

Low-cost Multi-Channel Interface for Passive Resistive Sensors

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Abstract – The paper elaborates the design and implementation of a low-cost multichannel interface for passive resistive sensors. The interface is based on a multivibrator in a monostable configuration and is suitable for direct interface to a programmable devices (e.g. microcontrollers, field programmable gate arrays, etc.). In the paper, details concerning the sensor interface are presented, and different calibration techniques are described. The theoretical analysis are supported by a practical implementation.

Keywords – multivibrator, sensor interface, passive sensors, multi-electrode sensors

I. INTRODUCTION

Very often there is a need for measurement of a lot of physical quantities by a single data acquisition system, such as when performing a sensor fusion. These systems, must have multiple input channels in order to interface all of the sensors. Regarding the application, the implementation of the systems are ranging from individual sensor signal conditioning and separate analog-to-digital (AD) or time-to-digital (TD) conversion for each channel, to sensor multiplexing and interfacing with only one input channel. However, quite often, the overall performances of the system, its size, and cost, relies on the implementation of the sensor signal conditioning module.

Multi-channel sensor interfaces are used in many applications: in multi-electrode sensor systems [1], sensor data fusion [2], [3], multi-sensor systems regulated in standards [4], etc. Generally, the sensor interfaces can be divided in two groups: ones based on AD conversion that utilize analog-to-digital converters (ADC), and other based on relaxation oscillators (multivibrators) and time-to-digital (TD) or frequency-to-digital (FD) conversion. The second approach can be sometimes advantageous, especially when the sensors are directly interfaced to a digital programmable devices (such as microcontrollers). Microcontrollers usually include peripherals for accurate measurement of time events, which can be used for TD or FD sensor interfacing without the need of ADC.

II. MULTIVIBRATOR-BASED SENSOR SIGNAL CONDITIONING

Generally, a multivibrator is an oscillating electronic circuit with discrete signal output, which is rather suitable for direct digital interface. It can be configured in monostable or astable operation. When triggered by an external trigger pulse, the monostable multivibrator changes state and remains in this second state for an amount of time determined by the external RC components used. Once this time interval has passed, the monostable multivibrator return itself back to its original state awaiting a new trigger pulse. The result is output pulse, whose width is proportional to the RC time constant, arising each time the multivibrator is triggered. In astable operation, the multivibrator constantly switches between two states. The time duration of each stage is determined by the external RC network. This time, the multivibrator delivers a pulse train whose frequency, time interval, or duty cycle is determined by the RC network. The basic electrical circuits in monostable and astable operation are given in Fig 1.a and Fig 1.b respectively.

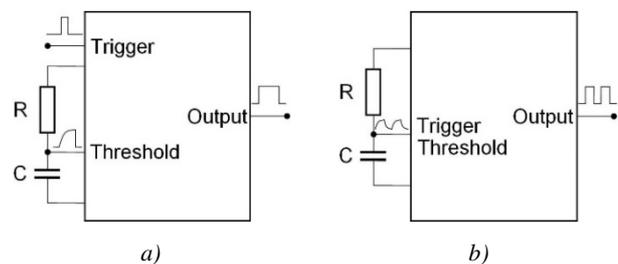


Fig.1 a) Monostable multivibrator, b) Astable multivibrator

When used as a passive sensor interface circuit, the sensor (resistive or capacitive) is placed in the multivibrator RC network, whereas the other remaining component (R or C) is fixed. Despite the fact that both circuits (monostable or astable) can be used as sensor signal conditioners, they have different metrological performances. Namely, the measurement uncertainty of such interface circuit is analyzed in [5], where it is proven that the standard deviation of the output pulse width (Type

A measurement uncertainty) of the monostable multivibrator is lower than that of the astable configuration. Therefore, the proposed signal conditioning circuit in this paper is based on the monostable multivibrator topology.

In monostable operation, the multivibrator generates a single output pulse whenever the trigger input has been triggered by an external pulse. In such case, the voltage across the external capacitor increases exponentially with time constant $\tau=RC$, where R is the value of the external resistor and C the value of the external capacitor. The waveforms of the characteristic signals during monostable operation are given in Fig. 2.

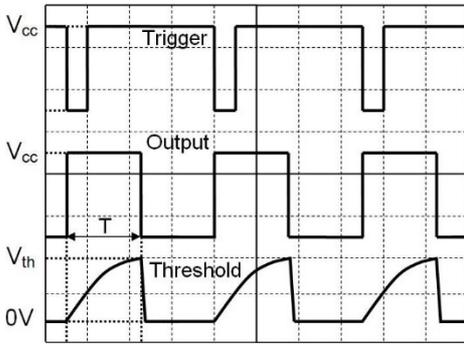


Fig. 2 Waveforms of the characteristic signals of a multivibrator in monostable configuration

The output pulse width of the monostable multivibrator T is given with:

$$T \propto kRC, \quad (1)$$

where, the constant k depends on the power supply voltage V_{cc} , and the threshold voltage V_{th} of the “threshold” port in Fig. 1.a. Hence, assuming that R in (1) is a resistive sensor, the output pulse width T is directly proportional to the sensor resistance. From the metrological point of view, the instability of k (and C when analyzing resistive sensor interface) in (1) is problematic. This is usually solved by calibration [6]. Another challenge is the ability to interface a larger number of sensors with less interface connections.

III. MULTICHANNEL SENSOR INTERFACE DESCRIPTION

One possible solution towards increasing the number of sensors in the multivibrator-based sensor interfaces, while keeping low number of interface connections to the programmable logic, is by time multiplexing. Such solution is given in Fig. 3, which allows interface of $n \times n$ passive resistive sensors, where n is the length of the ring counters 1 and 2. The ring counters change the state of their outputs D_1 to D_n on every clock (CLK) period. When the counter reaches the final state (D_n is “high”), it returns itself back to the initial position and generates a carry out bit (COUT). The carry out bit signal acts as a clock of the

ring counter 2. Therefore, the clock frequency of the ring counter 2 is n -times lower than the frequency of the ring counter 1. Even though there are commercially available integrated solutions of a ring counters, a discrete implementation with D flip-flops is given in Fig. 4. The sensors are wired to the ring counters through MOSFET transistors forming a sensor matrix, where the ring counter 1 activates the rows and the ring counter 2 activates the columns of the matrix. In a given moment, only a single sensor in the intersection row-column point is brought at the input of the monostable multivibrator. An example of a simple monostable multivibrator is given in Fig. 5. After “selection” of the sensor, the time constant of the multivibrator is determined by the sensor resistance R_x and the fixed capacitor C . In this way, a consecutive sensor read-out is performed in a form of pulse train on the output of the multivibrator. It is important to note that, in this solution, the speed of the measurements decrease proportionally with the number of sensors in the matrix. However, having in mind the speed of the actual digital programmable devices, time multiplexing is often acceptable, especially when measuring a slow-varying physical quantities (such as temperature or humidity).

When particular resistive sensor is selected with the switching matrix, and the monostable multivibrator is triggered, the output pulse width is given with:

$$T_x = -(R_x + 2R_{dsON})C \ln \left(1 - \frac{V_{th}}{V_{cc}} \right), \quad (2)$$

where R_{dsON} is the drain-to-source ON resistance of the MOSFET transistors, considering that all transistors in the matrix are identical. In order to implement the simplest “single point” calibration, a second measurement through a fixed calibration resistor is performed. This time the output pulse width is given with:

$$T_c = -(R_c + 2R_{dsON})C \ln \left(1 - \frac{V_{th}}{V_{cc}} \right). \quad (3)$$

The sensor resistance is calculated by dividing (2) and (3), that is:

$$R_x \approx \frac{T_x}{T_c} (R_c + 2R_{dsON}) - 2R_{dsON}, \quad (4)$$

where R_c is the value of the calibration resistor. By considering the following approximations: $R_x \gg 2R_{dsON}$ and $R_c \gg 2R_{dsON}$, (4) becomes:

$$R_x \approx \frac{T_x}{T_c} R_c \quad (5)$$

It is clear that (4) suggests errors in a form of offset and gain in the transfer characteristics. However, these errors can be reduced by implementing a two point calibration [6], or the three signals method [7].

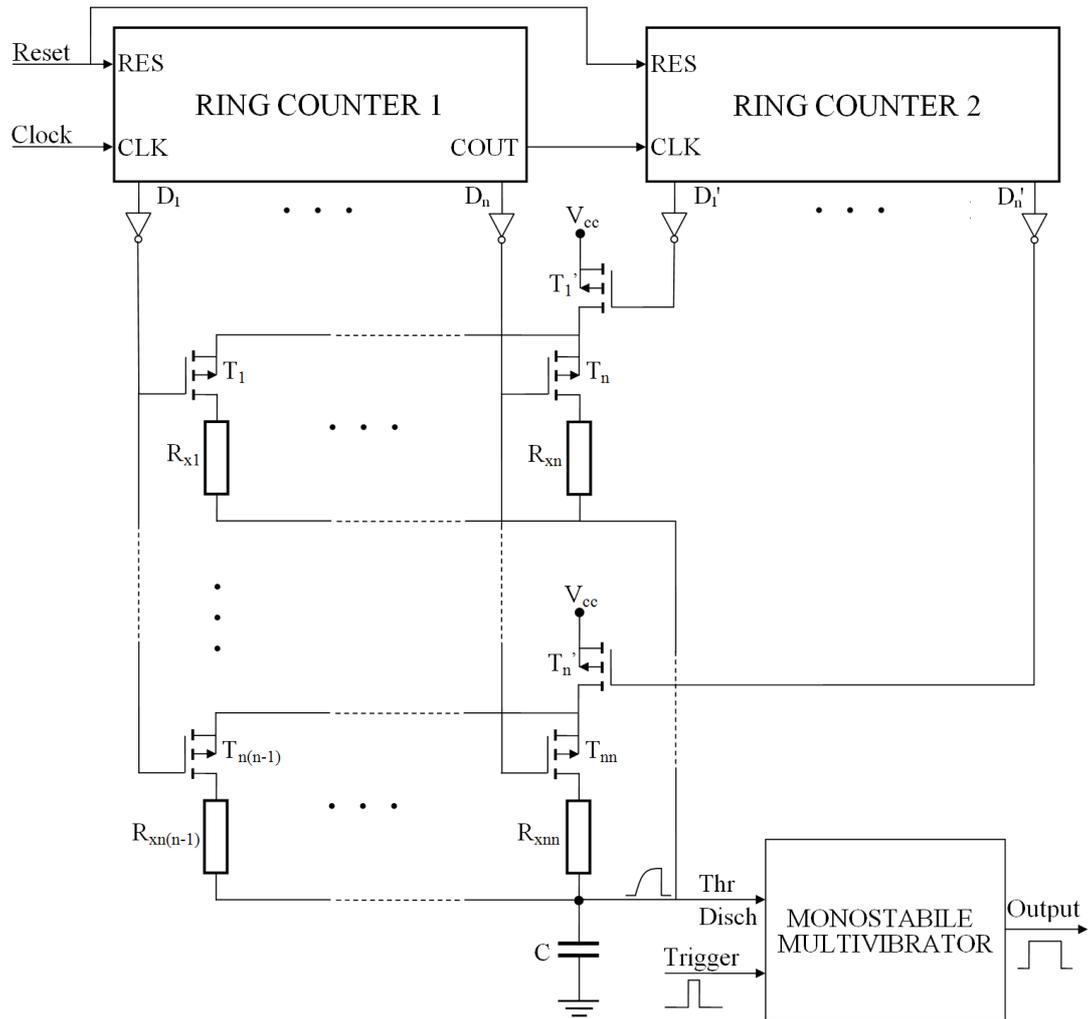


Fig. 3 Multivibrator-based multi-channel resistive sensor interface circuit

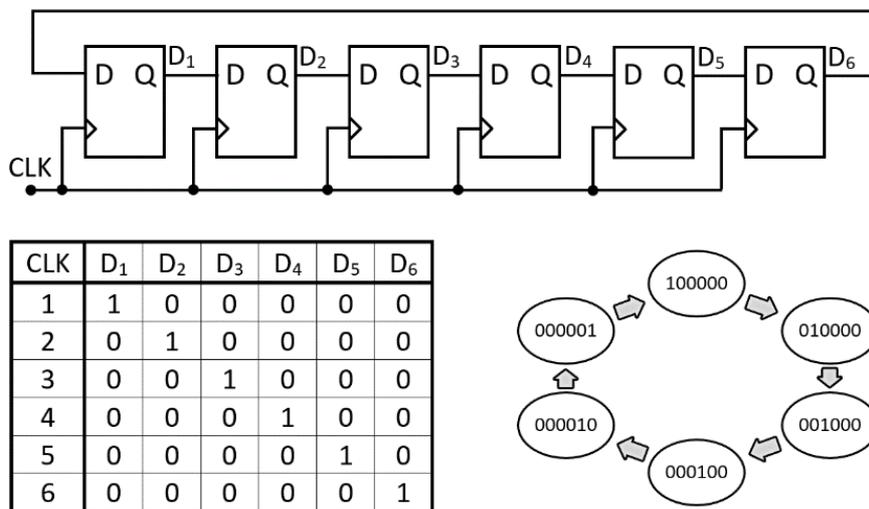


Fig. 4 State diagram and implementation of a six bit ring counter with D Flip-flops

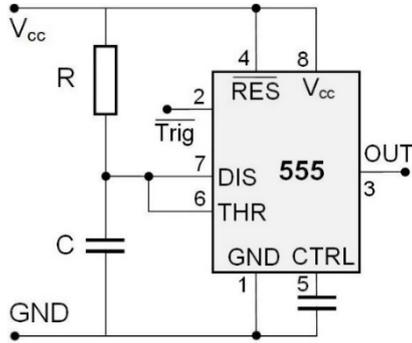


Fig. 5 Example of a simple monostable multivibrator based on the 555 circuit

The two point calibration is performed in three phases: measurement of the sensor resistance R_x , measurement of the first calibration resistor R_{c1} , and measurement of the second calibration resistor R_{c2} . The measured time intervals in the three measurement phases will be T_x , T_{c1} and T_{c2} respectively (which can be expressed similarly as (2) and (3)). According the two point calibration, the sensor resistance can be estimated by using a two point linear approximation given with:

$$R_x = \frac{T_x - T_{c2}}{T_{c1} - T_{c2}} (R_{c1} - R_{c2}) + R_{c2} \quad (6)$$

This time the offset in the measurements will not be in the order of the drain-to-source ON resistance (as with the single point calibration), rather of its mismatch between different MOSFET transistors.

Three signals method can be considered as a special case of two point calibration where the second calibration resistor is zero. Respectively, the equation (6) becomes:

$$R_x = \frac{T_x - T_{c2}}{T_{c1} - T_{c2}} R_{c1} \quad (7)$$

However, in order to implement the three signals method it is necessary to use a current protection resistor in all measurement phases (resistor in series to C in Fig. 3). In general, the three signals method is more accurate than the single point calibration, but it is more cost effective than the two point calibration.

IV. EXPERIMENTAL IMPLEMENTATION

To support the theoretical analysis, a prototype multichannel resistive sensor interface (Fig. 6) and virtual instrument for sensor read-out (Fig. 7) was designed. The prototype system was realized by using the timer NE555P from Texas Instruments wired in a

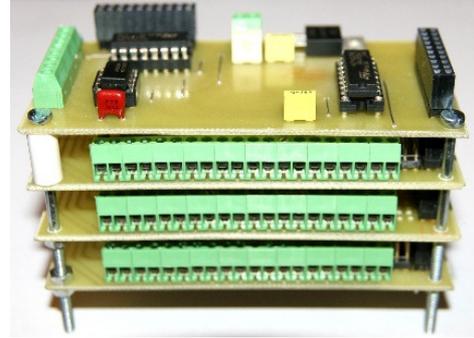


Fig. 6. Prototype thirty channel resistive sensor interface

monostable multivibrator configuration. Low drain-source on-resistance MOSFET transistors BS250D for all transistors in the switching matrix were used. The boards were supplied from a “clean” 9 V battery with LM78L05 positive voltage stabilizer to obtain 5 V. As recommended from the manufacturer, a 1 μ F electrolytic and 100 nF ceramic capacitor was placed between the 555 power supply pins. The ring counters were realized with integrated HCF4017 10-bit decade counters. In the current implementation, the resolution of the ring counters allow theoretical interface of 100 resistive sensors, which are modularly connected in the groups of ten (Fig. 6). The output pulse period was measured with a data acquisition card USB6218 from National Instruments connected to a PC in a LabVIEW environment. The DAQ card contains two 32 bit timers/counters with selectable time base and two 8-bit digital input/output ports. The time base of the timers was 20 MHz with 50 ppm accuracy. The digital output pins P1.0, P1.1, and P1.2 were used as drivers (“Clock”, “Reset”, and “Trigger” pins).

The experiments were performed by interfacing six NTC temperature sensors with nominal resistance of 2000 Ω , one NTC temperature sensor with nominal resistance of 10 k Ω , and two resistors with nominal values of 1 k Ω and 10 k Ω (variable). The 1 k Ω resistor was used for calibration. The transfer characteristic of the interface circuit was measured in the range from 1000 Ω to 15 k Ω in ten discrete steps (by using the variable resistor). The maximal relative error recorded was 0.43%, which is satisfactory considering the simplicity of the signal conditioning circuit. However, the metrological performances can be improved even more, by using a lower drain-to-source resistance MOSFET transistors, or by implementing a two point calibration, or a three signals method.

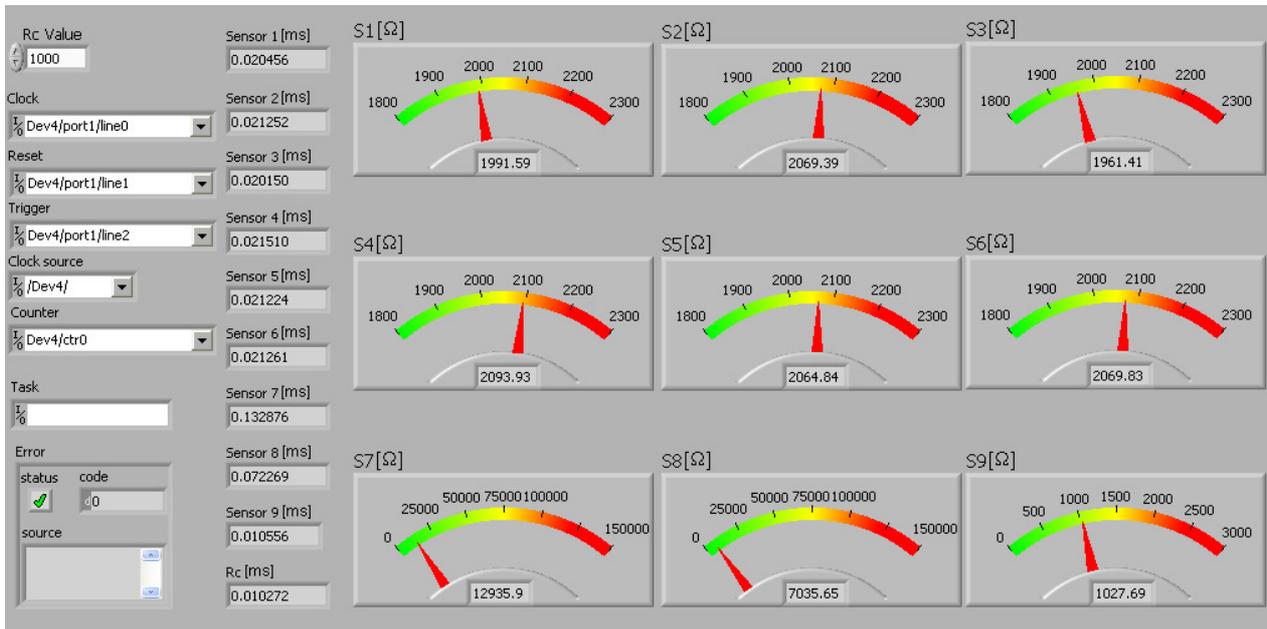


Fig. 7. Realization of virtual instrument in LabVIEW for read-out of nine resistive sensors

V. CONCLUSIONS

In the paper, a multi-channel interface for passive resistive sensors was proposed. The sensor interface incorporates a multivibrator in monostable configuration, and sensor multiplexer implemented with ring counters and a MOSFET switching matrix. The implementation of three calibration techniques was described: single point calibration, two point calibration, and three signals method. The theoretical analysis were supported by practical realization of a prototype multichannel measurement system. The experimental results showed that, when implementing a sensor interface for nine resistive temperature sensors in the range from 1 k Ω to 15 k Ω , and by implementation of the simplest “single point” calibration, a maximal relative error of 0.43% was achieved. The performances of the signal conditioning circuit can be improved by using a two point calibration or three signals method.

Authors believe that such sensor interface is advantageous for a low-cost, small size, and a medium accuracy implementations.

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