https://doi.org/10.26552/com.C.2011.2A.92-96

Martin Vestenický – Peter Vestenický *

LPG CONCENTRATION MEASUREMENT IN VEHICLES TRANSPORTING DANGEROUS GOODS

This paper describes the design of intelligent sensor unit for LPG (Liquefied Petroleum Gas) concentration measurement in the air. The sensor unit is a part of sensor network which has been designed for vehicles transporting dangerous goods. The described sensor unit uses sensor element based on SnO_2 structure which is vapoured on the aluminum substrate. Main part of the paper is focused on hardware solution of the sensor unit, signal processing applied on signal from its sensor element, compensation of air temperature and relative humidity influence on the sensor resistance and description of its application layer communication protocol.

1. Basic Conception of Inteligent Sensor Unit

The presented sensor unit is designed as an autonomous subsystem which is able to inform the onboard unit (OBU) – about concentration of LPG in ambient air. The sensor unit consists of analog sensor elements whose output signals are processed by microcomputer in real time (Fig. 1). The result values are transferred into master unit by using of CAN bus [1] and proprietary communication protocol on the application layer.

For LPG concentration measurement the sensor Figaro TGS 813 [6] based on the SnO_2 structure vapoured on aluminum substrate was selected. The LPG influences the resistance of sensor. This influence can be modeled by formula (1), where A, α are constants for given type of LPG sensor, C is LPG concentration (in ppm) and R_{S20} is sensor resistance at temperature 20 °C and relative humidity 65 %. Moreover, the value of sensor resistance depends on air temperature and relative humidity. For compensation of their influences the sensor unit is equipped with temperature sensor and relative humidity sensor. The compensation of LPG concentration is being performed in real time by microcomputer software which uses mathematical apparatus described in next text.

$$R_{S20} = A \cdot C^{-\alpha} \tag{1}$$

2. Measurement of LPG Concetration

The LPG sensor element is connected into the microcomputer in accordance with schematics in Fig. 2. The LPG in ambient air influences its resistance so that measurement of LPG concentration is changed to measurement of sensor resistance. Therefore the sensor element is connected as a part of voltage divider with variable ratio of division together with resistor R_M. Input of the divider is connected to the supply voltage U_{CC}. The voltage U_{RM} from resistor R_M is connected to the input of A/D converter whose reference voltage is connected to U_{CC}, too. Therefore the resistance of sensor element can be calculated from formula (2). Voltage U_{RM} is measured by the A/D converter with resolution rb according to formula (3) where RES_{AD0} is the result of A/D conversion. Combining the formulae (2) and (3) the sensor resistance R_S can be calculated from formula (4). Note that the formula (4) is independent on supply voltage U_{CC}. This fact has positive influence on precision of measurement.

$$R_S = R_M \cdot \frac{U_{CC} - U_{RM}}{U_{RM}} \tag{2}$$

$$U_{RM} = RES_{AD0} \cdot \frac{U_{CC}}{2^{rb} - 1} \tag{3}$$

$$R_S = R_M \cdot \frac{(2^{rb} - 1) - RES_{AD0}}{RES_{AD0}} \tag{4}$$

The value of LPG concentration (in ppm) can be calculated according to formula (5) which comes out from (1). In the formula (5) the R_{S20} is resistance of sensor element after compensation of temperature and relative humidity influence. This compensation is given by formula (14). The constant R_0 is resistance of sensor element at C = 1800 ppm, T_{MEAS} = 2 0 °C and RH = 65 %. K and α are specific constants for the given type of sensor.

$$C = 10^{\frac{\log\left(\frac{R_{S20}}{R_e \cdot K}\right)}{\alpha}} \tag{5}$$

* Martin Vestenický[1], Peter Vestenický[2]
[1] Department of Telecommunications and Multimedia, Faculty of Electrical Engineering, University of Zilina, Slovakia,
E-mail: martin.vestenicky@fel.uniza.sk
[2] Department of Control and Information Systems, Faculty of Electrical Engineering, University of Zilina, Slovakia,

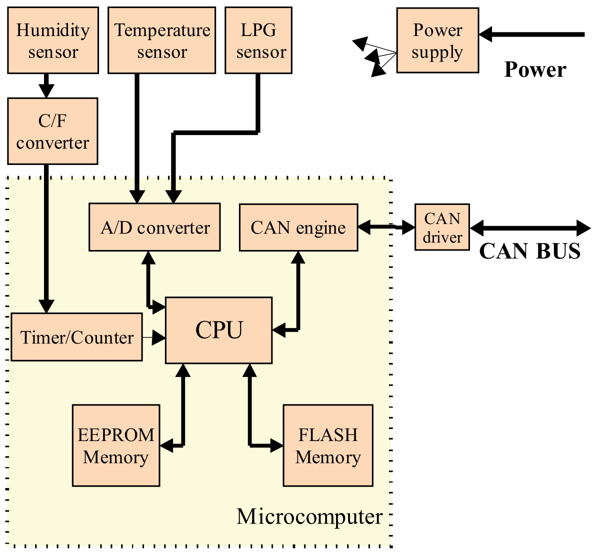

Fig. 1 Block diagram of LPG sensor unit

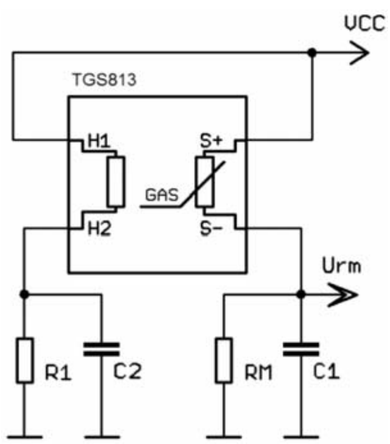

Fig. 2 Schematic diagram of the LPG sensor

3. Measurement of Relative Humidity

For measurement of relative humidity a capacitive sensor element Philips 2322 691 90001 was selected. Capacity C_S of this sensor depends on the relative humidity. Inverse function of this dependence is shown in Fig. 3 (points). This dependence can be approximated by polynomial function of the second order which is given by formula (6) – curve in Fig. 3.

Measurement of the relative humidity is converted to the measurement of capacity. One of the simplest but sufficiently accurate methods of capacity measurement is utilization of measured capacity as element which determines the frequency of oscillator. In the described sensor unit the oscillator with well known CMOS timer 555 was used. The signal of astable flip – flop circuit configured according to Fig. 4 has duty cycle 1:1 and frequency is given by formula (7) where $a_F = 1.4$ is constant and R_t is timing resistance (Fig. 4). The frequency of oscillator is measured by two timers / counters which are built into used microcomputer. The first timer/counter works as counter and the second one works as time base generator. Resultant formula (8) which goes out from (6) and (7) determines the relative humidity. Values of constants for the described sensor unit are summarized in Table 1.

$$RH = a_{C_2} \cdot C_S^2 + a_{C_1} \cdot C_S + a_{C_0} \tag{6}$$

$$f = \frac{1}{a_F \cdot R_t \cdot C_S} \tag{7}$$

$$RH = a_{C_2} \cdot \left(\frac{1}{a_F \cdot R_t \cdot f} \right)^2 + a_{C_1} \cdot \left(\frac{1}{a_F \cdot R_t \cdot f} \right) + a_{C_0} \tag{8}$$

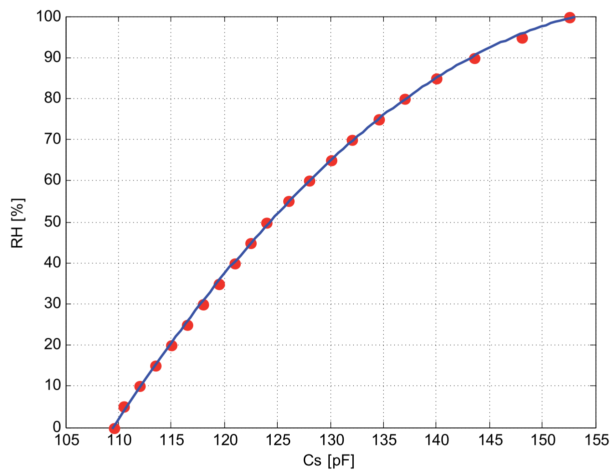

Fig. 3 Dependence of relative humidity on the sensor capacity and its approximation

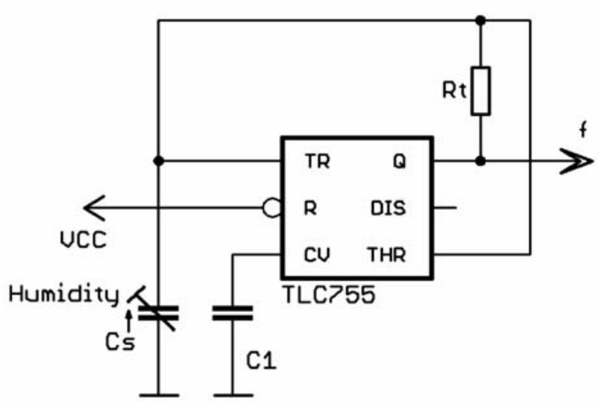

Fig. 4 Convertor of capacity to frequency

4. Measurement of Temperature

The temperature is being measured by linear temperature sensor LM335 (product of National Semiconductor Corp.) whose output voltage depends on absolute temperature linearly. This dependence is described by formula (9) where a_{TS1} and a_{TS0} are constants for the given type of sensor. The temperature sensor can be calibrated by proper selection of these constants [5]. Measured temperature can be calculated from formula (10). Taking A/D process into account (11) the resultant formula for temperature calculation is (12).

$$U_{TS} = a_{TS1} \cdot T_{MEAS} + a_{TS0} \quad (9)$$

$$T_{MEAS} = \frac{U_{TS} - a_{TS0}}{a_{TS1}} \quad (10)$$

$$U_{TS} = RES_{AD1} \cdot \frac{U_{CC}}{2^{rb} - 1} \quad (11)$$

$$T_{MEAS} = \frac{RES_{AD1} \cdot U_{CC} - (2^{rb} - 1) \cdot a_{TS0}}{(2^{rb} - 1) \cdot a_{TS1}} \quad (12)$$

5. Compensation of Temperature and Humidity Influence on the LPG Sensor

Since the temperature and relative humidity influence the LPG sensor resistance it must be compensated. The real temperature dependency of relative resistance (R_S/R_{S20}) of the LPG sensor with relative humidity as parameter is shown in Fig. 5 as points which are taken from [6]. This dependency is approximated by function of two variables R_H and T_{MEAS} according to formula (13) whereby constants for given sensor unit a_2, a_1, a_0, c_2, c_1 and c_0 are listed in Table 1. The result of approximation is depicted as curves in Fig. 5. The compensation function (14) is derived from the formula (13). Then the compensated value R_{S20} from (14) enables to calculate the LPG concentration from formula (5) if the temperature of air T_{MEAS} and the relative humidity R_H are known.

$$\frac{R_S}{R_{S20}} = \left(a_2 \cdot \ln(RH + 1) + c_2\right) \cdot T_{MEAS}^2 + \left(a_1 \cdot \ln(RH + 1) + c_1\right) \cdot T_{MEAS} + a_0 \cdot \ln(RH + 1) + c_0 \quad (13)$$

$$R_{S20} = \frac{R_S}{\left(a_2 \cdot \ln(RH + 1) + c_2\right) \cdot T_{MEAS}^2 + \left(a_1 \cdot \ln(RH + 1) + c_1\right) \cdot T_{MEAS} + a_0 \cdot \ln(RH + 1) + c_0} \quad (14)$$

Values of constants for LPG sensor unit Tab. 1.

α [-]	K [-]	a_{TS1} [V°C^{-1}]	a_{TS0} [V]
0.5413	57.82	0.01	2.73
a_F [-]	rb [-]	a_{C2} [F^{-2}]	a_{C1} [F^{-1}]
1.4	10	$-3.77 \cdot 10^{22}$	$1.21908 \cdot 10^{13}$
a_{C0} [-]	a_2 [°C^{-2}]	c_2 [°C^{-2}]	a_1 [°C^{-1}]
−882.9328	4.382·10-5	5.359·10-5	−0.003517
c_1 [°C^{-1}]	a_0 [-]	c_0 [-]	R_0 [Ω]
−0.007298	−0.1052	1.7970	1149
R_M [Ω]	R_t [Ω]	U_{CC} [V]	
4700	8200	5	

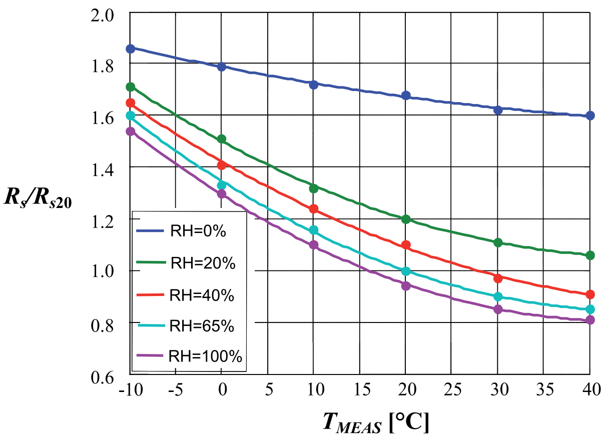

Fig. 5 Dependency of LPG sensor relative resistance on temperature and relative humidity

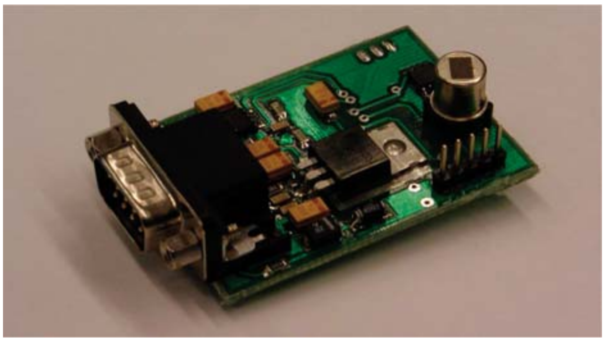

Fig. 6 Manufactured LPG sensor unit

6. Communication Protocol on the Application Layer

A simple communication protocol was designed for communication between sensor unit and the OBU. Standardized application protocols working on the CAN bus (CANOpen, DeviceNet) were not used for their complexity. The protocol is based on command

Structure of the PDU Tab. 2.

ID	D0	D1	D2	D3	D4	D5	D6	D7
SENS_ID	CMD_ID/ ANS_ID	MES_NBR	SENS_NBR_L	SENS_NBR_H	VAL_1_L	VAL_1_H	VAL_0_L	VAL_0_H

– answer principle. Protocol data units are transferred by using standard data frames with 8 octet data field in accordance to CAN 2.0A specification [4]. The PDU structure is given in Tab. 2. The CAN message identifier (11 bits) is used to address group of sensor units which measure the same quantity (000H – OBU, 010H – inclination sensors, 020H – pressure sensors, 030H – gas sensors, 040H – temperature sensors). The sensor unit uses CAN filter to select only the messages relevant for its group. The whole sensor network is addressed by message with identifier 000H. Individual sensors can be addressed on the application layer by the 16 bits sensor unit number SENS_NBR.

The command, answer or alarm is identified by the CMD_ID/ ANS_ID field (Table 3). Command parameters or measured values are transferred in the fields VAL1_L – VAL0_H. If longer message must be fragmented the field MES_NBR gives number of fragments (4 bits) and fragment order (4 bits). Fig. 7 shows an example of communication.

7. Conclusion

The described intelligent sensor unit (Fig. 6) was manufactured as a part of system for monitoring dangerous load transport [1, 2] which was solved within the international project Connect, subdomain 4.9 “Dangerous goods monitoring and information system” [3]. The method of LPG concentration measurement including compensation of temperature and relative humidity influences was implemented into firmware of the sensor unit.

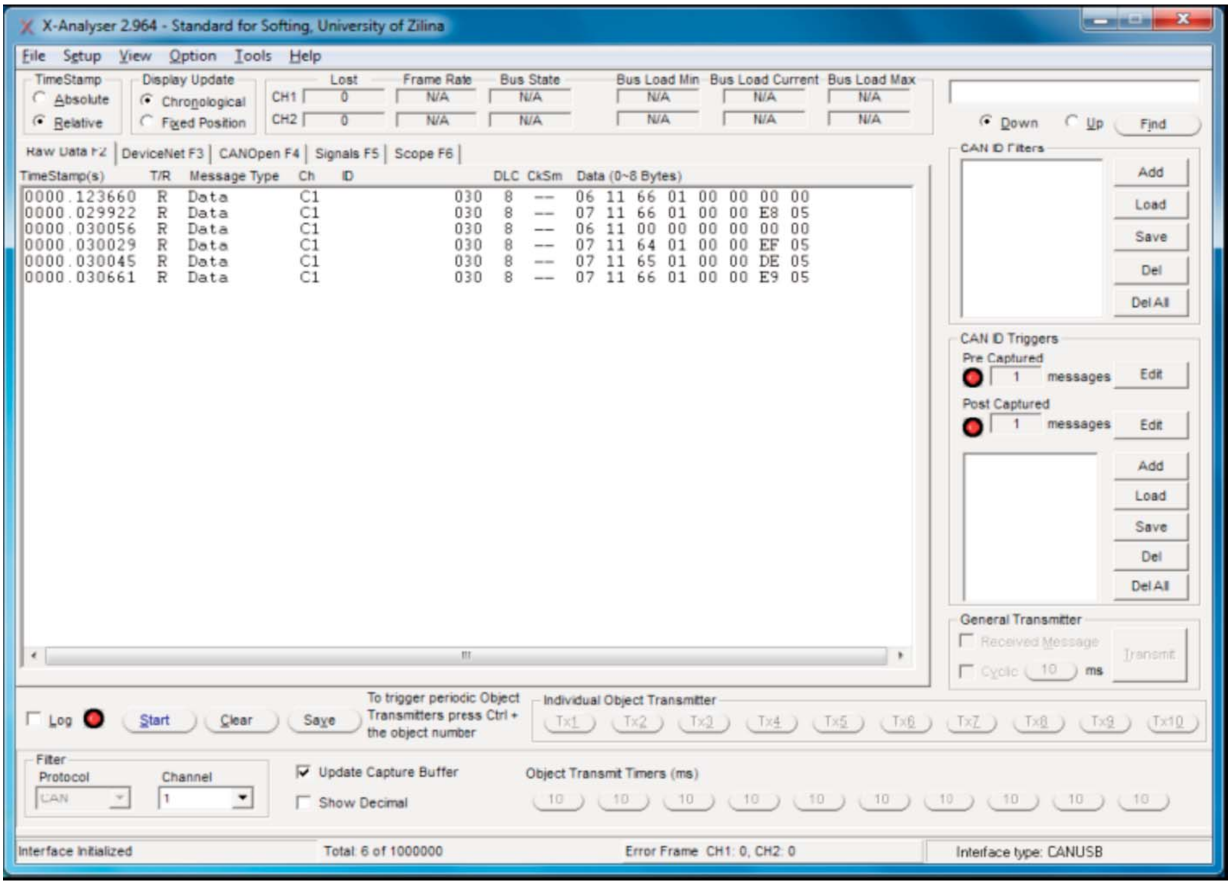

Fig. 7 Snapshot of CAN protocol analyzer

Definition of commands, answers and alarms Tab. 3.

CMD_ID/ ANS_ID	TYPE	Description
00H	CMD	Get sensor unique identifier
01H	ANS	Number of sensor unit
02H	CMD	Set number of sensor unit
04H	CMD	Get sensor unit status
05H	ANS	Sensor unit status
06H	CMD	Get actual sensor data
07H	ANS	Actual sensor data
08H	CMD	Set sensor limit value
0AH	CMD	Get sensor limit value
0BH	ANS	Sensor limit value
0DH	ALM	Upper limit exceeded
0FH	ALM	Lower limit exceeded
11H	ALM	Sensor error
12H	CMD	Sensor reset
13H	ANS	OK
15H	ANS	Error

For the test purposes three sets of master units and sensor networks (including sensor units for measurement of pressure, inclination, and temperature) were manufactured. The tests were performed on the territory of north Slovakia by staff of Transport Research Institute, Inc. and University of Zilina. Results of the tests prove full functionality of manufactured sensor unit prototypes. Next development will be focused on design of new sensor units, for example "black box" for road traffic accident analysis.

Acknowledgment

This work was created as a part of solution of international project "Coordination and Stimulation of Innovative ITS Activities in Central and Eastern European Countries – CONNECT", TEN-T Programme EC. Project number: Addition no. 3 to Contract no. 472/ VÚD 2002.

This work has been supported by the Grant Agency VEGA of the Slovak Republic, grant No. 1/0023/08 "Theoretical Apparatus for Risk Analysis and Risk Evaluation of Transport Telematic Systems."

References

[1] VACULIK, M., FRANEKOVA, M., VESTENICKY, P., VESTENICKY, M.: On-Board Unit and its Possibilities of Communications on Safety and Security Principles. *AEEE 7*, 2008, No. 1-2, pp. 235–238. ISSN 1336 – 1376

[2] VACULIK, M., VESTENICKY, P., VESTENICKY, M.: *Vehicle On-board Unit (in Slovak).* Proc. of Int'l conference ITS, Bratislava, 2007, ISBN 978-80-254-0207-8

[3] CONNECT, *Co-ordination and Stimulation of Innovative ITS Activities in Central and Eastern European Countries.* [online]. URL <http://www.connect-project.org/>

[4] CAN specification, Version 2.0. Robert Bosch Gmbh. 1991. [online] URL <http://www.semiconductors.bosch.de/pdf/can2spec.pdf>

[5] BLAGOJEVIC, M., PETKOVIC, D.: A New Approach to the Interpretation of Signals from Temperature Sensors. *Communications – Scientific Letters of University of Zilina,* Vol. 8, Nr. 4, 2006, pp. 57–60. ISSN 1335-4205.

[6] Figaro product information: *TGS 813 - for the detection of Combustible Gases,* rev. 9/02. [online] URL http://www.figarosensor.com/products/813pdf.pdf.