Scalable measurement system for multiple impedance gas sensors

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Abstract

Author proposes scalable architecture of the measurement system for gas sensor with impedance dependance of the gas concentration. The main part of the system is a single-board impedance analyser. The number of analysers working in parallel can be configured according to specific application. The system is controlled by a single computer which organises the measurement cycle and store the acquired measurement data. The system is based on I2C-like interface and uses broadcast addressing to achieve parallel synchronisation and individual addressing to program individual setting and retrive the measurement data.

Keywords: impedance measurement, gas sensors, scalable measurement system, single-board impedance analyzer.

1. Introduction

Semiconductor gas detecting sensors [1, 2] are getting more and more popular. One of a possible application area of such sensor is an electronic nose which has dedicated conference [3, 4]. Another application area is air quality assessment [5-7] which is important due to safety reasons [8, 9], alcohol contents [10] or food quality [11, 12] testing. Semiconductor gas sensors are relatively cheap, easier to use than electrochemical sensors, highly sensitive When gas contents changes, the sensor resistance is changing. The sensors have some drawbacks: low selectivity (sensor reacts not only for the dedicated gas but also for other gases), they need to be heated (need to supply additional power). In many cases the selectivity of the sensors can be obtained thanks to different measurement techniques [6, 13, 14] or sensor response processing (e.g. sensor response fusion [12]). The sensor fusion requires several or more sensors to be measured at the same time and then process the data. To address this problem Author proposes the flexible, scalable measurement system architecture which allows measuring easily configurable sensor number from 1 up to 120.

2. Architecture of the measurement system

The block diagram of the proposed measurement system is presented in Fig. 1. M identical impedance analysers working as a sensor's modules are connected using I2C (also called TWI – Two Wire Interface) bus. Each sensor module (see Section 3) allows connecting one sensor: controls sensor's heater and measures sensor impedance.
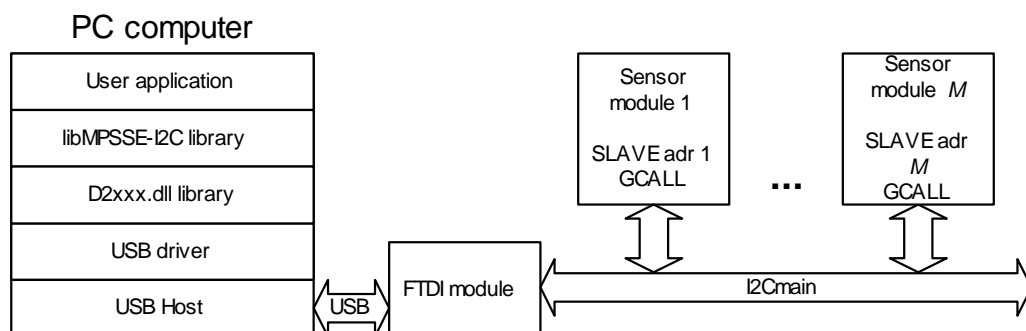

Fig. 1. Block diagram of the scalable measurement system for impedance gas sensor.

The control function of the system is located in the personal computer with dedicated user application. To communicate with sensor's modules FTDI MINI MODULE [15] based on FT2232H chip was used. Using dedicated DLL library libMPSSE-I2C [16] and working together D2xxx.dll library as well as manufacturer's supplied USB driver, it is possible to create simple USB-to-I2C bridge. Table 1 presents FTDI module pin assignment.

TABLE 1. FTDI MINI MODULE pin assignment for I2C bus

Pin name	Usage	Description
AD0	SCL	I2C clock
AD1	SDA	I2C data (output)
AD2	SDA	I2C data (input)
USBPWR	–	USB power supply
IOPWR	–	I/O interface power
3V3	–	3V3 power
GND	–	Ground

Communication module and sensor modules were connected using 10(14)-pin IDC connectors and 10(14)-wire flat ribbon cable, signal assignment in the cable was presented in Table 2. The connectors/cable with higher number of wires (14) is used when using high number of sensor's module to supply enough power to the modules.

TABLE 2. Wires assignment for cable connecting the system

Pin number	Name	Description
1	*RST	Reset (active low)
3	*SRQ	Service request (active low)
5	SDA	I2C data
7	SCL	I2C clock
9 (11, 13)	VCC	Power to analysers
2, 4, 6, 8, 10, (12, 14)	GND	Ground

Signals SDA and SCL are used for bi-directional communication over I2C. Additional signals allow to reset all sensors modules (*RST) and allow modules to request service (*SRQ). The communication module can also supply the measurement modules from USB (if number of sensors is up to 4) or from external supply for higher number of sensors. Sensor's heaters have to be powered from additional power supply (parameters of this supply depends on the sensor type).

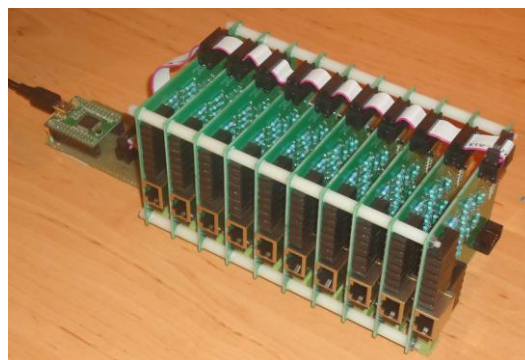The realized measurement system containing 10 impedance analysers is shown in Fig. 2.

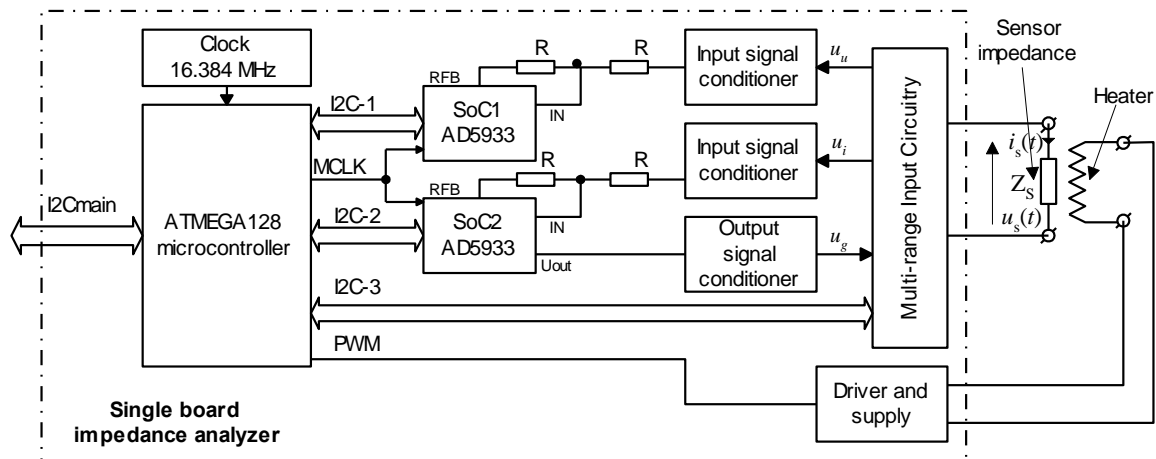Fig. 2. The realised measurement system.

Fig. 3. Block diagram of the single-board impedance analyser.

3. Single-board impedance analyser

The presented single-board impedance analyser is based on the simplified solution proposed in [17] and uses two AD5933 chips [18]. The block diagram of the analyser is presented in Fig. 3. The analyser working horse is ATMEGA128 microcontroller managing measurement cycle. Using two separate (but synchronized) I2C busses (I2C-1 and I2C-2), the microcontroller works as I2C master and controls two AD5933 System-on-Chips (SoC). Microcontroller also provides clock signal for AD5933s as well as changes measurement range of the input circuitry using third I2C bus (I2C-3). An additional function of the microcontroller is driving sensor heater using PWM signal.

AD5933 marked as SoC2 generates excitation signal u_g (SoC1 generation circuit is not used). Generated signal is additionally conditioned (filtered, amplified, buffered) and supplied to the input circuitry. The input circuitry feeds the measured sensor impedance Z_S with excitation signal and extracts two signals: u_u proportional to voltage u_s across the sensor and u_i proportional to current i_s flowing through the sensor. These signals are preconditioned (filtered, amplified and added with appropriate DC offset) and then given to SoC1/SoC2, which sample signals and determine orthogonal (Re, Im) parts of the signals. The microcontroller reads Re, Im parameters and calculates the impedance parameters (modulus, argument, real and imaginary parts) [17].

The ATMEGA128 microcontroller provides externally I2C bus (I2Cmain) acting on this bus as a SLAVE device with individually set slave address ADRk. The microcontroller also responds to I2C General Call Address. This solution allows to connect multiple analysers to the same bus and control them separately (using ADRk) or in the same time (using General Call Address) by the PC controller with USB-to-I2C bridge.

Communication with the analyser (sending commands and reading results) is possible using internally addressed set of registers. This solution is similar to the use of I2C EEPROM memories: user first sends I2C address of slave device (to select chip and determine transmission direction: read/write) and than the address of the internal memory cell/register. Table 3 presents the selected most important internal registers of the analyser and their functions.

TABLE 3. The analyser internal registers assignment

Name	Address	Description	
STATUS	0x00	Device status 0 – ready/ 1- busy (measuring)	
COMMAND	0x01	Write command e.g.: 0x50 – set measurement parameters 0x51 – make measurement	
RANGE	0x08	Range resistor select	
		0 – auto	8 – 100 kohm
		1 – 100 ohm	16 – 1 Mohm
		2 – 1 kohm	32 – 10 Mohm
		4 – 10 kohm	64 – 100 Mohm
ARANGE	0x09	Autorange starting resistor:	
		0 – last used	8 – 100 kohm
		1 – 100 ohm	16 – 1 Mohm
		2 – 1 kohm	32 – 10 Mohm
		4 – 10 kohm	64 – 100 Mohm
ACVAL	0x0A	Measurement signal amplitude	
HEATER	0x0F	Heater state	
ZXMAG	0x20	Result: Zx modulus [ohm] (4B float)	
ZXPH	0x24	Result: Zx argument [deg] (4B float)	
ZXRE	0x28	Result: Re(Zx) [ohm] (4B float)	
ZXIM	0x2C	Result: Im(Zx) [ohm] (4B float)	

Figure 4 shows the realized single-board impedance analyser with localization of main connectors.

System bus connector

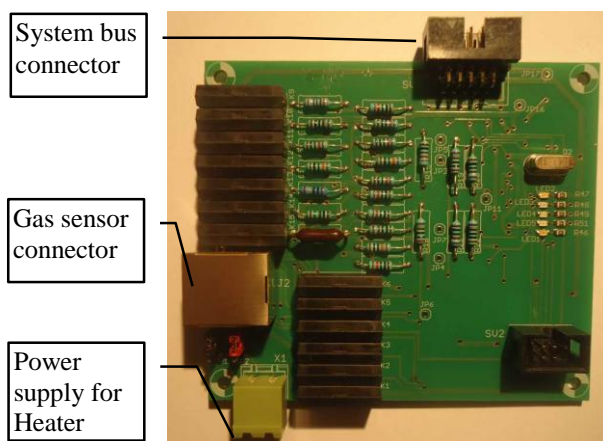Gas sensor connector

Power supply for Heater

Fig. 4. Single-board impedance analyser.

4. Multiple sensor measurement organisation

User application running on PC allows to organise measurement cycle and use available features of the single-board analyser. The analysers are designed in a form of a virtual instrument – there is no user interface on the board (except LEDs for debugging purposes) – all functions of the analyser are controlled via I2C interface by PC software, which creates whole user interface.

The most important task of the PC software is organization of the measurement cycle. The algorithm of the impedance spectrum measurement cycle organization is presented in Fig. 5. Lets make the following assumptions:

- there are M sensor's modules, the addresses of which are organized in a list ADR_{tab};
- there are K measurement frequency points which are organized in a list f_{meas}.

In the current version of the analyser measurement frequency range starts from 10 mHz up to 100 kHz with ten measurement points in each frequency decade.
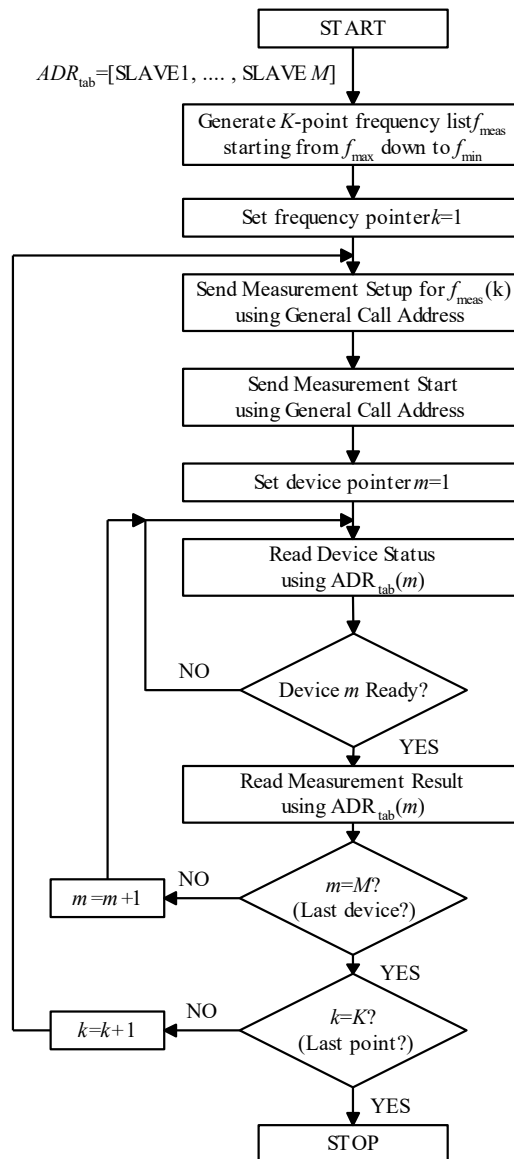

Fig. 5. Spectrum measurement cycle algorithm

The measurement starts at the first frequency from f_{meas} list. For this point, the measurement setup is sent to each analyser using General Call Address (when setup is identical for each analyser) at the same time for all analyser, which is the fastest way, or sequentially, separately for each analyser (when setup is different for each analyser), which takes M times more time. Next, the measurement is started for all analysers at the same time using General Call Address, which guarantees the impedance measurements synchronization. After the assumed measurement time dependant on the currently measured frequency, all devices, starting from the first on ADR_{tab}, are queried to detect if the measurements are finished. When the devices are ready, the results are read sequentially from all devices.

The procedure is repeated for the next f_{meas} frequency.

5. PC software user interface used for testing the system

The software was prepared using National Instruments LabWindows/CVI. The front panel allowing measurement using multiple sensors/analysers is shown in Fig. 6.
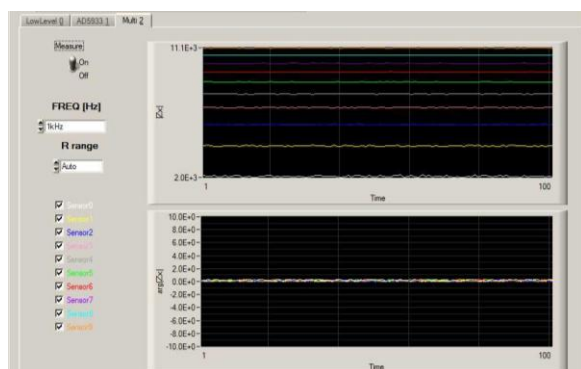

Fig. 6. Control panel of the virtual instrument.

The virtual instrument is universal and can be used for impedance measurement using single or multiple analyser(s) at single frequency or full spectrum acquisition. All results of the measurements can be shown on the screen as well as logged into a file for further processing (e.g. model fitting).

In the graphs shown in the Fig. 6, ten impedance analysers were working in parallel measuring ten different reference resistors (in the range from 2 kΩ to 10 kΩ). The exemplary results are presented in the form of modulus (upper graph in Fig. 6) and argument (lower graph in Fig. 6) of impedance. Each resistor was measured by each analyser ten times thus creating measurement series. The results were averaged and errors were calculated in relation to the reference component values measured with Precision LCR meter Agilent E4980A. The relative modulus errors are presented in Fig. 7a and absolute argument errors are shown in Fig. 7b. For each serie the standard deviation was also calculated and presented in Fig. 7c.
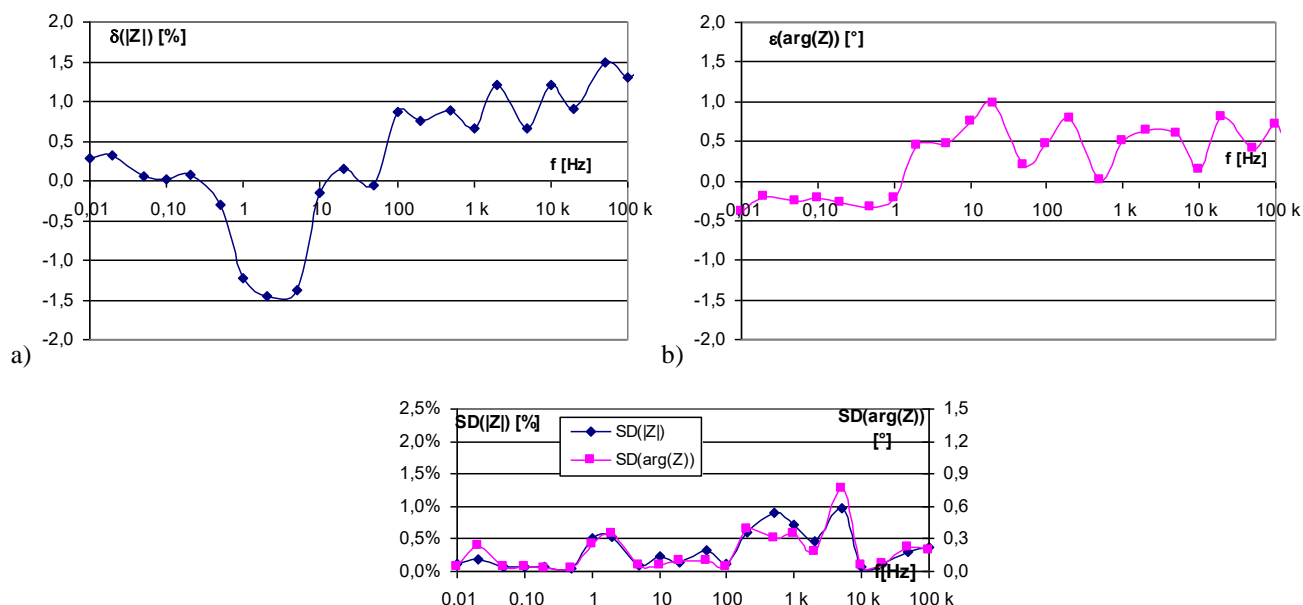

Fig. 7. The scalable system prototype test results with the use of reference resistors set:

a) relative error of impedance modulus, b) absolute error of impedance argument, c) standard deviation of results.

The obtained errors are in the range of +/-1.5% in case of impedance modulus and in the range of +/-1° in case of the impedance argument. The standard deviation does not exceed 1% in case of the impedance modulus and 1° in case of the impedance argument. These parameters are satisfactory in case of the instuments to be used in the field or low-cost impedance analysers.

The measurement properties of the solution based on AD5933 chips were precisely investigated by the Authors of [17].

6. Conclusions

The paper presents scalable, easy to configure, measurement system designed for impedance measurement of multiple sensors, e.g gas sensors with impedance dependant on gas concentration. The system was realized in a form of a virtual instrument controlled by dedicated PC software implementing the presented measurement algorithm allowing multiple measurements performed at the same time (in the parallel) thus allowing shortening of the measurement process. The hardware part of the system consists of a number of independent, single-board impedance analysers working in parallel. The basics of the analyser architecture were presented in previous works [17]. The analysers are connected using I2C bus, which can be controlled by PC software using MPSSE (Multi-Protocol Synchronous Serial Engine) technique and FT2232H chip with appropriate software drivers/libraries creating USB-to-I2C bridge. The analyser is based on two AD5933 SoCs which made possible simplification and miniaturisation of the measuring device.

Achieved miniaturisation, flexibility and scalability as well as a low price, give fair promise of wide usage of the instrument in research and practical use with gas sensors.

Acknowledgments

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