Microelectronics Reliability 54 (2014) 2064–2069

Contents lists available at ScienceDirect

Microelectronics Reliability

journal homepage: www.elsevier.com/locate/microrel

Signal noise perturbation on automotive mixed-mode semiconductor device generated by graded substrate defect

Y. Weber [a,*], L. Buffo [a], B. Vanhuffel [a], N. Lee [a], N. Stirlen [b], J. Chen [b], X.D. Wang [b]

[a] Freescale Semiconducteurs France SAS, Toulouse Product Analysis Lab, 134 avenue du Général Eisenhower, B.P. 72329, 31023 Toulouse Cedex, France
[b] Freescale Semiconductor Inc, 1300 North Alma Road, 85224 Chandler, AZ, USA

ARTICLE INFO

Article history:
Received 27 June 2014
Accepted 8 July 2014
Available online 20 August 2014

Keywords:
Mixed-mode device
Failure analysis
AC noise
SCM
SIMS
Wafer substrate defect

ABSTRACT

The semiconductor technologies evolution allows greatly reducing noise impact on products and many structures have been created to reduce its effect. However, this paper presents the apparition of a noise issue during the production of a mixed-mode device dedicated to automotive applications. The research investigations concerned the fact that failure was not detected at test level but at customer level; therefore, it was determinant to understand the root cause of this failure mode to drive corrective actions in order to secure customer. The challenge was to analyse noise in Failure Analysis (FA) without fault spatial localization results. Indeed, Light Emission Microscopy (EMMI) and Thermal Laser Stimulation (ex: Soft Defect Localization – SDL) were unable to provide any defective area in the product. The lack of failing device identification led us to combine electrical and design analyses in order to define hypothesis on the failure origin. It was then possible to drive physical investigations through different approaches, using physical cross-section, Secondary Ion Mass Spectrometry (SIMS) and Scanning Capacitance Microscopy (SCM) techniques. Finally, the obtained complementary results will be discussed and an explanation of the failure mechanism will be presented as the root cause issue, allowing defining the defective step in production process.

1. Introduction

Since first development of semiconductor technologies, the noise problem remains a determinant aspect in order to minimize perturbations of signals on the product function. From the elementary crystal structure up to the assembled chips in systems, the understanding of noise generation mechanism is key to optimize the designed structures [1]. The constant evolution of technologies allows greatly reducing noise impact on products and many structures have been created to reduce its effect.

Nowadays, the noise in semiconductors is well controlled and quantified: it is very rare to find this type of defect in production. However, this article presents an atypical noise issue on a Mixed-mode device dedicated to automotive applications. The challenge was to analyse noise in Failure Analysis (FA) without fault spatial localization results, such as Light EMission MIcroscopy (EMMI) and Thermal Laser Stimulation (ex: Soft Defect Localization – SDL). The lack of failing device identification required to combine electrical and design analysis in order to define hypothesis on the failure origin. It was then possible to drive physical analysis through different approaches, in a similar method to the Fault Tree Analysis (FTA) [2]. Complementary results will be discussed and an explanation of the failure mechanism will be presented as the root cause issue.

2. Problem description

This atypical case study concerns field failure customer returns on defective devices; it means that the devices were considered as good parts in production line or electrical automatic testing were not able to detect this specific failure. Initially, the reported product failure concerned the DC Sensor, on Aout pin, and no other pins were found defective. Then, the customer used a filter on Aout pin and the defect was significantly reduced. Based on this test and the observation of noise on this signal by an oscilloscope, a noise perturbation was supposed to create the failure mode. In automotive environment, customers require low cycle time for FA and rapid containment (<3 weeks). It was not obvious to determine the origin of noise in FA point of view with classical approach. During the crisis, it was observed that only one lot was affected by this problem and 3 parts were returned for analysis.

The challenges were to clearly characterize the noise signal, its interaction with the different function in the device and determine

* Corresponding author. Tel.: +33 5 61 19 11 85; fax: +33 5 61 19 91 06.
E-mail address: yann.weber@freescale.com (Y. Weber).

http://dx.doi.org/10.1016/j.microrel.2014.07.061
0026-2714/© 2014 Elsevier Ltd. All rights reserved.

its nature and type. The case study presented involves a 250 nm technology mixed mode device, in LQFP64 plastic package. It is principally used as a voltage supply and it acquires analog diagnosis interfaces and sensors for an automotive airbag ECU. The communication to the MCU is via a SPI bus. The failure was first characterized by customer in AC mode despite the DC did not presented any noise. In a system point of view, the problem could be solved by using a filter, but it is not acceptable for semiconductor supplier. Accordingly, it was not obvious to electrically characterize the failing device and determine its physical origin root cause. Especially, literature study showed that all semiconductor devices generate noise, with different nature origin. The principal sources of noise can be summarized by the following terms [3,4]:

- Thermal Noise: created by random motion of charge carriers due to the thermal excitation.
- Shot Noise: it is mainly associated with individual carrier injection through the PN junction in a discrete structure.
- Generation-Recombination Noise: caused by the fluctuation of number of carriers due to existence of the generation-recombination centers.
- 1/f Noise: is the dominant noise in the low frequency range and its spectral density function is proportional to 1/f. This noise is present in all semiconductor devices under biasing.

In this study, the importance of signal/noise ratio was not really depending on the frequency of the device operation, but it was caused by a coupling effect between structures in standard operating mode. It resulted in a permanent noise generation including thermal, shoot and 1/f noises, induced by parasitic current injections.

3. Failure electrical characterization

3.1. Failure mode characterization

In the studied product, several functions are present (Fig. 1). DC Sensor (DCS) interface allows the main microcontroller determines the status of up to nine independent external switches. The DCS Interface also contains multiplexers controlled by SPI commands. When interface is active, the input signals are multiplexed on the output, connected to the analog buffer where its output is Aout pin (Fig. 2). According to the product specification datasheet,

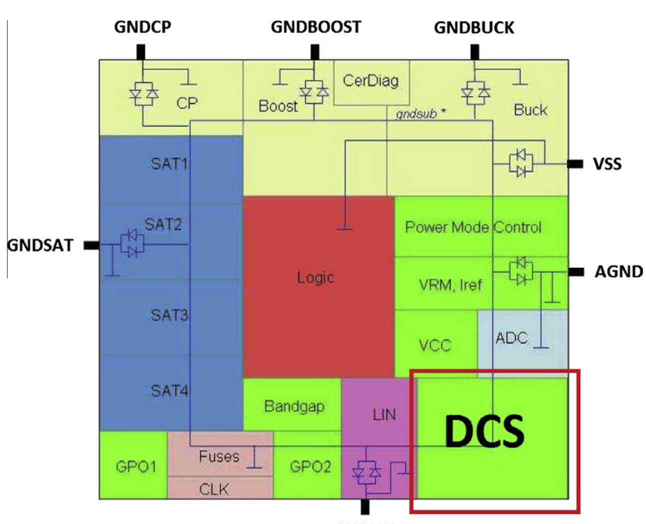

Fig. 1. Description of general functions in failing product.

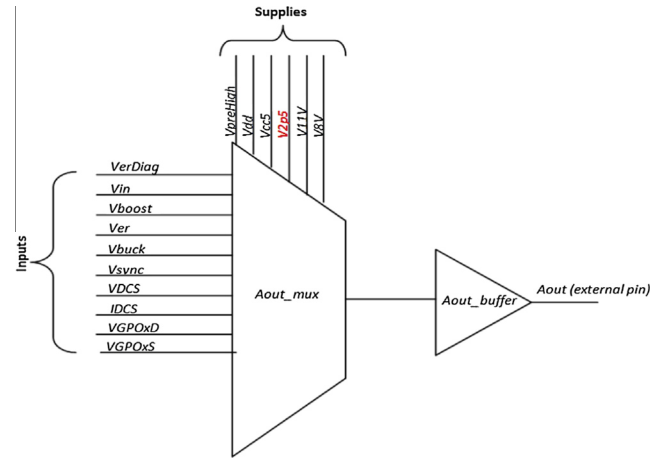

Fig. 2. Block diagram extract from DC sensor block.

concerning output noise parameter on Aout, it is defined by 5 mVpp MAX value. Based on this known data, the electrical characterization was done on the failing product using application board with specific setup and application software to set the device in its failure mode. This non-usual measurement of Aout signal was monitored by setting oscilloscope in the appropriate adjustment, with selection of AC measurements and average acquisition mode. As a result, the 60 mVpp AC noise measured on Aout pin was out of specification and explained the failure on customer application (Fig. 3). (NB: in this study, all the measurements were done in comparison with reference part).

In a customer return context, fault spatial localization using EMMI technique was performed with the part configured in the failure mode. Compared with a reference device, no significant differences were highlighted. Based on that result, an experiment using thermal gun to heat the failing part, demonstrated that the noise was reduced, from 60 mVpp to 40 mVpp. Thus, SDL technique was applied by using the laser stimulation to highlight any change in failing part. SDL technique was then set with noise of Aout signal parameter as Pass/Fail. It should be noticed that this analysis was performed from the backside; indeed, the frontside presented many large metal plates which covered a huge surface of the die. Hence, it would result in undesired thermal dissipation. Unfortunately, this approach did not succeed. No abnormal sensitive area was observed on the die; the laser power was probably not high enough to modify behavior of the defective area. As a perspective view, Photoelectric Laser Stimulation technique, such as LADA, could be more appropriate in that case. Using a 1064 nm laser, this technique allows the laser to generate photo carriers in the silicon, increasing the electrons in valence bands. With this over current path induced, the photo-electric effect would have potentially amplified the phenomenon, increasing the chance to localize the defective area. However, this technique was not available for the present study.

Then, microprobing analysis was chosen to focus on internal function. The first investigation concerned supplies: a specific set-up was used to switch between external supply (from voltage source) and internal supply (provided by the product). The purpose was to control and monitor if the noise generation is depending on supply or not. The analysis did not find any differences from a basic supply point of view.

At that time, it was decided to study the multiplexer inputs. By software configuration, inputs were selected separately and Aout_mux output was measured to determine if one input had any influence on noise in Aout signal which was monitored to verify if noise remained on that pin. Without inputs influences, an external signal