioning systems (GPS) can be an excellent application to investigate the trade-off between system performance and implementation complexity in presence of hardware errors. It contains a very interesting set of different signal processing problem with different requirements of reliability: Correlation process, tracking loops (recursive operations), FFT processing, state machine, Gold and carrier generators.... The objective of the this paper[1] is to address the fault tolerance topic in the GPS context. Starting from a noiseless GPS receiver, redundant mechanisms can be added to design a more resilient GPS receiver in the presence of errors due low supply voltage. An Application-specific integrated circuit (ASIC) will be designed, using the 28 nm technology, to compare theoretical results and measured results.

II. GPS SIGNAL PROCESSING

A GPS is a well known technology that allows determining both the physical position and the absolute time of a receiver. The position in time and in space is determined thanks to a precise distance measurement with at least four GPS satellites. GPS satellite signals are made of three components: spreading code, navigation message and carrier. For each GPS satellite visible in view, the GPS receiver tries to extract the corresponding navigation message. This is accomplished by comparing a locally generated signals (estimate of the spreading code and the carrier of the tracked satellite) against the received signal, then moving in time local signals until it is time aligned with the received signal. A maximum correlation

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output between signals is achieved when they are aligned. Two feedback loops are used to update the local generated signals: the carrier tracking loop (to align the local generated carrier in frequency ad phase) and the code tracking loop (to align the local generated code in time). Each loop is made of discriminators and filters. A simplified representation of the channel tracking module is given in Fig. 1.

III. The proposed tolerant schema

All state of the art techniques have in common that they requires hardware cost or/and performance penalties (reducing system throughput). System-level technique is identified as the key to minimize the implementation overhead for error detection and recovery compared to low-level techniques. To track satellites signals, GPS receivers uses feedback loops to determine over time Doppler offsets. It has been shown in [10]–[12], that the natural design of the tracking loops can tolerate low rate of hardware errors with a loss of less than 1m of error in the position given by the GPS receiver. For moderate and high hardware error rate, we propose a combination of low-level and system level techniques to deal with hardware errors' effect. In this paper, we present three main methods proposed for the robustness of the correlation process, discriminators and gold generators.

A. Feedback freezing loop (FFL) and Last Correct Value (LCv) methods

These methods have been proposed to deal with timing and upsets in the correlation process. Detection of errors is realised by the double sampling method (DS) cited in [3]. The main idea of DS method is to take advantage of the temporal nature of transient (and timing) errors, and achieve detection by observing the output signals of a given circuit at two instants. An incoherence between the two outputs is flagged when errors occur. Recovering is done by either a freezing loops or using previous correct correlation's output. More details are given in [10].

B. Tuning Loops Bandwidth

The effect of time and frequency errors estimation (error in the discriminator modules) can be greatly reduced by tuning appropriately the bandwidth of the feedback filters. This system level method gives interesting results in terms of robustness against errors. With no error, the modification of the bandwidth filter values induces only a 0.11 m of standard deviation, with 40 % of errors at the output of the carrier discriminator, the standard deviation of the error in the position increases to 2 m while the natural design of tracking loop does not support more than 6% of errors [13].

C. Hardware redundancy

In GPS receivers, spreading codes are generated by two 10-stage LFSR (Linear feedback shift register) modules, designated G1 and G2. If the LFSR register states are disturbed, then the code state becomes corrupted. To mitigate from this problem, methods based on error correction and modular redundancy have been proposed in [11]. These methods were evaluated in terms of their performance benefit and gate overhead. It has been shown, in [11], that the Hamming proposed method can provide the required reliability (in term of Mean Time To Failure (MTTF)) with 42% of gate savings compared to the classical TMR.

IV. Conclusion

We have demonstrated in this paper that techniques based on different layer of abstraction can lead to have a mutual trade-off of system performance (quality of the position given by the GPS receiver), hardware reliability and implementation complexity. An ASIC will be designed based on this results to compare theoretical results and measured results. Additional results from our research on the GPS receiver chain can be found in [14].

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