Degradation Stochastic Resonance Concept: Benefits of Controlled Noise Injection in Adaptive Averaging cell-based Architecture

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I. INTRODUCTION

Future nano-scale technologies will exhibit high defect ratios, large parameter variability and reduced noise margins. Special architectures are needed to build reliable mid/large nanocircuits. Several architectures at different system levels have been proposed to build circuits based on nanoscale devices[1,2]. Among them the architectures based on active redundant circuits, such as R-modular redundancy (RMR) or NAND multiplexing are designed to tolerate malfunctioning elements by combining the information of redundant circuits performing the same function. Such techniques are capable of protecting the system against transient and permanent errors without testing and reconfiguring but have a reduced capacity to tolerate static errors or defects in its original organization. These techniques distribute the information processing, storage, and communication along N identical elements. The redundant elements combined with some form of signal restitution—which recover the signal levels before the information is lost—permit the design of reliable circuits using unreliable elements. These structures are promising for nanotechnology. Of them the alternative named Averaging Cell (AVGc) has recently shown a very high efficiency as the decision element uses an analog computing principle. In a recent work[3] authors have introduced the principle of adaptive-averaging cell (AD-AVG), architecture that is able to deal not only with permanent and dynamic but also with the independent time-varying variability of the elements caused by the degradation of components. In this abstract we present how AD-AVG-based computer design can benefit of the appearance of a counterintuitive degradation stochastic resonance effect.

II. THE AD-AVG ARCHITECTURE

The AD-AVG architecture, graphically depicted in Fig (1), is a fault-tolerant technique based on hardware redundancy. It calculates the most probable value of a binary variable from a set of error-prone physical replicas. The AD-AVG is demonstrated to tolerate high amounts of heterogeneous variability and accumulated degradation in the physical replicas.

The AD-AVG operation is based on a weighted average of R input replicas *yi* of a binary variable *y*.

$$y' = \sum_{i=1}^{R} c_i y_i \qquad \hat{y} = \begin{cases} V_{cc} & \text{if } y' > V_{cc}/2 \\ 0 & \text{if } y' < V_{cc}/2. \end{cases}$$

where c_i is the weight corresponding to replica *i*. The AD-AVG calculates the respective weights following a variability monitor and weight driver (Fig. 1)

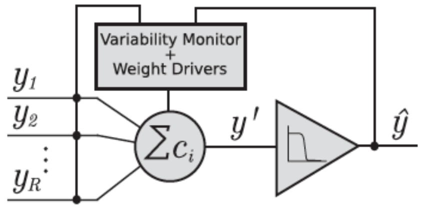

Fig. 1. AD-AVD architecture. Different weights are applied to inputs determined with the use of the monitor.

III. DEGRADATION STOCHASTIC RESONANCE (DSR)

We analyze (by analytical and simulating methods) what happens in an R-input AD-AVG when the variability of the input replicas increases independently as a consequence of degradation. A complete analysis can be found in a recent paper[3]. Fig. (2) depicts the resulting function yield of the AD-AVG cell against degradation, we assume noise in the variability monitor (σ_s).

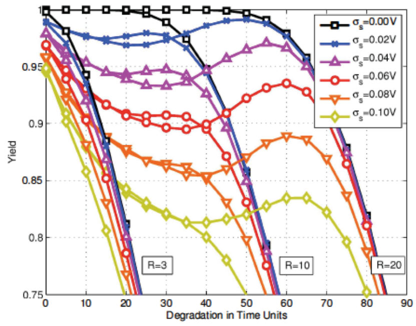

Fig. 2. Yield analysis of different size AD-AVCs agains degradation. We consider different levels of noise in the variability monitor σ_s.

In the figure we clearly observe how the yield characteristic of the cell changes over time due to degradation stochastic resonance effect. Thanks to this effect it is possible to obtain higher factors of AD-AVG yield after specific amounts of degradation. Regarding this experiment on the DSR effect we can extract the following ideas:

- The DSR effect becomes more relevant in AD-AVGs with larger number of inputs.
- Given an AD-AVG in a particular situation of degradation in time and noise level it is not always the best option to use all the available replicas. There are situations in which less input replicas provide higher yield with the same degradation in time and noise in the variability monitor.

IV. CONTROLLED DEGRADATION STOCHASTIC RESONANCE IN AD-AVG CELLS

The main idea behind extending the DSR effect occurrence to get benefit of the resonance peak is to add virtual degradation to the system in order to force DSR peak degradation conditions regardless of its actual degradation level. Degradation affects the hardware and causes a variability increase in the input signals. Therefore, one way to achieve this virtual degradation is to increase the input variability levels to make the system behave like it would have been in a higher degradation status. It may be considered the option of adding a controllable noise generator to each of the input replicas to virtually increase the instantaneous amount of degradation in time up to the resonance point. This operation is feasible as long as the level of degradation in time is below the resonance point. Fig.3 shows the modification of the AD-AVG to inject independent controlled-level noise at the cell inputs. Fig. 4 shows the effect of behavior of a 20-input AD-AVG when we inject different levels of noise at the inputs σ_x.

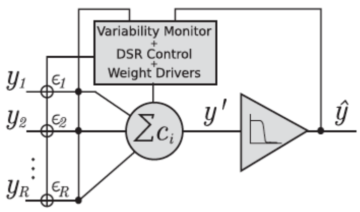

Fig. 3. Adaptive averaging cell with independent noise generators added to the inputs ε_i.

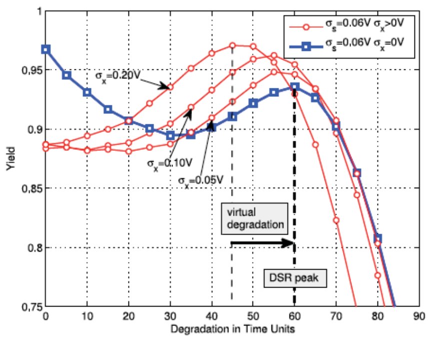

Fig. 4. Yield agains degradation with different levels of noise. Thick blue line corresponds to the AD-AVG cell a noise σ_x=0.06V.

Given that we demonstrated that we can control the DSR peak position by means of input variation levels, we can make a step forward and define a strategy that allows us to get the maximum yield during all the circuit lifetime, by enabling DSR peak relocation as a consequence of degradation evolution. The basic principle of the DSR control is to check at runtime the instantaneous amount of degradation in terms of the input variability estimators and update the input noise magnitude accordingly.

The target is to keep the reliability characteristic at the highest value regardless of the particular degradation level. In order to observe which is the input noise magnitude that we have to inject into the circuit in order to accomplish our goal, we present in Fig. (5) simulation results for a 20-input AD-AVG with noise in the Variability Monitor of magnitude σ_s = 0.06 V sweeping over different input noise levels from σ_x = 0 V to σ_x = 0.9 V.

Fig. 5 depicts in thick blue line the curve associated to the null input noise case, thin colored lines are the curves associated to the sweeping values of σ_x from 0 to 0.9 V. We also highlight in the figure in thick black line the curve that the yield follows when we apply the proper input noise magnitude at each degradation level. If we apply the proper noise magnitude, we can move along the involute of the thin colored curves obtaining a yield even higher than that provided by the resonance peak.

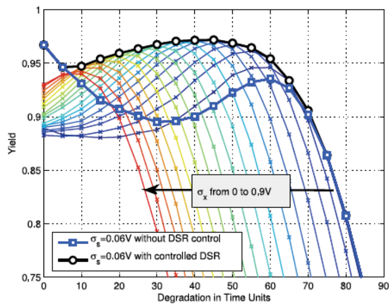

Fig. 5. Impact of adding noise to the input of the cell. The thick black line corresponds to the obtained yield when the noise is plied to maximize reliability.

V. CONCLUSIONS

In this paper, we present the DSR effect in the context of AD-AVG architectures. This counterintuitive effect implies an enhancement in the system reliability against hardware degradation for specific noise conditions. For example, the yield of a 20-input AD-AVG, with a noise level of 0.06 V in the Variability Monitor, decreases from 1 to 0.89 as the system degradation is increasing, then it grows up to 0.94 at the DSR peak, and finally decreases to zero when the system reaches its end of life. Moreover, in order to take the full advantage of the DSR effect, we propose to add controllable noise injectors to the AD-AVG inputs to virtually increase the amount of hardware degradation and create the DSR conditions regardless of the degradation level. By this method, we shift the characteristic yield to the DSR peak, regardless of the degradation level, and significantly enhance the system yield. Simulation results indicate that by applying the proper noise magnitude we can provide an optimum and nearly flat reliability level at any time before the DSR peak degradation level

ACKNOWLEDGEMENTS

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