Microelectronics Journal 40 (2009) 1350–1357

Contents lists available at ScienceDirect

Microelectronics Journal

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

Design, qualification and production of integrated sensor interface circuits for high-quality automotive applications

M.J. Ohletz *, F. Schulze

ZMD AG, Grenzstr. 28, D-01109 Dresden, Germany

ARTICLE INFO

Article history:
Received 1 April 2008
Received in revised form
11 August 2008
Accepted 21 August 2008
Available online 16 October 2008

Keywords:
Automotive design
Sensor signal conditioning
AEC Q-100
DPAT
ESD
EMC
Sensor interface
Testing
Built-in quality

ABSTRACT

The product development of integrated sensor interface circuits for automotive applications requires various additional features accounting for the harsh environment in automotive applications. Unlike in a pure prototype development yield is key to achieve the required automotive quality targets of zero ppm. The paper first describes the general automotive requirements like electro-static discharge (ESD) and reverse polarity protection. Then the design flow from specification until start of production for an industrial product development is outlined. Finally, the requirements for automotive circuits qualification based upon the international standard AEC Q-100 are described. Furthermore, the automotive test requirement and additional measures such as the dynamic part average testing and statistical bin analysis are discussed to achieve at zero ppm quality. The paper includes a real product example of ZMD.

1. Introduction

Over the last two decades the electronic content in automobiles, busses and lorries has significantly increased. In contemporary cars it has reached a value of about 15–20% and it is expected to further increase to 35–40% due to legislation and environmental requirements. This trend is supported by the fact, that the automotive development tends to "dry and light", i.e. the replacement of liquids such as hydraulic oils and the replacement of pure mechanical solutions such as the steering column or the mechanical throttle control. Towards this development so-called x-by wire solutions are slowly replacing pure hydraulic, mechanical and hydraulic–mechanical solutions. One key element in all x-by wire applications are sensors and thus sensor interface circuits beside the actuators. In contemporary car between 70 and 150 sensors are accommodated measuring pressure, temperature, position, air flow, acceleration, yaw rates, tilt angles, humidity to only name a few applications. Thus, sensors have become an important element in the overall automotive electronic system.

Due to the central importance of such sensor systems, the development of integrated automotive sensor interface and conditioning circuits require a dedicated development, qualification and test flow to meet the very demanding requirements of automotive quality and to avoid costly call-back actions. As can be seen from the chart in Fig. 1 the number of official call-backs in Germany has increased significantly since 1998. Amongst the 2006 call-backs, cars in 106 instances and lorries in 31 cases were involved.

In 60% of all call-backs in Germany cars have been older then 3 years. Though still mechanical issues are the main root cause for call-backs, Fig. 2 shows that electrical issues are on rank 9. However, electronics are distributed all over other systems mentioned in Fig. 2. As costs are involved in those actions, high-quality requirements are imposed upon the development of such electronic systems and their sub-systems like application-specific integrated circuits (ASICs) or application-specific standard products (ASSPs) to avoid call-backs due to low-quality electronics.

Various aspects have to be incorporated into such an automotive product development. Beside the architectural aspects of implementations, system aspects have to be taken into account, such as system redundancy for applications with elevated reliability requirements and circuits with high safety integrity levels (SILs) according to the international safety standard IEC 61508 [2] e.g. the automotive anti-blocking system (ABS) or the gear-box anti-theft lock.

---

* Corresponding author. Tel.: +49 351 8822406.
E-mail addresses: ohletz@zmd.de (M.J. Ohletz), schulze@zmd.de (F. Schulze).

0026-2692/$ - see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.mejo.2008.08.018

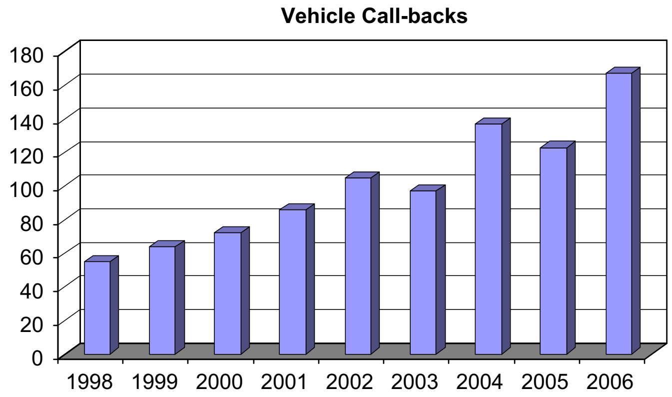

Fig. 1. Number of call-backs in Germany since 1998 [1].

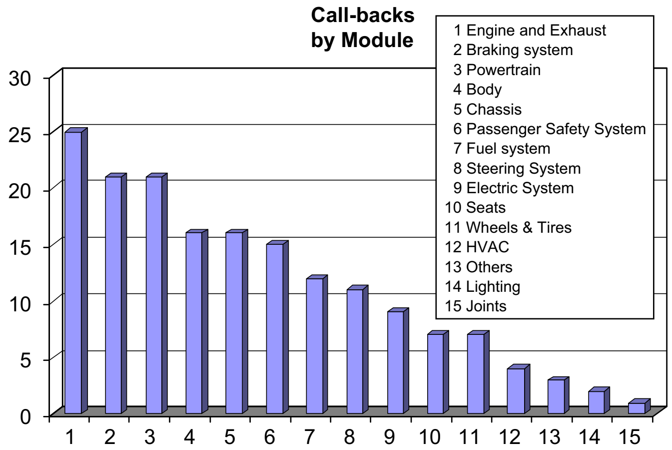

Fig. 2. Call-backs Germany since 1998 by module root cause [1].

2. Automotive requirements

Any automotive product development starts with an in-depth specification. In case of an ASIC, the specification is derived from the module specification of the customer. This phase is one of the most important phases, as here the later application or application platform is defined. Beside the ASIC pin-to-pin specifications, quality specifications as described in the international standard Automotive Electronics Council standard AEC Q-100 rev. F [3] are under intense discussion along with customer-specific requirements.

2.1. *Electro-static discharge (ESD)*

Typically, automotive ASICs or ICs must meet different ESD requirements. The most widely used ESD model is the human body model (HBM, AEC Q-100-002). This model is aimed at simulating human body-induced ESD events. The model consists of a 100 pF capacitor with a series resistor of 1.5 kΩ. Today's circuits must meet levels of 2–4 kV on all package pins. At system level so-called system ESD levels up to 16 kV must be met. In particular, in the Japanese market a similar ESD model is widely spread which has also spread out into the US and European market. This model is referred to as machine model (MM, AEC Q-100-003) and is aimed at better describing the discharge conditions due to contact with equipment rather than with human beings. The model uses a capacitor of 200 pF which is directly discharged to the pins. Typical values are 200–400 V. Since damage by ESD occurs less and less due to human handling, handling the equipment became more significant, but is not sufficiently covered by either described model. Therefore, an additional model, referred to as charged device model (CDM, AEC Q-100-011) has been introduced. There are two models used: (a) direct charge CDM and (b) field-induced charge CDM. Both models are simulating ESD events, e.g. caused during sliding of parts in the handler. In particular, corner pins are considered as more vulnerable to ESD than "inner" pins. During the test the packaged part is in the so-called "dead bug" position on an isolated metal plate. Sufficient CDM protection is assumed for values of 550 and 650 V on the corner pins, respectively. Within an automotive design flow, each revision of the ASIC must be evaluated before the next tape out. To meet those requirements, an overall ESD protection scheme needs to be implemented beside specific ESD protection structure within the pad cells.

2.2. *Electro-magnetic compatibility (EMC)*

The second important but much more difficult item is EMC. Two aspects have to be addressed during the design: (a) electro-magnetic radiation (EMR) and (b) electro-magnetic susceptibility (EMS). EMC by nature is difficult to simulate, as EMC is dealing with high-frequency wave transmission typically described by partial differential equations, while normal circuit design is based upon ordinary differential equations. Furthermore, the complexity of EMC is beyond contemporary circuit simulator capabilities. However, since the wavelength e.g. $\lambda = 30$ cm at 1 GHz is much larger than the on-chip geometries, the TEM-field can be modelled by quasi-stationary electrical fields and thus, modelled by lumped elements of L, C and R. In circuit design several measures are employed to minimise EMR and to improve the EMS. In automotive application circuits must withstand electrical fields of $E > 200$ V/m without functional disturbance, i.e. the sensor interface has to operate within specification also in the presence of EMC disturbance. On the other hand, EMR is important as the circuit must not disturb other electronic modules. Though not included in the EMC qualification, the EMC performance must also be met over the whole temperature range and life time aging. Before any car is released EMC tests of the whole vehicle in anechoic chambers are performed with electrical field strength of up to 700 V/m. EMC has to be addressed early during the design and evaluated for each prototype version of the sensor interface ASIC even for small metal tune redesigns. There are three major standards defining the EMC requirements. For the narrow band between 150 kHz and 1 GHz the EMR requirements are defined in the IEC 61967 [4] standard, whereas for EMS the requirements are defined in the IEC 62132 [5] standard. Beside those two standards, for power supply lines disturbance the ISO 7637 [6] standard also known as "Schaffner" tests are standard requirements for automotive circuits which they have to withstand. In design, special EMC filters are implemented to block EM-induced HF signals from being rectified or pumping up devices inside the sensor interface circuit. In some cases external ferrites might be even necessary, though those are of additional costs and therefore are not easily accepted by automotive customers.

The EMR profile is described by so-called EMR charts depicting the radiation over the frequency range of 150 kHz–1 GHz as e.g. shown in Fig. 3. In either case, EMR and EMS are depending on the antenna effect of the PCB, module and wire harness layout. Thus, in automotive ASIC/ASSP design the conductive EMR and EMS are the prime focus. Since for each design iteration respective EMC measurements are required, special measurement set-ups must be installed. For conductive EMR the so-called $1\,\Omega/150\,\Omega$