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Dynamic Offset Canceling Technique Applied in the Universal Transducer Interface

Jun Ye and Gerard C. M. Meijer

Abstract - **This paper presents methods to reduce the offset of the Universal Transducer Interface (UTI). It has been found that the limited common-mode rejection of the instrumentation amplifier (IA) that is used in some resistive-bridge modes causes a systematic offset, which is proportional to the amplitude of the common-mode square-wave voltage Two dynamic offset-canceling techniques have been proposed. One of them has successfully been realized on board. In this way, the input-referred systematic offset has been reduced from 150μV to about 7μV.**

Keywords –**Universal interface, resistive, offset canceling**

I. INTRODUCTION

The Universal Transducer Interface (UTI) is a sensor-to-time signal converter [1], which is capable of interfacing and digitizing various kinds of sensor signals [1]. To reduce the systematic offset, advanced techniques such as three-signal auto-calibration and chopping have been applied [2]. However, in some of the resistive bridge modes of the UTI, in which the small output signal is amplified by a differential-to-differential instrumentation amplifier (IA), the measurement results show a systematic error, which increases linearly with the increase of the amplitude of the common-mode square-wave voltage of the IA. In this paper, this phenomenon is analyzed. It is shown that this problem can be solved by using an additional chopper. A board-level implementation has been realized and experimentally tested.

II. WORKING PRINCIPLE OF THE UTI IN RESISTIVE BRIDGE MODE

Fig. 1 shows the main structure of the UTI working in the resistive bridge mode (mode 12). Fig. 2(a) shows how a resistive (sensor) bridge is connected, while Fig. 2(b) shows how in the same mode a (sensor) resistor R_x can be measured.

The sensors are excited by a chopped DC voltage. According to the three-signal method, three voltages V_{off}, V_{ref} and V_x are converted to three period times T_{off}, T_{ref} and T_x, respectively (Fig. 3). These time intervals are digitized by a micro-controller, and the data are transferred to the PC via a serial port (RS232) and can be analyzed by, for instance, the Labview program. For identification purposes, the time interval of T_{off} is split into two periods.

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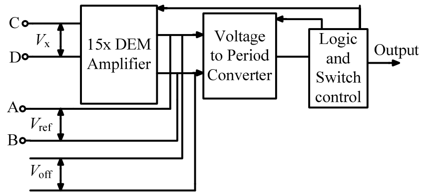


FIGURE 1. THE MAIN STRUCTURE OF UTI IN MODE 12

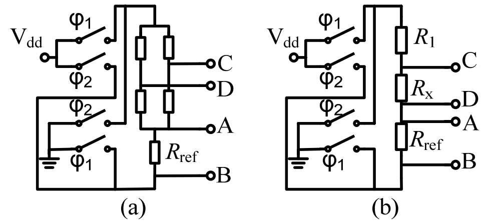


FIGURE 2. THE CONNECTIONS OF THE SENSOR TO UTI IN MODE 12

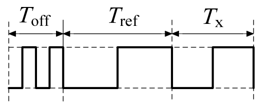


FIGURE 3. THE OUTPUT OF THE UTI

The differential-to-differential instrumentation amplifier (IA) with a gain of 15 is shown in Fig. 4, in which dynamic element matching (DEM) is applied. In the phase of measuring V_x, the resistive DEM loop rotates 8 cycles in slow mode so that the gain error introduced by the mismatch of the resistances is reduced to the second order. Since the differential-mode gain is 15 and the common-mode gain is 1, the differential-mode and common-mode outputs of the IA can be represented respectively as follows:

$$V_{o,IA\_dm} = 15V_x \tag{1}$$

$$V_{o,IA\_cm} = V_{cm} \tag{2}$$

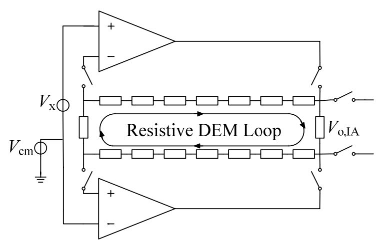
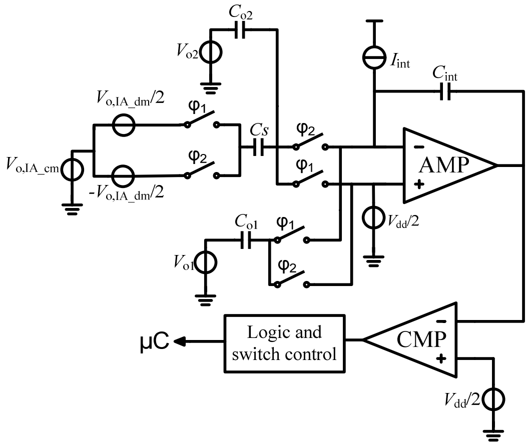


FIGURE 4. THE INSTRUMENTATION AMPLIFIER WITH DEM LOOP

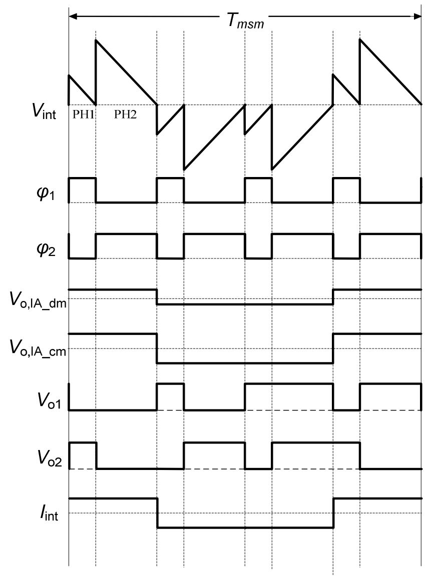
Fig. 5 shows the voltage-to-period converter and the related signal in one measurement cycle. In phase 1, the charge of $Q_1=V_{o1}C_{o1}$ of C_{o1} is pumped into the integrator and removed by integration of I_{int} while the charge of $Q_+=$

$(V_{o,IA\_dm}/2+V_{o,IA\_cm})C_s$ is pumped into C_s. In phase 2, the charge of $Q_-= (-V_{o,IA\_dm}/2+ V_{o,IA\_cm})C_s+V_{o2}C_{o2}$ is pumped into C_s and the difference of the charges, which is $Q_2= V_{o,IA\_dm}C_s + V_{o2}C_{o2}$, is removed by the integration of I_{int}. Therefore, combined with equation (1), for the complete period in one measurement cycle, T_{msm}, it is found that:

$$T_{msm} = \frac{4(15V_xC_s/2+V_{o2}C_{o2}+V_{o1}C_{o1})}{I_{int}} \qquad (3)$$



(A)



(B)

FIGURE 5. (A) THE VOLTAGE TO PERIOD CONVERTER (B) THE RELATED SIGNALS

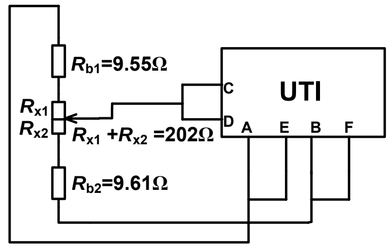
III. MEASUREMENT

In the UTI, three-signal auto-calibration and chopping are applied to eliminate the offset and to increase the immunity for low-frequency interference. Yet, in mode 10, mode 12 and mode 14, the measurement results show that the systematic offset increases with the amplitude of the common-mode square-wave voltage.

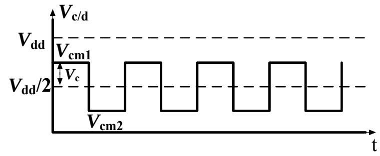
Fig. 6(A) shows the measurement setup in which nodes C and D are short-circuited so that the input-referred offset can be calculated from the output signal. Fig. 6(B) shows the common-mode square-wave voltage at the input of the IA and the V_c is defined as follows:

$$V_c = V_{cm1} - \frac{V_{dd}}{2} = \frac{R_{b2}+R_{x2}}{R_{b1}+R_{b2}+R_{x1}+R_{x2}} V_{dd} - \frac{V_{dd}}{2} \qquad (4)$$

When R_{x2} is increased from 0 Ω to 202 Ω, V_c increases from -2.2V to 2.2V. Fig. 7 shows the input-referred offset measured in *mode 10* (with IA). When V_c is lower than -1.1V or higher than 1.1V (Fig. 7(A)), the offset varies significantly. For -1.1V < V_c < 1.1V, Fig. 7(B) shows the zoomed-in plot of the measurement results. This figure shows a linear relation between the offset and V_c.

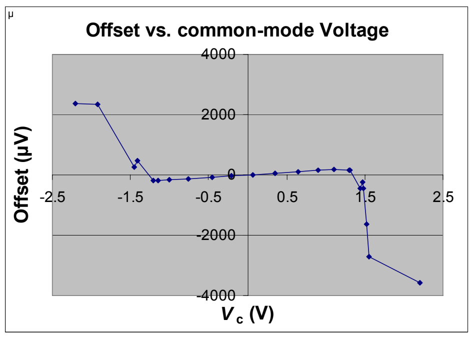


(A)

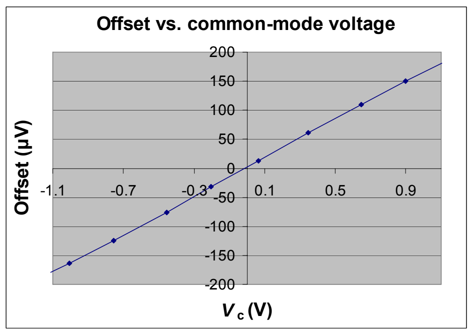


(B)

FIGURE 6. (A) THE MEASUREMENT SETUP (B) THE COMMON-MODE SQUARE-WAVE VOLTAGE



(A)



(B)

FIGURE 7. OFFSET VS. THE COMMON-MODE VOLTAGE: (A) WHEN R_{x2} IS INCREASED FROM 0 Ω TO 202 Ω (B) CLOSE-UP GRAPH

IV. Analysis

The experimental results depicted in Fig. 7 can be explained as follows. Herewith we distinguish two regions:

Region A, where V_c is lower than -1.1V or higher than 1.1V

In this region, the UTI is out of function because the switches in the resistive DEM are implemented with NMOS transistors only. In the mentioned region the ON-resistances are so high that the Op-amps of the IA is out of order.

Region B, where -1.1 V < Vc < 1.1V

Fig. 8 shows the schematic of the system when the input is driven with a common-mode voltage only. Due to the finite CM rejection of the IA, a differential output signal V_{o,IA_dm} is produced. The finite CM rejection is mainly caused by the mismatch of the gains of the Op-amps. Consequently, the DM output voltage V_{o,IA_dm} is linear related to V_{cm}, which can be represented with the equation:

$$V_{o,IA\_dm} \approx \frac{15\Delta A}{A_1 A_2} V_{cm} \qquad (5)$$

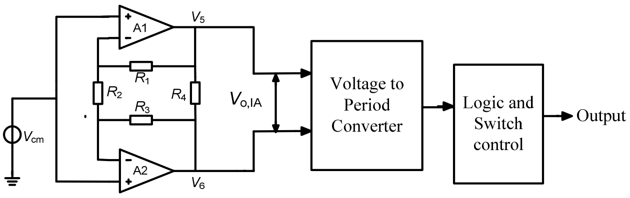


FIGURE 8. THE SCHEMATIC WHEN THE INPUT IS DRIVEN WITH A COMMON-MODE VOLTAGE ONLY

As is seen in Fig. 9, the differential output signal V_{o,IA_dm} caused by the common-mode input voltage can not be distinguished from the desired signal, since they have the same frequency.

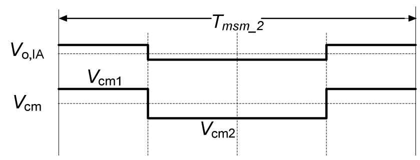


FIGURE 9. THE RELATED SIGNALS

The period time T_{msm2} of one complete measurement cycle equals:

$$T_{msm\_2} = \frac{4(V_{o,IA\_dm}C_s/2 + V_{o2}C_{o2} + V_{o1}C_{o1})}{I_{int}} \qquad (6)$$

So the error T_{error} amounts to:

$$T_{error} = \frac{2V_{o,IA\_dm}C_s}{I_{int}} \qquad (7)$$

V. Dynamic Offset Cancelling Technique

A. Dynamic Op-amp Matching (DOAM)

When the two Op-amps would be perfectly matched, the measured offset would be zero. To deal with the unavoidable mismatching, the same result can be achieved by dynamic Op-amp matching (DOAM) [3].

To realize DOAM two quads of switches are used in front and after the IA (Fig. 10). Fig. 11 shows the related signals. In T_{msm1}, φ_4 is close while φ_3 is open. The time interval T_{msm1} equals:

$$T_{msm1} = \frac{4(V_{o,IA\_dm}C_s/2 + V_{o2}C_{o2} + V_{o1}C_{o1})}{I_{int}} \qquad (8)$$

In T_{msm1}, φ_3 is close while φ_4 is open. The time interval T_{msm2} amounts to:

$$T_{msm2} = \frac{4(-V_{o,IA\_dm}C_s/2 + V_{o2}C_{o2} + V_{o1}C_{o1})}{I_{int}} \qquad (9)$$

Therefore, the offset introduced in T_{msm1} is compensated by that introduced in T_{msm2}.

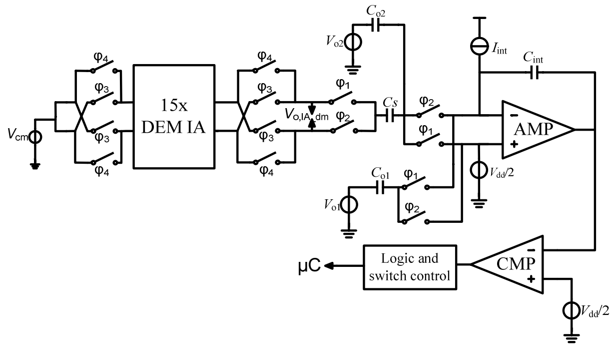


FIGURE 10. DYNAMIC OP-AMP MATCHING

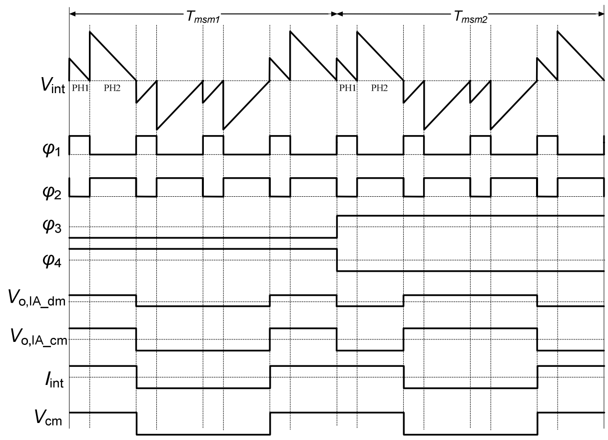


FIGURE 11. RELATED SIGNALS

B. Dynamic common-mode voltage Matching (DCMVM)

An alternative method to remove the offset is to use matching of the dynamic common-mode voltage (Fig. 12).

In this case, the switches are placed after the excitation signal and in front of the inputs of IA to realize DCMVM.

DOAM and DCMVM realize the same offset canceling function. To increase the immunity to interference, the ON-resistances of the quad of switches at the right-hand side of the sensor resistor (Fig.12) should be as low as possible, because they are placed in the signal path of the sensor.

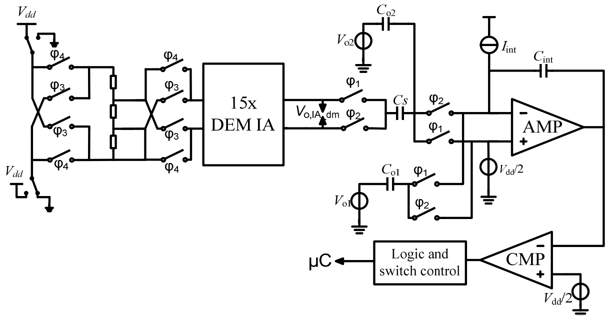


FIGURE 12. DYNAMIC COMMON-MODE VOLTAGE MATCHING

VI. BOARD-LEVEL REALIZATION

Since the IA is integrated in the chip of UTI, it is not possible to mimic DOAM with discrete components. In contrast to this, DCMVM can be realized on board. The excitation voltage of the sensor is also used to control the analog switches in DCMVM. As is shown in Fig. 10, the frequency of the control signal should be at least two times less than that of the excitation voltage.

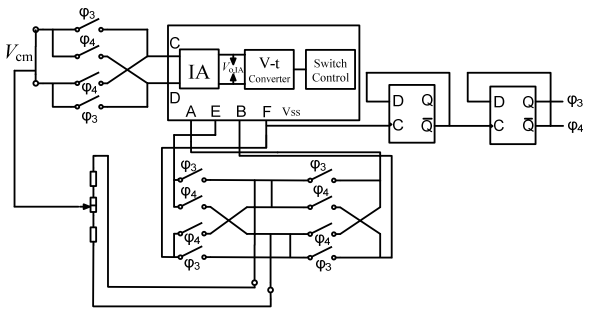


FIGURE 13. BOARD-LEVEL REALIZATION OF DCMVM

Fig. 13 shows the structure of the board-level system. The frequency divider circuit is realized by two D flip-flops and it provides a division ratio of 4. Fig. 14 shows the related signals. The offsets caused by the common-mode voltage cancel each other in each time interval of four measurement cycle.

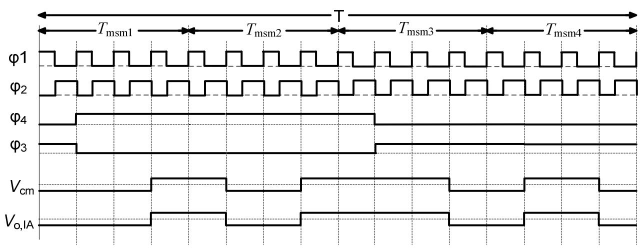


FIGURE 14. RELATED SIGNALS

The same measurement described in section 2 (Fig.6) has been performed on the UTI with DCMVM. Fig. 15 shows the input-referred offset performance. It is found that with the help of the DCMVM technique, the input-referred offset is reduced to only 7 µV.

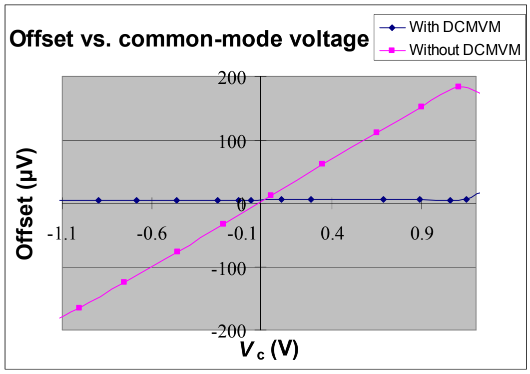


FIGURE 15. OFFSET VS. COMMON-MODE VOLTAGE

VII. CONCLUSION

The systematic offset of the UTI in the resistive bridge mode with instrumentation amplifier IA (mode 10/mode 12/mode 14) is caused by the limited common-mode rejection amplifier. Two dynamic offset canceling techniques are proposed and the dynamic common-mode-voltage matching (DCMVM) technique has been realized on board. It successfully reduces the input-referred systematic offset from more than 150μV to only 7μV.

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