SENSORS INTERFACING USING FPAA

Peter Ivanov Yakimov, Emil Dimitrov Manolov

Department of Electronics, Technical University - Sofia, 8 Kliment Ohridski bul., 1000 Sofia, Bulgaria, phone: +359 2 32 65, e-mail: pij@tu-sofia.bg

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Sensors are the essential parts of the measuring devices. They convert the non-electrical quantity into electrical signal - voltage, current, frequency, resistance. Sensors interfacing requires analog circuits for amplifying and normalizing the signal in order to improve the accuracy. In addition attention should be paid to the linearization of the transfer characteristic of the sensor. The paper presents design and investigation of universal sensor interface as integrated analog IP core using the FPAAs of Anadigm®. Because they are programmable and reconfigurable, just one device can provide multiple sensors conditioning circuits under the real-time control of a digital microprocessor. Sensor signal linearization, offset compensation, calibration and signal modulation circuits can easily be implemented on a drift-free integrated silicon platform.

1. INTRODUCTION

The measurement of non-electrical quantities (temperature, pressure, humidity, etc.) has an important meaning in the industry, medicine, ecology and other fields of the real life. Sensors are the essential parts of the measuring devices. They convert the non-electrical quantity into electrical signal - voltage, current, frequency, resistance. Sensors interfacing requires analog circuits for amplifying and normalizing the signal fitting the measuring range. In addition attention should be paid to the linearization of the transfer characteristic of the sensor.

The common used schemes for sensors interfacing include operational amplifiers, voltage references and passive components. To obtain better accuracy all components should have temperature independence. Adjusting the gain and all other parameters of the circuit requires replacing the component with another one with different value or using components with variable values. Unfortunately all components change the values of their parameters with aging.

A possible approach for solving the problem with sensors interfacing is the using of Field Programmable Analog Arrays (FPAA). They are one of the most contemporary and perspective products for fast and flexible implementation of different circuit and devices. Essentially, FPAAs are the analog equivalent of well-known digital Field Programmable Gate Arrays (FPGA). Some of the most popular FPAAs are the chips of Anadigm Inc. They are integrated circuits that possess the possibility of programming and dynamic reconfiguration of different analog and mixed-mode functions in one chip. These very advanced products offer an attractive way of reducing cost, size and complexity of electronic circuits. The analog circuits based on FPAA can perform multiple functions, adjust to different environmental conditions, or compensate for equipment aging [1].

2. SENSORS INTERFACING CIRCUITS

Usually the transfer characteristic of most of the sensors is non-linear (fig. 1). Another disadvantage is the narrow dynamic range of the changes of the electrical signal, caused by the change of the non-electrical quantity. The principles of measurement for achieving high resolution require the value of the input quantity to be near to the upper limit of the measuring range [2]. It is defined by the range of the reference voltage of the used analog-to-digital converter.

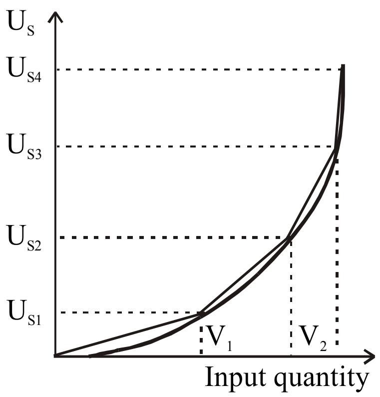

Fig. 1. Sensor characteristic

Fig. 1 shows splitting the sensor characteristic into sub-ranges. A piece-wise approximation is used for achieving better accuracy. Every sub-range is defined by lower and upper limit.

A possible circuit for resistive sensor interfacing is shown on fig. 2. This circuit assures amplification of the sensor output voltage U_S, subtraction the lower limit of the sub-range and normalization of the output voltage U_o, fitting the range of the analog-to-digital converter. The circuit comprises two operational amplifiers A_1 and A_2, summing stage Σ, reference voltage U_{ref} and sensor excitation voltage U_{exc}. The sensor output voltage U_S is amplified by A_1. The summing stage forms the difference U_2 between U_1 and U_{ref}.

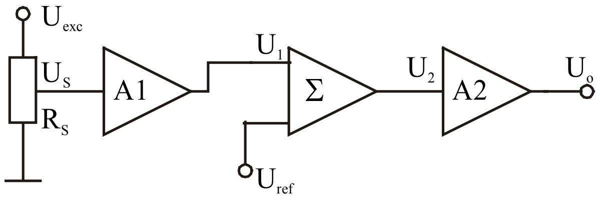

Fig. 2. Sensors interfacing circuit

The value of U_{ref} defines the lower limit of the measuring range. The output voltage of the summing stage U_2 is amplified by A_2 in order to fit the range of the analog-to-digital converter. The calculations of the circuit parameters may be done in the following way. For example, if the input non-electric quantity changes between values V_1 and V_2, the sensor output voltage will be in the range with limits U_{S1} and U_{S2}. Then the transfer functions of the stages will be as follows:

(1) $$U_1 = U_S G_1$$

(2) $$U_2 = U_1 - U_{ref}$$

(3) $$U_o = U_2 G_2$$

G_1 and G_2 are the gains of the amplifiers A_1 and A_2. To obtain a maximum wide measuring range the value of U_{ref} must be:

(4) $$U_{ref} = U_{S1} G_1$$

The values of G_1 and G_2 have to be chosen that if $U_S = U_{S2}$, non-linearity should not occur at A_1 output and U_o should not exceed the range U_{max} of the used analog-to-digital converter. Thus the lower limit U_{S1} and the upper limit U_{S2} of the range can be defined:

(5) $$U_{S1} = \frac{U_{ref}}{G_1} \Rightarrow G_1 = \frac{U_{ref}}{U_{S1}}$$

(6) $$U_{S2} = \frac{U_{max} + U_{ref}}{G_1 G_2} \Rightarrow G_2 = \frac{U_{max} U_{S1}}{U_{ref}\left(U_{S2} - U_{S1}\right)}$$

For the concrete application the values of U_{ref} and U_{max} are defined and depend on the used components. So, in order to calculate the circuit that when $U_S = U_{S1}$, the output voltage must be $U_o = 0$, and for $U_S = U_{S2}$ - $U_o = U_{max}$ is only necessary to determine the values of G_1 and G_2 by using equations (5) and (6).

Calculated following the equations mentioned above, the circuit will operate only in the specified range. If the range has to be changed or the operation has to be performed in more sub-ranges with the same accuracy, the circuit has to be multiplied as much times as the sub-ranges are.

This problem can be solved by using dynamically re-programmable circuits like Field Programmable Analog Arrays (FPAA) [3].

3. FPAA BASED SENSOR INTERFACING CIRCUIT

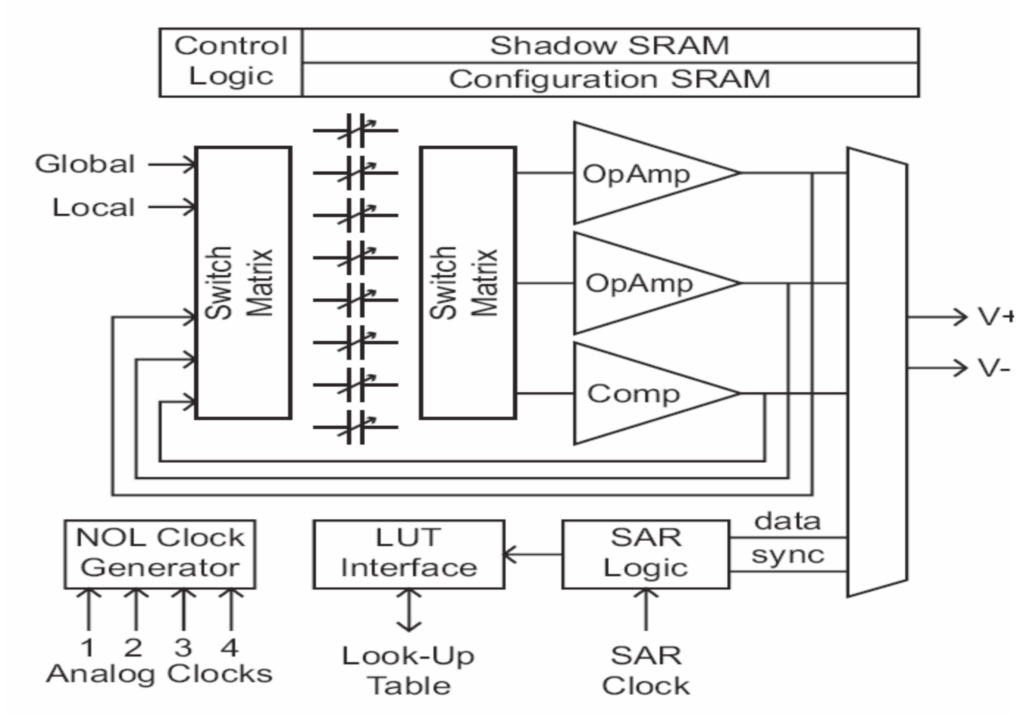

Fig. 3. Block diagram of configurable analog block (CAB)

As the physical platform the FPAA architecture is built on the natural precision, generic form, and switching fabric of a CMOS-based switched-capacitor (SC) network. Different types of analog circuits like amplifiers, sample-and-hold circuits, integrators, differentiators, filters, etc. are available as library components – Configurable Analog Modules (CAM). They consist of configurable analog blocks (CAB) and SRAM. Fig. 3 shows the block diagram of a configurable analog block. There is a bank of 8 programmable capacitors. Each of these 8 capacitors is actually a very large bank of very small but equally sized capacitors. Each of these 8 programmable capacitors can take on a relative value between 0 and 255 units of capacitance. The configuration data is stored in SRAM based configuration memory distributed throughout the FPAA. There are two SRAM memories on the chip: Shadow SRAM and Configuration SRAM. Configuration data is first loaded into Shadow SRAM, and then on a single user-controllable clock edge, is loaded into Configuration SRAM. The device's analog functionality behaves according to the data in Configuration SRAM. This method allows configuration data to be loaded into the device in the background and take effect instantly when required.

Changing the configuration data, stored in the memory, the functionality or parameters of the CAMs can be controlled. Within the device, there are four Configurable Analog Blocks (CABs). The functions available in the CAM library are mapped onto these programmable analog circuits.

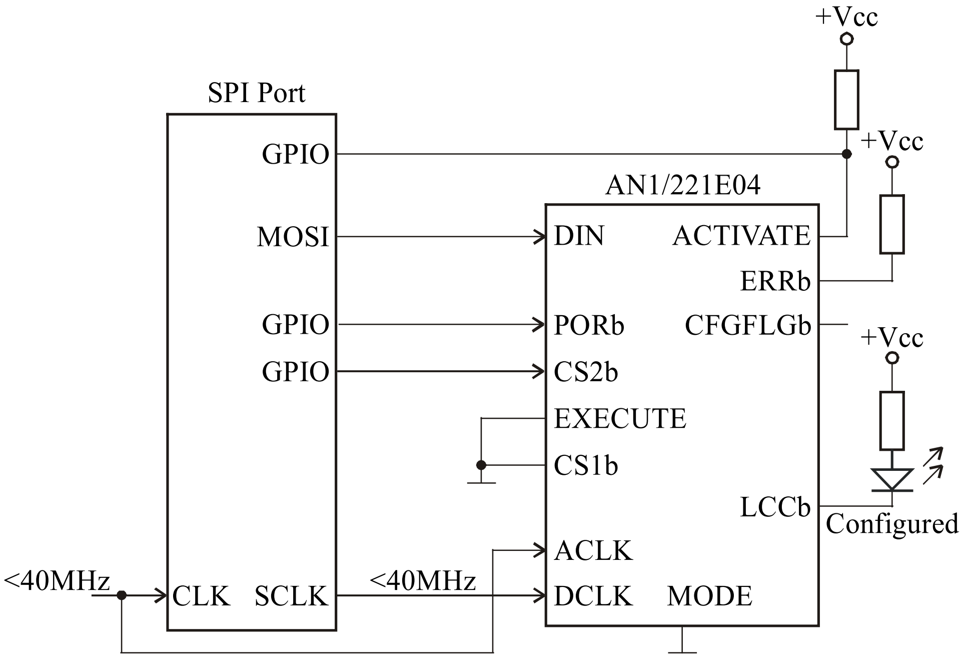

Fig. 4. A typical SPI connection between microcontroller and FPAA

In applications demanding on-the-fly adjustments to the analog circuitry, there will be a host microprocessor available to: perform the calculation of new circuit values, assemble these new values into a configuration data block and transfer that data block into the FPAA. The device's flexible configuration interface is designed to accept input from either serial memories or any of three major microprocessor interface types: Synchronous Serial Interface (SSI), Serial Peripheral Interface (SPI), or a conventional external peripheral bus interface. Fig. 4 shows a system comprising FPAA and a microcontroller connected by SPI interface.

Fig. 5 shows FPAA implementation of temperature sensor (*Pt100*) interfacing circuit. The design of the circuit follows the structure shown on Fig. 2. The excitation of the sensor is performed by excitation voltage and a reference resistor. The sensor output voltage (U_S) appears at pin 1. This voltage is amplified by 16 by the input amplifier. The output voltage of the amplifier is applied to the first input of the inverting summing stage. This stage has two inputs with independent setting of the gain for each of them. The second input of the summing stage is connected to the reference voltage source +3V. By adjusting the gain of the corresponding input the necessary value according (4) is achieved. Thus the lower limit of the measuring range is set. The output signal of the summing stage is applied to the input of the inverting amplifier with proper chosen gain in order to reach the upper limit of the measuring range. The output voltage (U_o) is obtained between pins 7 and 8. Because of that the maximum output voltage of the integrated circuit is 3V, U_o must not exceed this value. The circuit is designed by using specialized development software AnadigmDesigner2.

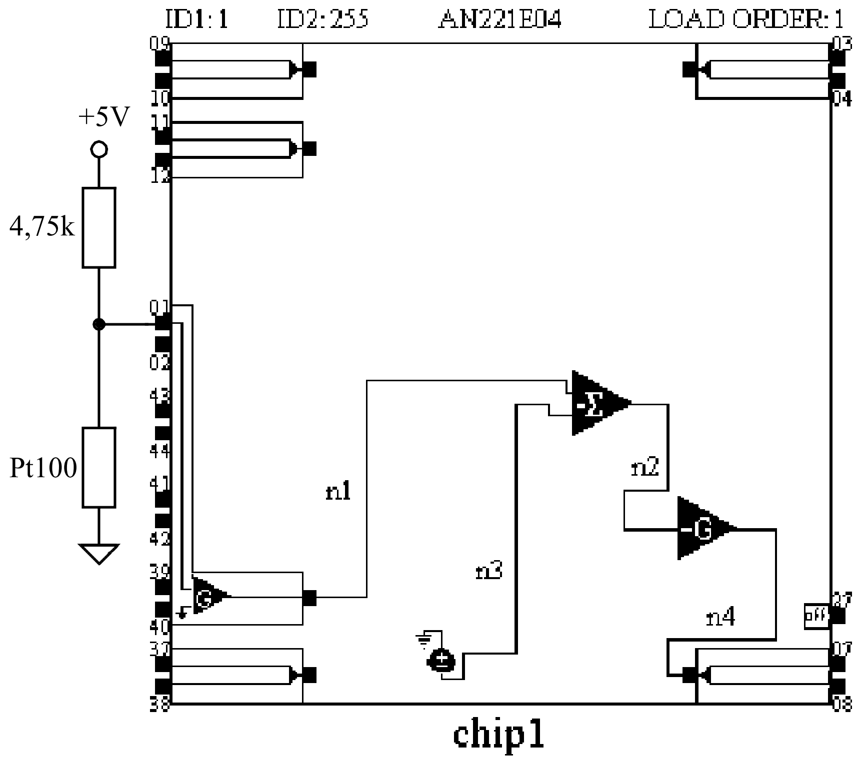

Fig. 5. Implementation of sensor interfacing circuit using FPAA

In order to change the sub-range is just necessary to change the gains of the amplifiers.

The temperature range chosen for the experiment is 0°C÷40°. So, the value of the sensor changes between 100Ω and 115,54Ω. Using excitation voltage +5V and reference resistor 4,75k, the lower limit U_{S1} is 0,10V and the upper limit U_{S2} is 0,12V. According (1)÷(6) U_{ref}=1,65V. The gains of the corresponding inputs of the summing stage have to be adjusted 1 and 0,55, and the gain of the inverting amplifier-12. In this case the output voltage U_o changes in the range 0V÷2,99V.

This approach may be used in the design of analog front-ends in automatic systems for measurement and control. In dynamic applications, the microcontroller must not only determine the appropriate configuration data but also transfer that data to the device using the specially defined protocol. Dynamic reconfiguration available on the AN221E04 device allows the microcontroller to send new configuration data to the FPAA while the old configuration is active and running. It is possible to develop innovative analog systems that can be updated (fully or partially) in real-time.

4. CONCLUSION

The paper proposes an implementation of universal sensor interface by using FPAA. To this aim, an analogy with classic circuits is used to determine the functional structure. On this base, FPAA circuit, which uses specific functional blocks from the library of the FPAA device, is synthesized. Because the used devices are programmable and reconfigurable, just one circuit can provide multiple sensors conditioning circuits under the real-time control of a microcontroller. Sensor signal linearization, offset compensation, calibration, and signal modulation circuits can easily be implemented as well.

5. REFERENCES

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