A Low-Cost and Accurate Interface for Voltage-Generating Sensors

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***Abstract* — A low-cost and accurate interface for the grounded and floating voltage-generating sensors, based on the use of a microcontroller and a universal transducer interface, has been presented. The proposed interface acts as an asynchronous voltage-to-digital converter employing a Universal Transducer Interface (UTI), amplifiers, switches and a microcontroller. A prototype of the interface which can process grounded and floating voltage signals has been built and tested. The measurement results are presented.**

I. Introduction

Many interesting sensor interfaces have been presented in which the measurand is converted into a period-modulated output signal [1 – 5]. The advantage of this way of modulation is that powerful low-cost processing circuits, such as microcontrollers can directly process these signals without needing an extrinsic A/D converter. The combined features of such an interface and a microcontroller enable smart signal processing. Using the memory and processing facilities of the microcontroller many nonidealities of the interface can be eliminated or significantly reduced.

A Universal Transducer Interface (UTI) which has been presented in [6] has especially been designed to support passive sensing elements, such as capacitive, resistive and resistive-bridge sensing elements.

In this paper, we present a low-cost and accurate interface based on the use of the UTI, but modified in order to process also signal of grounded and floating voltage-generating sensors, such as thermocouples, thermopile signals.

II. Measurement Concepts

A. Three-signal technique

The three-signal technique is a technique to eliminate the effects of unknown offset and unknown gain in a linear system [7]. In order to apply this technique, in addition to the measurement of the sensor signal (in our case voltage), two reference signals are required to be measured in an identical way. Suppose the interface has a linear transfer function of

$$M_i = kE_i + M_{off}. \tag{1}$$

The measured three signals are

$$\begin{aligned} M_{off} &= M_{off} \\ M_{ref} &= kE_{ref} + M_{off} \\ M_x &= kE_x + M_{off} \end{aligned} . \tag{2}$$

Then the measuring result is the ratio

$$M = \frac{M_x - M_{off}}{M_{ref} - M_{off}} = \frac{E_x}{E_{ref}}. \tag{3}$$

When the interface is linear, then in this ratio the influence of the unknown offset M_{off} and the unknown gain k of the measurement system is eliminated.

According to the working principle of the three-signal technique, a memory is required to implement this technique.

In the UTI, the phases are automatically controlled and outputted by itself. As an example, Figure 1 shows the output signal of the UTI with a complete cycle consisting of three phases.

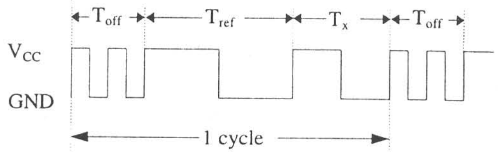

Figure 1. The output signal of the UTI for a 3-phase mode.

The three phases are time-multiplexed. The offset phase with two short intervals is also used as a synchronization signal for the microcontroller

B. Advanced chopping technique

In the UTI, the advanced chopping technique is used to suppress the interference signals at the input of the sensing element. For a common chopper, the signal is switched in a +,-,+,-,+,-, ... sequence, In the improved chopping technique [1], a +,-,-,+,+,-,-,+, ... sequence is applied. The sampling sequence results in a filter operation which is applied to the interference. The filter transfer function is given in the z-domain by:

$$1 - z^{-1} - z^{-2} + z^{-3}. \tag{4}$$

This equation can be transformed into an expression in the frequency domain. A second-order frequency behavior for low frequencies of the interference is obtained.

C. Asynchronous charge-balancing technique

Figure 2 shows a simplified front-end circuit diagram for the voltage signal measurement. The voltage signal V_x is sampled by the capacitor C_s and switches S_1 and S_2. The charge in the capacitor C_s, which value is proportional to the voltage V_x is dumped into the integrator. The integration of the current I_{int} with the comparator gives the charge-to-time conversion. Meanwhile, the control logic of switches S_1 and S_2 is synchronous with the output signal of the comparator.

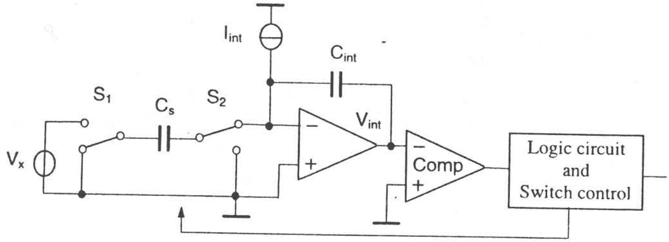

Figure 2 A simplified front-end circuit diagram for the voltage signal measurement.

III. Design of the Interface

The Universal Transducer Interface (UTI) is a sensor-signal-to-time converter, based on a period-modulated oscillator, which provides interfacing for the capacitive sensors, Platinum resistors, Thermistors, resistive bridges and potentiometers [6].

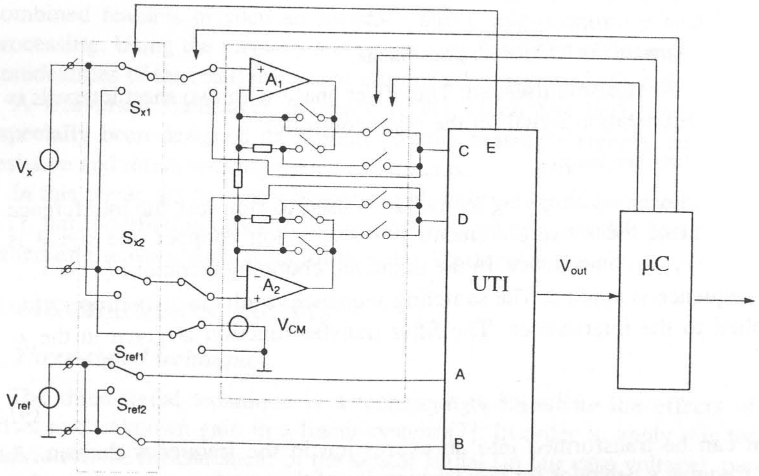

Figure 3 A schematic diagram for the measurement of the voltage signal by using the UTI.

Based on the use of the UTI, Figure 3 shows a schematic diagram of an interface for the measurement of grounded and floating voltage signals. In this circuit, V_x denotes an unknown voltage (measurand), V_{ref} is a known reference voltage. In this application, the mode 11 of the UTI is employed.

The interface acts as an asynchronous Voltage-to-Digital converter employing a UTI, amplifiers, switches and a microcontroller. The microcontroller is used to measure the output signal from the UTI, to process data, to control the switches and to output the measured sensor signal (voltage).

Amplifiers, A_1 and A_2, with few switches form a differential pre-amplifier for the floating voltage input.

Switches S_{x1}, S_{x2}, S_{ref1} and S_{ref2} form a chopping for the voltage signals V_x and V_{ref}. The chopping signal is offered by the UTI itself. As that described in above section, each signal is measured by four times in one cycle: $+V_x$, $-V_x$, $-V_x$, $+V_x$ and $+V_{ref}$, $-V_{ref}$, $-V_{ref}$, $+V_{ref}$. In such a measurement, the effects of many nonidealities, such as the low-frequency noise, temperature drift and the offset of the amplifiers, are eliminated.

As that described in Figure 1, the interface converts the voltage signal into the time period. Then the measured voltage is presented as:

$$V_m = \frac{T_x - T_{off}}{T_{ref} - T_{off}} V_{ref} \, . \tag{5}$$

The gain and offset parameters of the interface are eliminated by the use of the three-signal technique. The accuracy of the interface is only limited by the accuracy of the reference signal.

IV. MEASUREMENT RESULTS

A prototype has been implemented based on the circuit diagram shown in Figure 3. The switches were implemented with a simple quad bilateral switch (CD4066). A simple dual OPAMP (TLC272AC) with an offset of 5 mV (maximum value) was used for the pre-amplifier. The UTI is set to work as mode 11 with a oscillating frequency of about 20 kHz to 50 kHz, depending on the measurand. A microcontroller of the type INTEL D87C51FB with a 3 MHz counting frequency, is employed to measure the output period of the UTI, to process the data, to control the switches and to communicate with the PC. The interface is powered by a single 5 V supply voltage.

Experimental results show that the interface is able to measure grounded voltage in the range of 0 mV to 200 mV, with a resolution and linearity of 58×10^{-6} and 86×10^{-6}, respectively and to measure floating voltage in the range of -200 mV to +200 mV, with a resolution and linearity of 65×10^{-6} and 105×10^{-6}, respectively. The measurement time is about 100 ms.

V. CONCLUSIONS

In this paper a low-cost and accurate interface for the measurement of DC voltage signals has been presented. The use of the microcontroller, UTI, and same measurement concepts enables the elimination of many undesired nonidealities of the complete interface. A prototype of the interface has been built and tested. A relatively high degree of the resolution and linearity has been achieved for the measurement of grounded and floating voltages at a measurement time of about 100 ms. The proposed interface is very suited to be implemented in low-cost integrated CMOS technology.

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