Standardized Smart Acceleration Sensor for Vehicle Tests and Diagnostics

Georgi Geshev[1] and Yani Kolkas[2]

Abstract – **The real time vehicle monitoring has become widely used in practice. A precondition for that is the timely fault detection, which leads to on-time repair. This improves the reliability of the equipment and reduces the maintenance costs. The measurements and analysis of vehicles are used for the monitoring. This paper examines the design of acceleration sensor compatible with the IEEE 1451 standard and meeting the requirements to the electronic equipment for vehicle testing and diagnostics.**

Keywords – **Smart sensors, Real-time diagnostics, Measurement, Standards.**

I. INTRODUCTION

The paper presents the final design stage of a standardized smart acceleration sensor for vehicle run time diagnostics. The basic requirements according to the existing standards of compatibility are examined in [1]. A specific implementation of sensor compatible with the standard IEEE 1451.4 is proposed. The vehicle run time diagnostic electronic equipment recommendation examined in [2] are used as input as well.

Some additional requirements for smart functionality are also taken into account in order to improve the reliability and the trustworthy of measurement results.

II. SENSOR SPECIFICATION

The paper target is to meet the basic requirements and specificity during the design of a sensor compatible to 4-wire IEEE 1451.4 The electrical requirements related with the primary functionality of the transducer as acceleration measurement equipment are used as input as well.

The basic requirements related to the specificity of the transducer design are examined in [1]. Some of them are:

- Noise immunity of the analog channel – 4-20 mA current interface used for the sensor has good noise immunity, big data transfer range, communication line-break detection
- IEEE 1451.4 compatibility
  - transducer Electronic Data Sheet (TEDS)
  - 1-wire interface
- Smart functionality
  - self-test
  - self-calibration ability
  - emergency situation handling, etc.

III. HARDWARE DESIGN

The developed block schematic of IEEE 1451 compatible system is shown in fig.1.

In the proposed block schematic of the transducer hardware, a few subsystems could be seen:

- Signal path – this subsystem includes an acceleration sensor, normalizing amplifier and U-I convertor.
- Controlling subsystem – it is based onmicrocontroller. It handles the IEEE 1451.4 compatibility specifics such as TEDS, 1-wire communication and smart functionality control.
- Dedicated system test and calibration hardware.

A.Signal path design

The implementation proposed in [2] schematic is used as a basis for track design. Some modifications are made in order to improve the functionality to cover the requirements described above. The changes and the additions are:

- 2-axes acceleration registration. The first channel measures the acceleration on the X-axis and the other on the Y-axis.
- True “rail to rail” monolithic integrated amplifier used instead of the proposed one with two operational amplifiers.
- Dedicated voltage regulator instead of the used regulator based on the internal voltage reference of the U-I convertor. The LM7833 improves the quality of power supply and simplifies the schematic.
- The power supply module generates separate 3.3V for the analog and the digital parts and additional 5V used to drive the relays used.

The signal path schematic is shown in fig. 2.

[1]Georgi Geshev is with the Faculty of Electronics at Technical University of Sofia, 8 Kl. Ohridski Blvd, Sofia 1000, Bulgaria, E-mail: johny_bravo@mail.bg.

[2]Yani Kolkas is with the Faculty of Electronics at Technical University of Sofia, 8 Kl. Ohridski Blvd, Sofia 1000, Bulgaria.

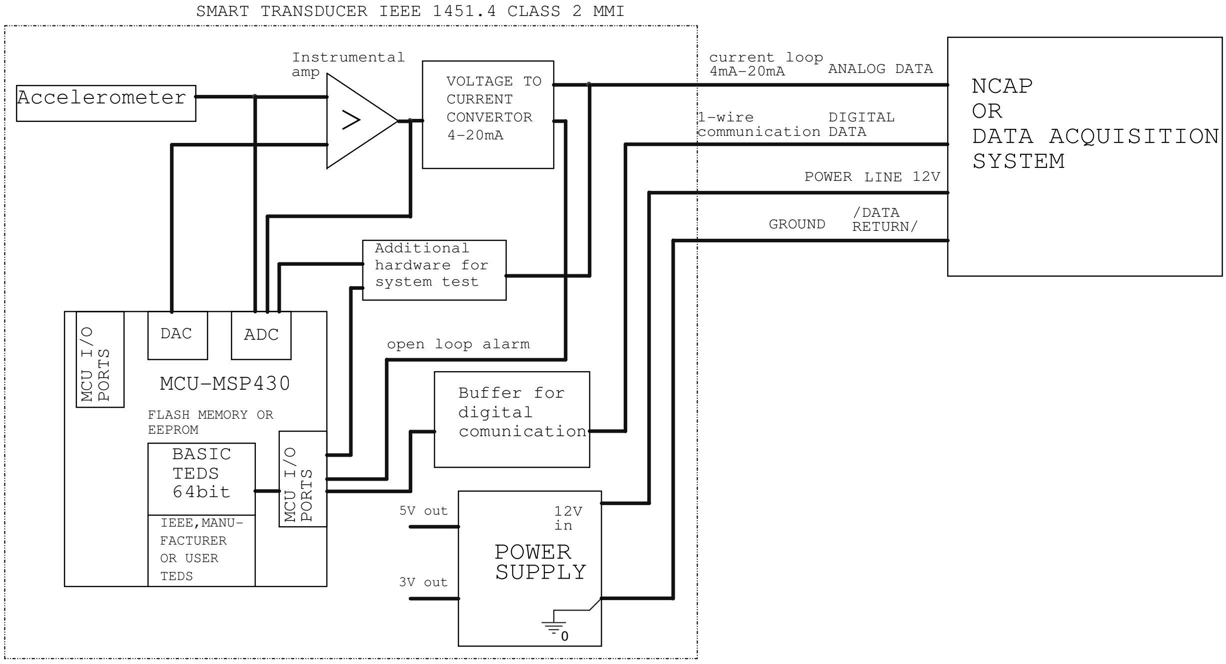

Fig. 1 Block schematic of smart acceleration sensor

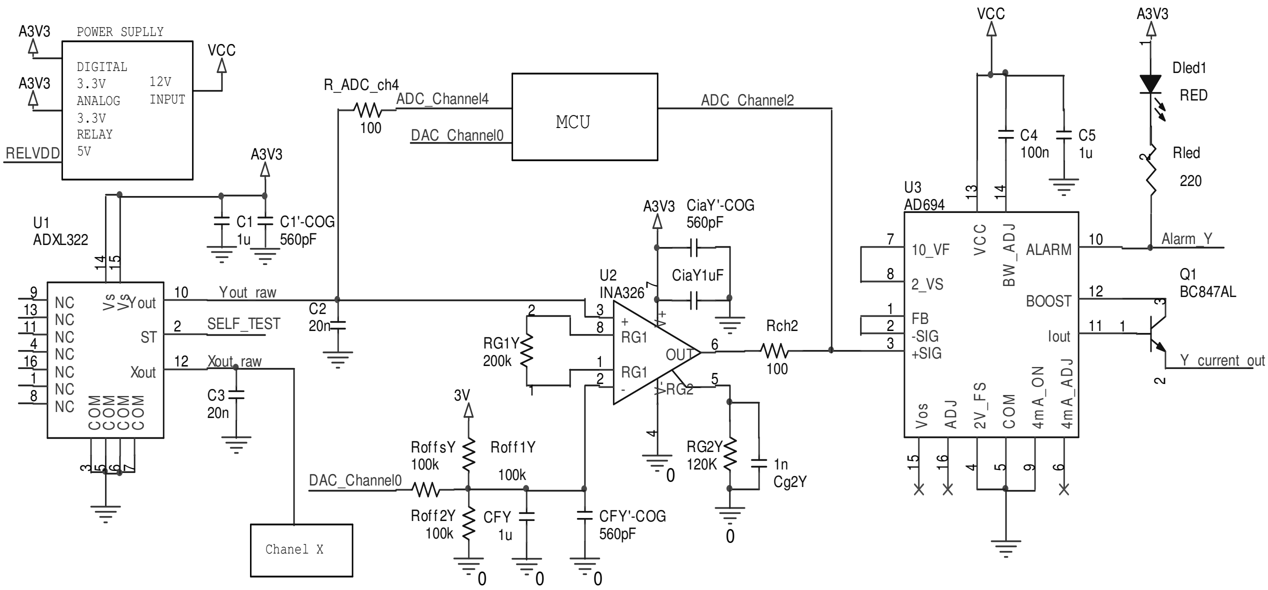

Fig. 2 Signal path schematic

The IC (U3 AD694) used is a voltage-to-current convertor. The main chip characteristics are: adjustable input range, two output ranges 0-20mA, 4-20mA and open-loop alarm. In the implementation suggested above the U-I convertor is connected in a way to enable 0-2V input voltage range and 4-20mA output range. An external transistor is used in order to decrease the self-heating error. The instrumental amplifier (U2 INA326) normalizes the acceleration sensor output to the input range 0-2V. It is a monolithic true “rail to rail” output integrated instrumental amplifier with a power supply range of 2.7V - 5.5V. In case of a non-“rail to rail” amplifier is used, a non linearity appears in the lower range of the measured accelerations. It is because of the lower input range of 0V and the single power supply used.

The acceleration IC sensor ADXL322 used is a two-axes accelerometer with -2g to +2g input range. The typical sensitivity is 430mV/g at 3V supply voltage. A self-test ability is foreseen in the chip. The output is situated at half of the voltage supply if no acceleration is applied. The maximum sensor output swing is 1.68V (typ). The output is changing from 0.66V (at -2g acceleration) to 2.34V (at +2g acceleration). The earth gravity acceleration influences the sensor output. This influence depends on the position of the transducer in the space.

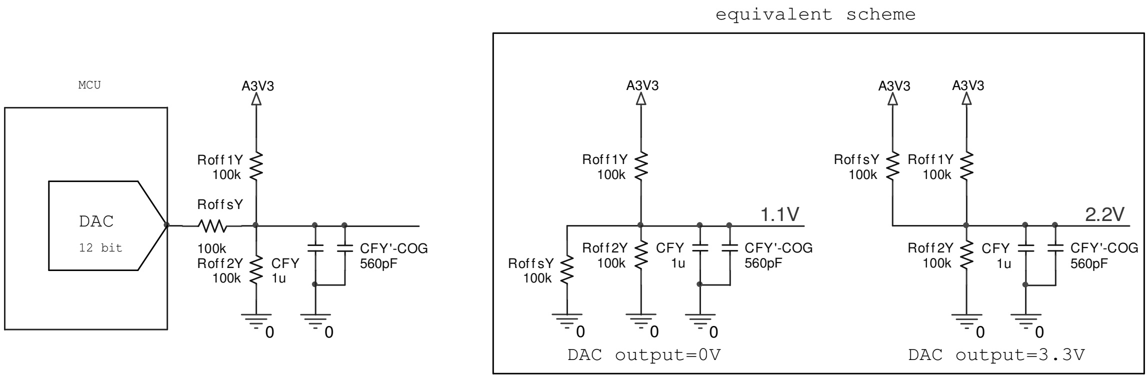

Fig. 3 Offset level control and equivalent schematic

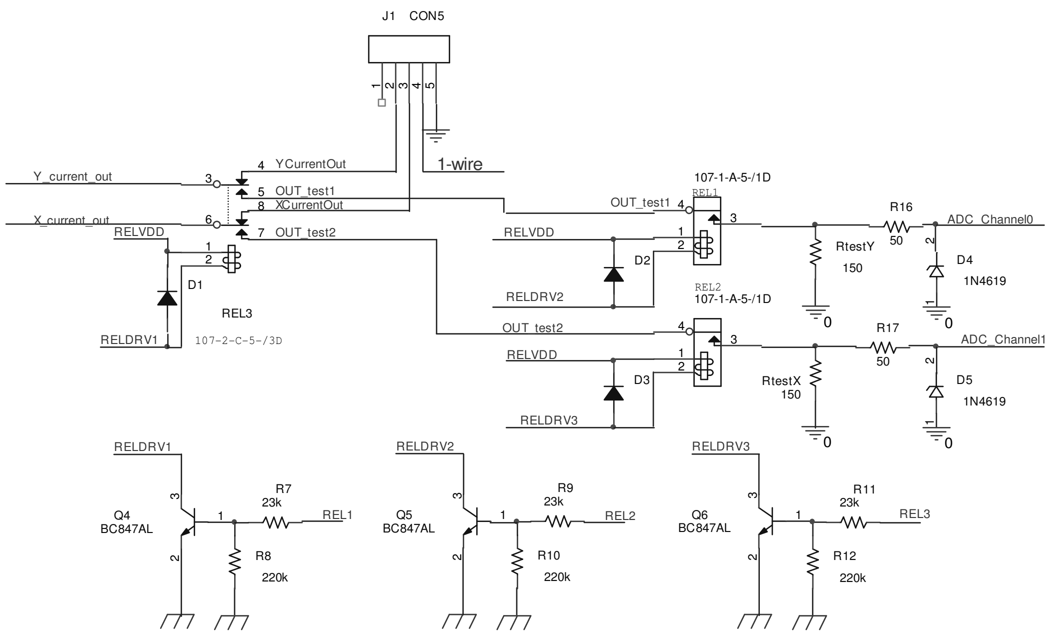

Fig. 4 Dedicated HW for system self-test

The accelerometer signal is applied to the non inverting input of the instrumental amplifier and to the inverting voltage is applied to compensate the sensor output offset and the positioning of the transducer as well. This aims to adjust and shift the output sensor signal to the input range of the U-I convertor. If no acceleration is applied to the transducer, the output current is 12mA, which is the middle of the range 4-20mA. This is implemented as voltage control on the inverting input using the DAC module of the microcontroller. The compensating voltage is set using the three 100kΩ resistors ROFFY1, ROFFY2 and ROFFSY. ROFFSY is connected to the DAC and used to adjust the middle-point voltage. Fig.3 shows the schematic and the equivalent schematic at 0V and 3.3V applied to DAC output. The voltage could be precisely changed from 1.1V to 2.2V.

A 32kΩ serial resistor is implemented in the output of the acceleration sensor. It is used as part of low pass filter if external capacitors are connected. Based on the references, a cut-off frequency of 300Hz is chosen. The frequency corresponds to 20nF value of capacitor C2.

The transducer highly noisy environment and additional digital control logic require special attention during the power supply design. The regulated 3V3 voltage is separated to analog and digital ones. They are separated using LC filters on the power line for both of them. High frequency capacitor NPO or COG are used in order to filter out the high harmonics of disturbance.

B. Self test hardware design

Three relays are used on that purpose. They are controlled by a microcontroller using buffer transistors to provide the current needed. The schematic is shown in fig. 4.

REL3 controls the output of the transducer. It opens the current loop if it is activated. This mode is used to test the alarm signal of the U-I convertor. If REL1 or REL2 is activated in combination with REL3, the output current is redirected to 150Ω reference resistors RtestX/RtestY. The voltage drop is measured using ADC channels. ADC inputs protection is foreseen – R16/D4 and R17/D5.

C. Control logic design

Based on the survey made on the IEEE1451 standards family in [2], two approaches could be used for the TEDS and 1-wire communication implementation:

- 1-wire memory for the TEDS and dedicated microcontroller for the smart functionality.
- Usage of single microcontroller that incorporates the smart functionality and the 1-wire communication protocol. The built-in FLASH is used to store the TEDS.

The second approach is chosen where the functionality of the transducer is extended.

The microcontroller used is MSP430F169 of 16-bit with 2KB RAM and 60KB FLASH. It has all additional functionality that is needed – ADC, DAC, timer systems, etc. An extended description could be found in [4]. The requirements that have to be taken into account concern power supply, its decoupling, the external components needed for the oscillator and the RESET.

The 1-wire interface uses time slots where the logical zero and one are transferred on one and the same physical level (low) but the duration of the pulse is different. The logical one is coded with a short negative pulse less than 15 µs and zero uses pulse with minimum width of 60 µs.

The communication is initiated by a master device. It is only with one master device connected to the bus and several slave devices could be also connected. A full description of the 1-wire interface could be found in [3]. A schematic of the buffering circuit is shown in fig. 5. This implementation uses pin 0 and 1 of port 4 of the microcontroller. This connection allows the usage of the timer system to control the time slots.

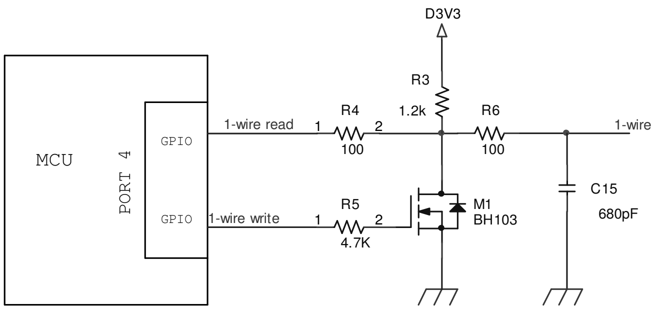

Fig. 5 1-wire buffer schematic

IV. Firmware Design

The following requirements are set to the firmware design:

- TEDS emulation in the microcontroller FLASH memory
- Communication with the Network Capable Application Processor (NCAP)
- Smart functionality implementation

The 1-wire software is implemented according the proposed in [6] procedure proposed by Maxim Co. The main target of the microcontroller-dedicated implementation is to form time intervals in the microseconds range. Two options are available: to generate the intervals within the software or to use the integrated timer subsystem of the controller.

TEDS is implemented as block of the FLASH memory. It consists of constants, coefficients and other data necessary for the module proper functionality. A Template Description Language (TDL) is used to modify the existing TEDS and to create new ones. More detailed information about the TEDS and TDL could be found in [5].

The self test smart functions algorithms are as follows:

- Acceleration sensor test – the IC sensor self-test pin is used. High level is applied to it and the output voltage change is measured.
- Instrumental amplifier test – the amplifying coefficient is measured. With microcontroller ADC the input differential voltage and the amplifying stage output voltage are measured. The measurement values are used to calculate the coefficient.
- Transfer characteristic of the signal path test – the U-I converter output is redirected to the reference resistor. The voltage drop on it is measured. This test has to be performed under the condition without motion.
- Open-loop alarm test – a relay disconnects the output of the U-I convertor. The microcontroller reads the state of the alarm pin.

V. Conclusion

An IEEE1451 standard compatible system has been developed. Wide self test and diagnostic capabilities are foreseen. The system could be used in other fields where the acceleration is an information parameter.

References

[1] Georgi Dotsov Geshev, Emil Nikolov Dimitrov -Feasibility assessment of the smart standartized sensors design for vehicle tests and diagnostics ELECTRONICS 2008 24-26 September Sozopol BULGARIA.

[2] E.N.Dimitrov,N.G.Nenov,G.D.Geshev -Train Spring System Diagnostic Equipment Using Acceleometer Sensors ISSE 2008.

[3] ONE WIRE ON-LINE TUTORIAL - http://www.maxim-ic.com/products/1-wire/flash/overview/index.cfm.

[4] MSP430x1xx Family User's Guide (Rev. F) SLAU049F 2006 TEXAS INSTRUMENTS http://focus.ti.com/lit/ug/slau049f/slau049f.pdf.

[5] “DS2430A 256-bit 1-Wire EEPROM,” Maxim/Dallas Semiconductor Corp. Datasheet, http://www.maxim-ic.com/DS2430A .

[6] “IEEE Std 1451.4-2004, Standard for a Smart Transducer Interface for Sensors and Actuators- Mixed-Mode Communication Protocols and Transducer Electronic Data Sheet (TEDS) Formats”, IEEE Standards Association, Piscataway, NJ, 2004.

[7] 1-Wire® Communication Through Software AN126 MAXIM 09/06/05: Version 2.2 http://www.maxim-ic.com/appnotes.cfm/an_pk/126