Available online at www.sciencedirect.com
ScienceDirect
Sensors and Actuators A 136 (2007) 441–455
SENSORS AND ACTUATORS A PHYSICAL
www.elsevier.com/locate/sna

Sensor testing through bias superposition

C. Jeffrey [a], N. Dumas [a,b,*], Z. Xu [a], F. Mailly [b], F. Azaïs [b], P. Nouet [b], R.J.T. Bunyan [c], D.O. King [c], H. Mathias [d], J.P. Gilles [d], A.M.D. Richardson [a]

[a] *Centre for Microsystems Research, Lancaster University, Lancashire LAI 4YU, UK*
[b] *Laboratoire d'Informatique, de Robotique et de Microélectronique de Montpellier, LIRMM-UMR 5506 CNRS/Université Montpellier II, 161 rue Ada, 34392 Montpellier Cedex 5, France*
[c] *QinetiQ, St. Andrews Road, Malvern, WORCS WR14 3PS, UK*
[d] *Institut d'Electronique Fondamentale, Université Paris Sud, Bâtiment 220, F-91405 Orsay Cedex, France*

Received 17 June 2006; received in revised form 31 October 2006; accepted 20 November 2006
Available online 6 February 2007

Abstract

A novel on-line monitoring technique for integrated MEMS is presented based on injection of an electrical test stimulus into the bias structure through both superposition or modulation. The techniques "bias superposition and bias modulation" both support integrated structural test that targets both production test and on-line condition monitoring through generation of dependability metric. It can in some cases be used to provide the raw data for on-line calibration and compensation. The techniques are demonstrated on three integrated MEMS structures from the field of consumer electronics, aerospace and environmental sensing and have been successfully applied to a thick film conductance sensor.

Keywords: Sensors; On-line monitoring; Condition monitoring; Design for Testability; Test; MEMS

1. Introduction

Advances in monolithic and hybrid system integration are stimulating new applications for single and multi-chip smart sensors. Many of these new systems are highly complex, have limited test access and require a known value of the measurand signal for calibration and test of the unit. Implementation of built-in self-test (BIST) techniques, which address both production and on-line test problems within these systems, has recently attracted considerable interest. However, the realisation of solutions is difficult as it is normally necessary to create a structure that does not require a calibrated measurand source and is capable of detecting problems related to cross sensitivities, drift and long term stability in addition to traditional hard faults. In addition many new integrated MEMS based sensors target harsh environment applications that add additional robustness requirements. In this paper, application of novel on-line monitoring techniques based on signal injection into the bias structure is presented. This will enable the systems to perform both measurement of the physical parameter and generate information that supports the detection of defects, the characterisation of the transfer function and in some cases self-calibration.

This paper will introduce the bias superposition and bias modulation test techniques and investigate their feasibility for application to various MEMS based sensors. The design considerations will also be presented and the impact on the sensor output will be discussed. The application to a magnetometer, an accelerometer and a conductance sensor will be presented.

This paper is organised as follows: Current test methods for sensors are reviewed in Section 2. In Section 3, the theory associated with the fundamentals of the method is presented. Section 4 introduces the technique on a Wheatstone bridge using piezoresistive gauges. In Section 5, the application to a magnetic field sensor using electrically induced thermal stimulus superposition or modulation is presented. Section 6 investigates the application of this technique to a capacitive accelerometer using an electrostatic stimulus. In Section 7, the application within a thick film conductance sensor is analysed. Hardware measurements are presented to back up the theoretical basis of the technique. These sensors are degraded and physical measurements presented and discussed. The paper is then concluded in Section 8.

* Corresponding author at: Centre for Microsystems Research, Lancaster University, Lancashire LAI 4YU, UK. Tel.: +44 1524592763; fax: +44 1524592777.
E-mail address: n.dumas@lancaster.ac.uk (N. Dumas).

0924-4247/$ – see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.sna.2006.11.030

2. Literature review

2.1. Self test solutions

Many test functions for integrated sensors that have been developed recently address the issue of reducing test cost in production. Test stimuli are electrically induced on-chip to enable the sensor test with standard electrical equipment or built-in-self-test (BIST) integrated into the sensor [1–3]. The advantages of BIST solutions include reducing demands on the test equipment, reducing the pin count used for test and possibly providing a means to test the device in the field during its life-time.

The generated stimulus can exercise the sensor in the same or equivalent way as the measurand. A well-know example is the test function available on the ADXL MEMS accelerometer [4]. Additional comb fingers can be electrically stimulated to generate an electrostatic force quasi-equivalent to acceleration. Different approaches have been developed to test capacitive accelerometers. An example is described in [5] where a MEMS accelerometer with a closed-loop force feedback system is presented. The self-test method consists of superposing a known electrostatic force and checking the corresponding output offset. This kind of test detects mainly the faults affecting the sensor sensitivity. More recently, in [6] and [7], it has been shown that the fault detection capability can be improved by associating a differential test which can detect the problems of symmetry within the device. Here a 2 by 2 crossbar switch is added to choose between sensitivity and differential testing. For sensors that cannot support the use of electrostatic force stimulus, an electro-thermal force is an interesting alternative that has been used with different approaches for several sensors, e.g. an accelerometer sensor [8], a fingerprint sensor [9], a pressure sensor [10] and a magnetometer [11]. Here electro-thermal dissipation induces a force through the dilatation of the structural materials. Another kind of example of stimulus that mimics the effect of the measurand on the sensor is found within an infrared sensor [12]. A heater has been added to the structure to simulate the thermal energy normally generated by infrared radiation.

Electro-thermal stimulus has been also used for testing sensors by stimulation it in a very different way to the measurand. In [11], the structural integrity of a cantilever structure is checked by heating the structure through an embedded dissipating element. The presence of some defects can modify the thermal dissipation and be detected by temperature measurement.

The test structures described above cannot be used while the sensor is online. The generic solution, bias superposition, presented in this paper enables these test method to be used for on-line monitoring.

2.2. Online testing solutions

A common solution for online testing of sensors is the use of redundancy with at least two identical sensors (typically three) working concurrently [13]. Assuming that all the sensors will not fail at once, the output of the sensors are compared and a voting circuit decides if the sensor system is safe or not, or if the output of a faulty sensor can be ignored. The supervisory system can be informed quickly of the failure and take necessary steps to guaranty safety. However, sensors are finding many applications in harsh environment systems where safety is critical whilst, at the same time, low-cost is required, e.g. automotive applications. Redundancy schemes can no longer be applied to satisfy these requirements.

The use of frequency response as a test criterion (OBIST) was proposed in [14]. More recently this has been adapted to on-line applications [15]. Contrary to the bias superposition technique presented in this paper, this is however a “quasi-on-line test” as the circuitry is removed from operation during test through a process involving scheduling of resources.

3. Theoritical basis of bias superposition and modulation

3.1. Test scheme

Numerous sensing systems used within integrated MEMS sensors are configured into an architecture where an electronic stimulus (bias) is applied to the sensor element to enable transduction of a physical stimulus. This signal is then fed into an analogue interface for signal conditioning (filtering, buffering, etc.) and is first shaped before being converted into the digital domain. The output signal of the sensor is usually non-ideal and requires calibration and compensation to ensure the output is directly proportional to the physical parameter.

The general test scheme for bias superposition or bias modulation is illustrated in Fig. 1. The test stimulus is injected in the normal electrical biasing structure of the sensor. It must have a specific signature to allow the response to be extracted from the functional signal at the output of the sensor. Typically the test stimulus has a frequency very different from that of the measurand. In this way the signal extraction can be implemented through electrical filters. The extracted test response supports the generation of pass/fail test information or a more detailed diagnosis of the health of the sensor. In some cases, this response can be used to generate a calibration error signal for online compensation of the calibration of the device or the test signal analyser needs the measured value of the measurand to generate the test output.

The implementation of the technique should not require modification on the sensor design because the existing biasing structure is re-used and should have a minimal impact on the conditioning electronics.

3.2. Stimulus types

The test components of the sensor bias have been categorised into four different types that are illustrated on the case studies sensor within this paper:

- *Differential bias*: exploits the sensor symmetry to identify whether the sensor is defect free.
- *Alternative bias*: exploits a signal injected into the bias that physically exercises the sensor element in a different way than