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Electronic interface for the accurate read-out of resistive sensors in low voltage–low power integrated systems

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Abstract

The accuracy of integrated sensors is often limited by errors of the electronic interface; this is the case in most low voltage–low power integrated sensor systems. In this paper we describe the dynamic op amp matching (DOAM) technique; the circuits using the dynamic op amp matching (DOAMCs) are a new type of circuits using dynamic element matching (DEMCs). In comparison with traditional DEMCs and with chopper circuits, DOAMCs may achieve a *gain enhancement*, while, in comparison with gain enhanced autozero circuits, they offer better noise performance. For these reasons DOAMCs are an attractive strategy for the implementation of accurate electronic interfaces in low voltage–low power integrated sensors; as a design example we present a DOAMC suitable for the read-out of resistive sensors.

Keywords: Low voltage–low power integrated sensors; Dynamic matching; Electronic interfaces

1. Introduction

In most cases, accurate electronic interfaces for sensors require operational amplifiers (op amps) with very high gain and with low input offset and noise voltages; in many practical cases *technological limitations* (that is non-idealities of available devices) and *design constraints* conflict with integration of such op amps.

With reference to *technological limitations*, as an important example, CMOS op amps typically have high input offset and noise voltages. With reference to design constraints, high gain requirements generally conflict with low voltage (limited headroom for transistors makes cascoding techniques problematic) specifications; furthermore low power also requires low biasing currents, resulting in low transconductances, which limits the achievable gain-bandwidth product of amplifiers.

Since *static* compensation techniques may not compensate time-varying errors (such as errors due to noise), *automatic* compensation techniques [1–7] have become very popular in CMOS systems, where, beside the offset voltages, the low frequency input noise voltages of op amps are also not negligible.

Circuits using automatic compensation techniques can be grouped into three main classes: autozero circuits (AZCs), chopper circuits (CHCs) and circuits using dynamic element matching (DEMCs). In previous classifications [1,2] DEMCs and CHCs have been grouped in the same class; however, although some overlap exists between DEMCs and CHCs (that is there are circuits which belong to both the classes), it is better to distinguish between them because their working principles are different [8]. For instance we have recently introduced [8–10] circuits based on dynamic matching of op amps (DOAMCs); DOAMCs are a particular type of DEMCs but they are not CHCs (in particular their accuracy and noise properties are substantially different from those of CHCs); in the same manner CHCs which make use of a purely sinusoidal modulation–demodulation are not DEMCs.

Although it is well known [1] that DEMCs and CHCs have better noise performance than AZCs, it has been believed [1] that, in contrast with AZCs, both DEMCs and CHCs may not achieve *gain enhancement* (that is the compensation of the finite op amp gain). As a consequence, in systems where the gain of op amps may be limited by low voltage–low power specifications, autozeroing has been generally preferred due to its *gain enhancement* capabilities. However we have recently shown [8–10] that properly designed DOAMCs (which are a subset of DEMCs) may

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achieve a significant *gain enhancement*, but having in addition better noise properties (and thus superior accuracy) than AZCs.

Furthermore, DOAMCs do not require high value linear capacitors, which is an important advantage for integration in digital CMOS processes [11–13]; on the other hand DOAMCs require, for low power consumption, high value resistors which could also be not feasible in digital processes where silicide reduces the sheet resistances of both polysilicon and diffusion layers [12,14]. However it is always possible to use an additional mask (with increased costs) in order to selectively block the deposition of silicide on regions needed for the integration of resistors and, in some cases, it could be possible to use well resistors, although their voltage dependence [14] must be taken into account (since it could easily degrade accuracy).

In order to further decrease the power consumption of DOAMCs, if slow operations are acceptable, the analog circuitry could be powered down for large amounts of time.

The dynamic matching of op amps could also improve the performance of the replica-amplifier circuits presented in [15–17] (in those circuits the gain enhancement was limited by gain mismatch), although the simple dynamic op amp matching would not contemporarily lead, in those circuits, to the reduction of the equivalent input offset and low frequency noise voltages.

In this paper we present the dynamic op amp matching principle and we show, as a design example, a new DOAM circuit for the accurate read-out of resistive sensors (such as *strain gauges*); SPICE simulations confirm theoretical expectations.

2. DOAM interface for resistive sensors

2.1. Dynamic op amp matching

Under the (unrealistic) hypothesis of perfect matching of two or more op amps, it is possible, in principle, to design circuits where the errors induced by different op amps compensate each other. The unrealistic matching hypothesis may be removed by dynamic op amp matching, that is the dynamic element matching applied to the op amps. Since the errors induced by op amps comprise, beside the errors due to input offset and noise voltages, also the errors due to the finite gain of the op amps, in principle DOAM makes possible to compensate the finite op amp gain (gain enhancement) without autozeroing.

Clearly, in order to effectively achieve the compensation of both the finite op amp gain and the input offset and noise voltages, it is necessary to design proper circuit topologies (for instance we have already presented elsewhere [3] some circuit topologies for the implementation of accurate buffers, inverting and non-inverting amplifiers using the DOAM).

For simplicity we will refer to DOAM amplifier (buffer, etc.) meaning an amplifier (buffer, etc.) based on dynamic op amp matching.

2.2. Errors of circuits containing op amps

In a given circuit we may define the output voltage error, E_{out}, as the difference between the output voltage and the ideal output voltage. We notice that in a short time interval, T_X, the input noise voltages with frequencies much smaller than $f_X = 1/T_X$ are about constant, so that, within that short time interval, those noise voltages may be regarded as additional input offset voltages [1,2] (in practice T_X is the time required for the single dynamic compensation operation); in the same manner the input offset voltage may be regarded as dc input noise voltage; for these reasons it is often unnecessary to consider contemporarily both the input noise and offset voltages.

In order to determine the errors of circuits containing op amps we can use the following simplified linear model:

$$V_{\text{out}} = G(V_+ - V_-) + G_{\text{CM}}\left(\frac{1}{2}(V_+ + V_-)\right) + V_{\text{off,out}} \quad (1)$$

where G is the differential open loop gain of the op amp, G_{CM} the common mode gain, V_+ and V_- are the voltages at the positive and at the negative input terminals, $V_{\text{off,out}}$ is the output offset voltage; for simplicity we assume all other components (but op amps) ideal.

2.3. Classic and DOAM interface for resistive sensors

In order to read out the variation of the resistance of a resistive sensor it is often convenient to transform such variation into a voltage variation and, therefore, an interface for resistive sensors generally comprise a *resistance variation to voltage converter*.

A classic *resistance variation to voltage converter* is shown in Fig. 1, where R_{2S} is the sensor resistance and is given by

$$R_{2S} = R_2 + \Delta R \quad (2)$$

In case of ideal op amp the output voltage would be

$$V_{\text{out}} = -V_{\text{REF}}\frac{\Delta R}{R_1 + R_2} \quad (3)$$

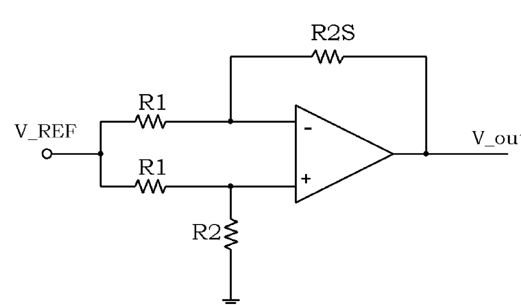

Fig. 1. Classic interface for resistive sensors.