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# Prototype of multifunctional transmitter with Rejection of disturbances

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***Abstract***

*The industrial instruments found in the different industrial processes allow supervisory and control actions to be carried out. These elements are usually composed of an electronic circuit, which varies according to the specifications given by the manufacturer. Another factor that influences the design of a circuit for elements of this type is cost, since, at a lower cost, electronic elements are susceptible to fail for reasons such as electric fields, motor interference or environmental conditions. This problem limits the operation of the instrument and reduces its useful life, which causes unnecessary stops of the automated processes increasing the cost of producing a product. Some partial solutions to this problem have been obtained by means of the implementation of additional circuits such as protections or filters, although the number of unexpected stops of the process is reduced, even this type of failures occur. This paper proposes an alternative solution to the problem through a low cost prototype, which has a mechanism for rejection of disturbances that increases the accuracy and precision of an instrument compared to the low-cost instrument technology developed so far.*

***Keywords****: paper measurement instrument, programmable system on chip, transducer, transmitter*



## 1. Introduction

The industrial-type instruments existing in the market emulate, by means of control systems, aspects that were normally carried out by a human being, such as measure, control or supervise. By incorporating these functions into the instruments, they have allowed the user and the process to interact automatically [1, 2]. This feature facilitates the implementation of control or monitoring algorithms in programmable devices, for the automation and control of a process [3, 4]. However, some of these monitoring mechanisms do not have an electronic system that allows them to reduce the effect of environmental or process conditions during their operation, increasing the margin of error between the measured value and the real value or causing emergency stops of the process [5-7].

There are some solutions to the mentioned problem, which increase the effectiveness in the measurement of the signal measured by the programmable device, by adding filtering or protection circuits to reduce the sources of error. When the sources of error are limited, it can be said that they are a constant of the process, which is controlled by incorporating adjustment strategies or coupling between stages in such a way that the recorded value is close to that of a calibration standard. However, this solution is not accessible to some researchers, since the cost of calibrating a device can be high. Furthermore, it does not solve the problem completely because ensuring that the equipment is calibrated and adjusted does not ensure that the effect of environmental conditions or the process on the instrument is reduced [8-10].

Another type of solution to this problem has been to develop signal processing mechanisms in digital devices, which have made it possible to increase the accuracy and precision of the measurement by means of algorithms for the improvement and reconstruction of an analogous signal. However, this type of algorithm is limited, since they do not have a general application if not a different one for each case. That is, the algorithm is customized for each industrial process, which limits its applicability in different environments to academic spaces [11-13]. On the other hand, there are approximate mathematical models to model variables, in order to find sets of parameters that allow an instrument to adapt to the process

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and reduce the margin of error. Some of the typical elements that are modeled are motors, valves and pumps. However, the theoretical implementations in the industry are insufficient, because the vast majority of environmental effects are eliminated from the analytical models to obtain a response in the simulator; this feature reduces the reliability of simulators when applied in industrial environments, limiting the number of possibilities that manufacturers have to determine the quality of their product [11, 14].

Finally, there are empirical approximation methods, which work properly in first and second order systems, for example tank systems and passive electrical circuits [14]. However, there are none for higher order systems such as engines and conveyor belts. This paper presents a partial solution to the limitations found in industrial instruments, by means of a prototype that incorporates an active mechanism of rejection of disturbances. These characteristics are structured in the following way: In sections 2 and 3 the basic scheme of the transducer is defined. Section 4 shows the results obtained when measuring with the proposed prototype.

## 2. Methodology

In an industrial process there are different types of sensors, which allow the control device to construct a representation of the environment by means of numerical approximations, to modify the value of a variable. The sensors can have transducers, which are responsible for converting the observed value of the variable to an industrial type [9, 11], sometimes, this conversion is made by a linear adjustment equation, which is developed using specialized electronic circuits such as microcontrollers, memories or processors; among them, the PSoC (Programmable System on Chip) has an advantage that allows it to adapt to several possible environments, since, the architecture of this type of microcontroller can be adjusted depending on the task to be performed [15].

The adjustment equation is usually found using the least squares technique. This technique consists of performing an analysis of sets of ordered pairs of data (independent variable vs. dependent variable) and by means of a group of functions it is tried to determine the continuous function that best approximates the given data set. The difference between the function found and the measured data is estimated by applying the minimum squared error criterion, that is, when comparing the estimated values using the function and the real ones, it is tried to minimize the difference squared between them [16].

However, a variable that is not taken into account when estimating an adjustment equation is usually the noise of the variable to be measured or the location of the instrument [16]. This variable increases the margin of error of the value detected by the instrument. To reduce the effect of environmental conditions during the operation of an instrument, filters tuned to different frequencies that vary depending on the output of the developed circuit are usually used. The location of the filters changes depending on the source that propagates the error, since in some cases it can be used to eliminate harmonics from the electrical network or the high frequency radio signals that are mixed with the sensor output of the variable to measure [17]. Once the source of error propagation is eliminated or reduced, the signal or the value of the measured variable is sent to a control or display device. This value is sent using a signal or standardized protocol of industrial type, to avoid loss of information. Among the most used industrial communication protocols or signals are; transmitters from (4) to (20) milliamps (mA), MODBUS [18, 19], CAN [20-23] or PROFIBUS [24]. Normally these protocols are implemented using the physical layer RS-485, since it is versatile enough to allow the connection of at least thirty (30) devices in the network without even presenting failures.

The specialized devices that are responsible for transmitting the value of the sensor to a control device is known as a transmitter and unlike a transducer, the transmitter allows the measured value to go from one point to another covering a distance much greater than the transducer can provide. However, there are transmitters that incorporate transducers within their electronic control circuit and can only measure one type of variable, such as temperature transmitters [1]. Due to the large number of mathematical operations that these types of instruments must perform, they have a single channel and are programmed to determine the temperature value with a single type of sensor. If a sensor other than the one determined by default is connected, the transmitter does not guarantee proper operation.

## 3. Implementation

The proposed prototype consists of adding a mechanism to eliminate signals with frequencies above 50Hz, which allows selecting between three (3) different sensors to determine the value of the magnitude to be measured. In this case, three different sensors are being used to determine the temperature value, which are: a 10kΩ thermistor, a RTD PT100 and a thermocouple type K. These were coupled to a transducer manufactured with a PSLO 5LP, which varies an output signal according to the behavior of the sensor. This signal can be mixed with another, which is used to emulate the possible disturbances that occur in an industrial environment and that can modify the value of a sensor. Finally, the filtered signal is connected to a transmitter that allows observing the temperature value using a standard industrial protocol, see Figure 1.

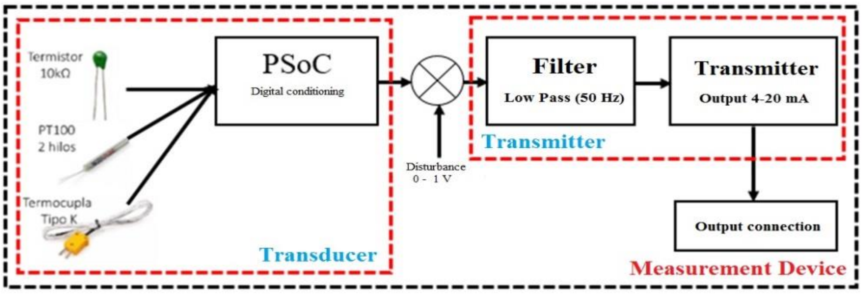



Figure 1. Block diagram of the proposed solution

Figure 2 shows the connections of the components used to implement the transducer. Each of the sensors has an adjustment equation to estimate the temperature value. The function of the thermocouple is a table in which the output value can be estimated according to the voltage measured at its terminals. The thermistor function calculates the value of the resistance according to the value present in a reference resistance, and then this value allows determining the temperature using an exponential regression equation whose coefficients are provided by the PSoC 5LP. The function of the RTD works in the same way as the thermistor, however, it uses the equation of adjustment shown in the IEC 60571 standard.

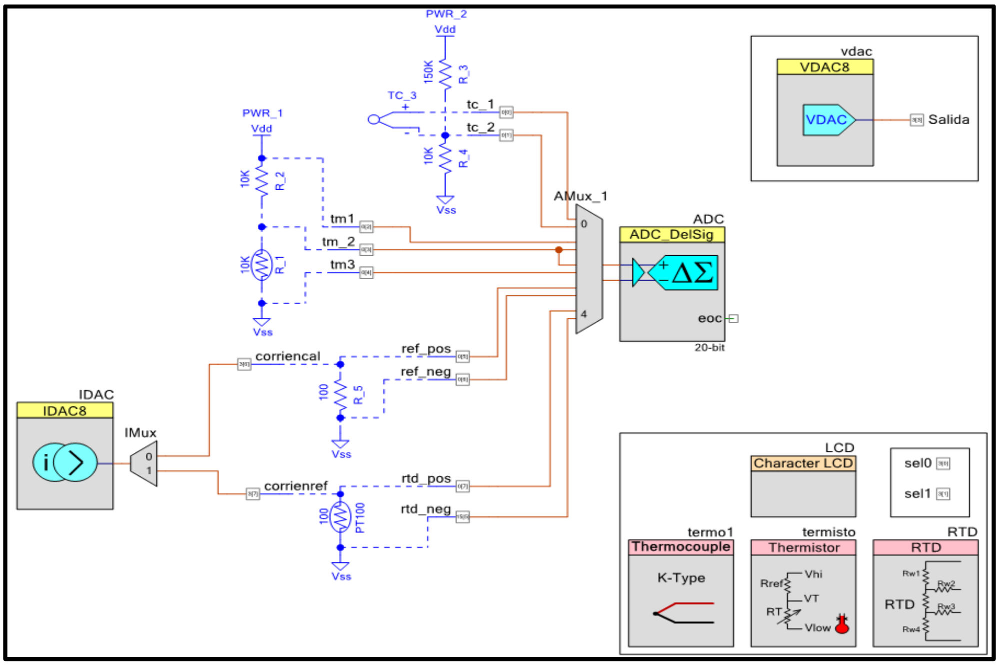



Figure 2. Connection diagram

The transmitter has a selector that allows exchanging the reading sensor and the DAC (Digital-Analog converter) generates a variable voltage signal that depends on the input value. This stage is connected to a low pass filter with Sallen Key topology [25] whose transfer function is shown in (1).

$$H(S) = \frac{9.87e04}{s^2 + 444.3\,s + 9.87e04} \quad (1)$$

Finally, the current transmitting circuit is composed by an array of operational amplifiers, see Figure 3. The first amplifier makes the signal in a range of 1 to 5V. Then, the second amplifier performs a pre-amplification of the output signal of the amplifier previous stage and finally a PNP transistor keeps the current stable.

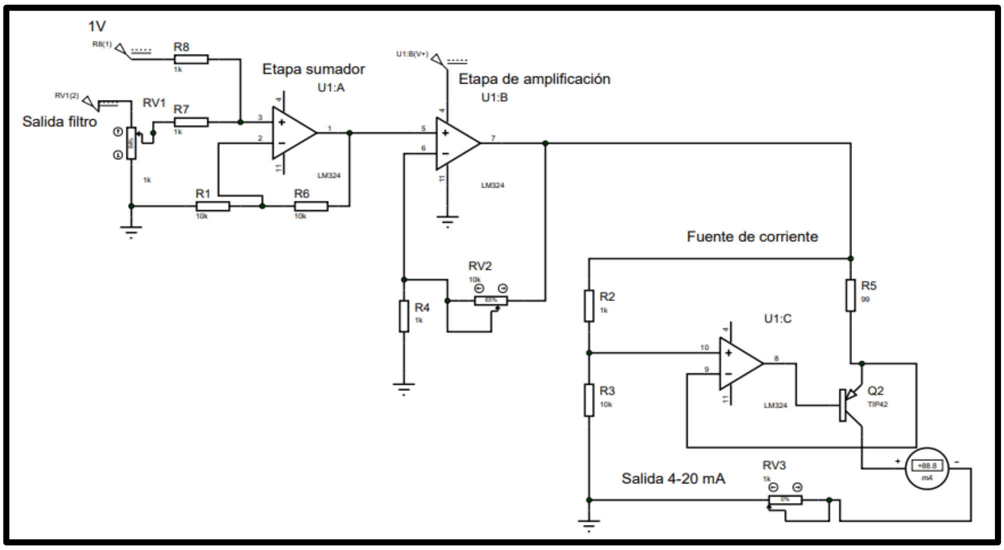
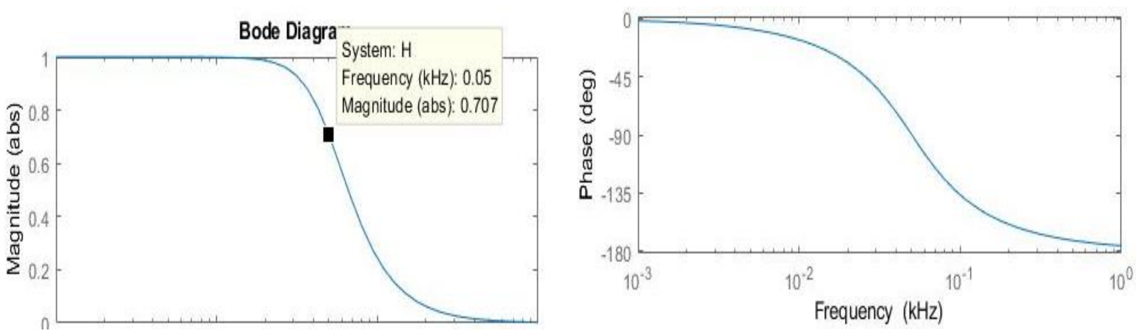



Figure. 3. 4-20 mA current transmitter

## 4. Results

Initially, the filter transfer function was simulated, where the cutoff frequencies were observed in a simulated and continuous manner, once the cut-off frequency was set at 50Hz, measurements were made to check the operation of the filter as shown in Figure 4 and Table 1. Finally, measurements were taken at the prototype output with different temperature values to verify the margin of error between the sensors. These values are presented in Table 2.




(a) (b)

Figure 4. Simulated filter behavior (a) magnitude response (b) phase response

Table 1. Frequency Sweep of the Filter Implemented
(The yellow line is the test signal and the blue line is the output signal)

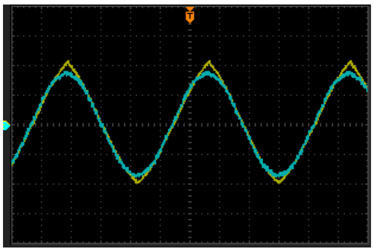
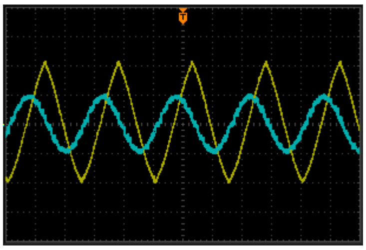
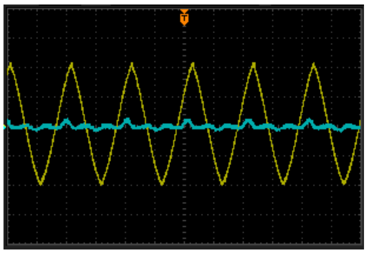
| 10Hz | 50Hz | 1kHz |
|---|---|---|
|  |  |  |

Table 2. Measurements

| PT100 | | THERMISTOR | | THERMOPAR | |
|---|---|---|---|---|---|
| Output (mA) | Temperature (°C) | Output (mA) | Temperature (°C) | Output (mA) | Temperature (°C) |
| 9.8 | 31 | 9.8 | 32.4 | 9.9 | 32 |
| 10.1 | 34 | 10.5 | 35 | 10 | 35 |
| 10.5 | 37 | 11 | 37 | 10.1 | 37 |
| 10.7 | 39 | 12.3 | 42.5 | 10.3 | 42 |
| 11.2 | 44.5 | 13.1 | 45.2 | 10.4 | 45 |
| 11.5 | 47 | 13.5 | 47.5 | 10.5 | 47 |
| 11.8 | 49.5 | 13.8 | 49 | 10.6 | 48.5 |

## 5. Conclusion

The verification of the operation of the three temperature sensors shows that the thermocouple is more sensitive to the temperature change than the other two sensors. That is, the time it takes to perform the temperature conversion is shorter compared to the thermistor and the RTD, since, their typical applications are different; normally the latter are used for measurement in environments or surfaces where the temperature is uniform. The linear adjustment that is made of each sensor and the relationship with the parameters of the ADC in each case is different, since the response of the transducer varies depending on the sensor. That is, the transmitter output does not reflect the exact temperature value due to the sensor's own behavior and because the sum of errors propagates from the input to the output. However, the disturbance rejection mechanism and the potentiometers allow reducing the margin of error with respect to a real calibration pattern. The coupling of impedances of the electronic circuits implemented in discrete, allows the system to process the digital signal of the transducer and reconstruct it to reduce information losses by eliminating the noise from the environment. Furthermore, that this filtering stage has an amplifier which allows maintaining the stable current level until the conversion is carried out by the transmitter.

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