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A Low Cost Resistive Sensor Interface Circuit and its Noise Model

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Abstract— Resistive based measurement principles and their applications in sensing technologies are widely used in industry and home automation. Resistive sensors apply a broad range of theories and phenomena from the fields of physics, material science, biology, electrochemistry, and electronics. Resistive sensors are the most commonly electronic component, module or subsystem whose purpose is to detect events or changes in their environment and send the information to other processing devices. In this paper, measurement of voltage from the sensing element through a resistive network is shown and different types of noise introduced in the circuit is also explained. Resistive sensors are the sensing elements which detect the changes in their resistance accordingly. The measurement of the physical quantity is quite difficult in current mode technique. Therefore the voltage mode conversion technique is being adopted to measure the physical quantities into variable resistance which is easily measured by the meters. The process of variation in resistance is widely used in the industrial applications. The resistive transducer can work both as the primary as well as the secondary transducer. The primary transducer changes the physical quantities into a mechanical signal, and secondary transducer directly transforms it into an electrical signal. Their applications span homeland security, industry, environment, space, traffic control, home automation, aviation, and medicine. Modern sensors are direct or indirect applications of the resistive sensing principles.

***Keywords*—**Resistive Sensor, Voltage Divider Network, Wheatstone Bridge Network, Noise

I. INTRODUCTION

Resistive sensors have assisted mankind in analyzing, controlling, and monitoring thousands of functions for over a century. Some milestones in the development of resistive sensors include the discovery of the Piezoresistive material since 1871[1]. The progress in micro and nano-machining technologies has significantly advanced traditional resistive transducers to a new level. High sensitivity, low power consumption, rapid response time, and miniaturization. Resistance and capacitance sensing principles can also be combined with other sensing technologies, such as ultrasonic, RF, CMOS, or fiber-optics, to create more sophisticated and powerful hybrid sensors.

Resistive sensors are among the most common in electronics specially instrumentation. The simple resistive sensor is the potentiometer and other resistive sensors include strain gauges, thermocouples, photoresistors and thermistors. In this article, it has been shown in detail about voltage sensor as they provide good accuracy, higher signal-to noise ratio (SNR) with better stability [2], [3]. A voltage sensor can in fact determine, monitor and can measure the supply of voltage. It can measure AC level or/and DC voltage level. The input to the voltage sensor is the voltage itself and the output can be analog voltage signals, switches, audible signals, analog current level, frequency or even frequency modulated outputs. That is, some voltage sensors can provide sine or pulse trains as output and others can produce Amplitude Modulation, Pulse Width Modulation or Frequency Modulation outputs[4], [5]. In voltage sensors, the measurement is based on the voltage divider [6]. Mainly two types are of voltage sensors are available- Capacitive type voltage sensor and Resistive type voltage sensor.

Section II of this brief describes the proposed circuit & its design related work, Numerical solution and experimental results are made in this Section. Section III describes the methodology for noise and noise equations. Results and Discussions are made in Section IV. Conclusion of research work with future directions is given in Section V.

II. RELATED WORK

Resistive sensors are used to monitor physical or chemical parameters that can induce a change in electrical circuits. The magnitude of the physical or chemical parameter, such as light, strain, voltage, magnetic field, or gas/liquid concentration, can be inferred from the measured resistance value. The value of resistance can be measured by the following methods: 1. Voltage dividers and 2. Wheatstone bridge. The mechanism of measurement is explained in this paper.

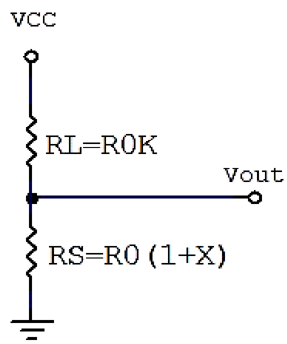

Figure 1. Voltage divider network

This circuit is able to measure the fractional change in resistance x of the sensor:

PΣ=P0(1+Ξ) (1)

R0 is the sensor resistance in the absence of stimuli. Load resistor expressed as RL=R0k. For convenience the output voltage of the circuit is calculated as under

ςOYT= ςXX PΣ/(PΣ+PΛ)=ςXX P0(1+Ξ)/[P0(1+Ξ)+P0K]

Oρ, ςOYT=ςXX (1+Ξ)/(1+Ξ+K) (2)

A. Resistive Voltage Network

There are two ways in converting the resistance of the sensing element to the voltage. First one is the simplest method that is to provide a voltage to the resistor divider circuit comprises of a sensor and a reference resistor which is represented below in Figure 2.

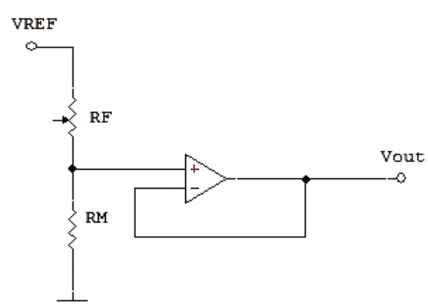

Figure 2. Resistive voltage sensor network

The voltage that is developed across the reference resistor or sensor is buffered and then given to the amplifier.

The output voltage of the sensor can be expressed as

ςOYT=ςPEΦPM/(PM+PΦ)] (3)

The sensitivity of the circuit can be calculated as under

$$S = \frac{dV_{out}}{dX} = \frac{d}{dX}V_{cc}\left(\frac{1+X}{1+X+K}\right)$$

$$= V_{cc}\frac{(1+X+K)-(1+X)}{(1+X+K)^2}$$

$$= V_{cc}\frac{K}{(1+X+K)^2} \quad (4)$$

The drawback of this circuit is, the amplifier present here will amplify the whole voltage developed across the sensor. But, it is better to amplify only the voltage change due to the change in resistance of the sensor. This is achieved by the second method implementing the resistance bridge which is shown below.

B. Wheatstone Bridge Network

A circuit that consists of two divider network called a reference voltage divider and another sensor voltage divider.

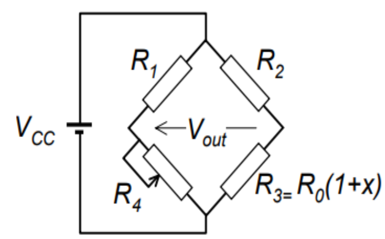

Figure 3. Wheatstone bridge sensor network

In this circuit R4 is adjusted until the balance condition is met.

ςουτ=0 ορ, P3=P4P2/P1 (5)

The unbalanced voltage Vout is used as the output voltage of the circuit in general condition in equation 6.

ςουτ=ςχχ[P3/(P2+P3)–P4/(P3+P4)] (6)

If we want to measure fractional resistance changes RS=R0(1+x), bridge is operating near the balance condition. And the condition is given by the equation 7.

K=P1/P4=P2/P0 (7)

The output voltage of the Wheatstone bridge becomes

$$V_{out} = V_{CC}\left(\frac{R_0(1+x)}{R_0k+R_0(1+x)} - \frac{R_4}{R_4k+R_4}\right)$$

$$= V_{CC}\left(\frac{(1+x)}{k+(1+x)} - \frac{1}{k+1}\right) = V_{CC}\frac{kx}{(1+k)(1+k+x)}$$

The sensitivity of the Wheatstone bridge circuit is calculated as under

$$S = \frac{dV_{out}}{dx} = V_{CC}\frac{d}{dx}\left(\frac{kx}{(1+k)(1+k+x)}\right)$$
$$= V_{CC}\frac{k(1+k)(1+k+x) - kx(1+k)}{(1+k)^2(1+k+x)^2}$$
$$= V_{CC}\frac{k}{(1+k+x)^2}$$

The voltage divider has a large DC offset compared to the voltage swing, which makes the curves look "flat" (zero sensitivity).

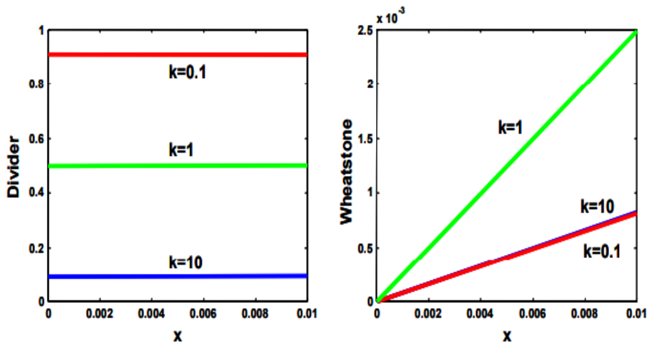

Figure 4. Comparison of sensitity between voltage divider and wheatstone bridge network

III. METHODOLOGY

In sensor network there are two basic classifications of noise; Inherent noise & Interference (transmitted) noise.

1. Inherent Noise: the signal, which is amplified and converted from a sensor into a digital form, should be regarded not just by its magnitude and spectral characteristics, but also in terms of a digital resolution. This noise can be produced by the monolithic amplifiers and other components, which are required for the feedback, biasing, bandwidth limiting, etc.

There are several sources of noise whose combined effect is represented by the noise voltage and current generators. One cause for noise is a discrete nature of electric current because current flow is made up of moving charges, and each charge carrier transports a definite value of charge. The mean-square value of noise voltage (which is representative of noise power) is generally calculated from;

$\varepsilon^2 = 4KTP\Delta\phi$ (8)

Where; k is Boltzmann constant, T is temperature in K; R is the resistance and Δf is the bandwidth over which the measurement is made. Even a simple resistor is a source of noise, a small resistors generate extremely small noise.

Noise voltage is proportional to square root of the bandwidth. It implies that if we reduce the bandwidth 100 times, noise voltage will be reduced by a factor of 10. Another type of noise results because of dc current flow in semiconductors. It is called shot noise, which is also white noise. Its value becomes higher with the increase in the bias current. This is the reason why in FET and CMOS semiconductors the current noise is quite small. A convenient equation for shot noise is;

$\iota\sigma\nu = 5.7\times10^{-4}\sqrt{(I\Delta F)}$ (9)

In the above equation I is a semiconductor junction current in pA and Δf is a bandwidth of interest in Hz.

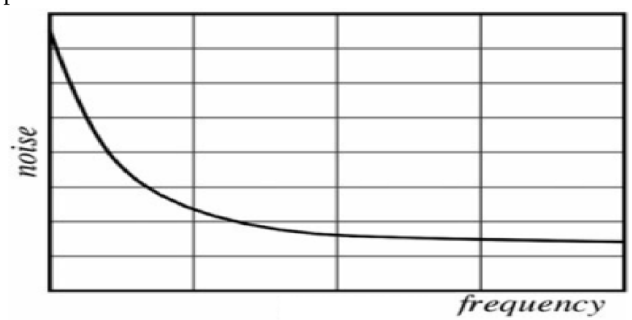

Figure 5. Graphical relation between noise and bandwidth

2. Interference (Transmitted) noise: Noise comes from a source, generally voltage surges in power lines, lightning, sun activity, change in ambient temperature, etc. which often cannot be identified is the Interference or Transmitted noise. These interferences propagate toward the sensor and the interface circuit, and to present a problem eventually must appear at the output.

They somehow must affect the sensing element inside the sensor, its output terminals or the electronic components in the circuit. Both the sensor and circuit act as receivers of the interferences.

Transmitted noise is classified, depending on how it affects the output signal, how it enters the sensor or circuit, etc.

With respect to its relation to the output signals, noise can be either additive or multiplicative.

Additive noise (e_n) is added to the useful signal (V_s) and mixed with it as a fully independent voltage (or current); the noise magnitude does not change when the actual signal changes. As long as the sensor and interface electronics can be considered linear, the additive noise magnitude is totally independent of the signal magnitude.

$\varsigma OYT = \varsigma\sigma + E\nu$ (10)

Multiplicative noise affects the sensor's transfer function or the circuit's nonlinear components in such a manner as V_s signal's value becomes altered or modulated by the noise:

$\varsigma OYT = [1 + N(\tau)]\varsigma\sigma$ (11)

Where, N(t) is a function of noise.

IV. RESULTS AND DISCUSSION

To improve noise stability against transmitted additive noise, sensors are combined in pairs; they are fabricated in a dual form whose output signals are subtracted from one another.

Since additive noise is specific for the linear or quasilinear sensors and circuits, the reference sensor does not have to be subjected to any particular stimulus.
Both sensors are subjected to identical transmitted noise (noise generated inside the sensor cannot be cancelled by a differential technique), it is a common-mode noise. This means that noisy effects at both sensors are in-phase and have the same magnitude. If both sensors are identically influenced by common mode spurious stimuli, the subtraction removes the noise component.
The quality of noise rejection is described by a number which is called the common-mode rejection ratio (CMRR):

$$XMPP=0.5\ [(\Sigma 1+\Sigma 0)/(\Sigma 1-\Sigma 0)] \quad (12)$$

The ratio shows how many times stronger the actual stimulus will be represented at the output, with respect to a common mode noise having the same magnitude.

V. CONCLUSION AND FUTURE SCOPE

The paper studies an interfacing circuit; Resistance to voltage conversion technique for differential operational principle to convert the change of resistance to direct voltage mode technique. And it also introduces the key technology of calculating noise and noise parameters. The noise shaping model and post processing filters can be studied and designed as Future Scope for improvement.

REFERENCES

[1] J. Fraden, “Handbook of Modern Sensors; Physics, Design, and Applications”, Fourth Edition, Springer Press 2010.
[2] S. Bhattacharyya, K.Chatterjee, S.N.Mahato, “A Dynamic Range Differential Capacitive Sensor Interface Circuit with Noise Shaping Model of Sigma-Delta Modulator”, International Conference on Signal Processing, Communication, Power and Embedded System (SCOPES), Year: 2016, IEEE Conference Proceedings, Issue-III, Pages: 296-299.
[3] K. Chatterjee, S. Chattopadhyay , S. N. Mahato and D. De, “A simple multi parameter measurement system using multi transducer,” 2015 International Conference on Energy, Power and Environment: Towards Sustainable Growth (ICEPE), Year: 2015, Pages: 1 - 4, DOI: 10.1109/EPETSG.2015.7510173.
[4] K. Chatterjee, S. N. Mahato, S. Bhattacharyya and D.De, “An interfacing circuit for differential capacitive sensor and its performance analysis,” 2015 International Conference on Energy, Power and Environment: Towards Sustainable Growth (ICEPE), Year: 2015, Pages: 1 - 3, DOI: 10.1109/EPETSG.2015.7510068.
[5] F. F. Mazda, 1987, Electronic instruments and measurement techniques, Cambridge Univ. Pr., New York.
[6] K. Chatterjee, S. N. Mahato, S. Chattopadhyay and D. De, “High accuracy mass measuring system using capacitive sensor,” Instruments and Experimental Techniques, Sept. 2014, vol. 57, Issue 5, pp. 627-630.

