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Abstract

A Transformer-Based Front-End Circuit for Grounded Capacitive Sensors with Square-Wave Excitation †

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Abstract: This work proposes and experimentally characterizes a novel front-end circuit for capacitive sensors with one electrode grounded, which are quite common in liquid-level and position measurement applications. The circuit relies on a properly shielded custom transformer, as already suggested in the literature, but uses a square excitation instead of a sinusoidal excitation, thus being a simpler solution. Furthermore, the sensor signal is read by a charge amplifier with a single supply voltage, instead of a transimpedance amplifier with a split supply voltage. The preliminary experimental results show an input–output characteristic with a non-linearity error lower than 0.5% FSS in the [0, 33] pF measuring range.

Keywords: capacitive sensor; front-end circuit; sensor interface electronics

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1. Introduction

Capacitive sensors are widely employed in industrial, automotive, and laboratory applications to measure magnitudes such as acceleration, liquid level, and displacement. There are two kinds of capacitive sensors [1]: (1) floating, in which the two electrodes are not connected by default to any potential, and (2) grounded, in which one of the two electrodes is always connected to ground due to safety reasons and/or limitations imposed by the application [2]. The design of the ensuing front-end circuit can be quite complex, especially when the sensor has a low capacitance and is remote (i.e., connected to the circuit via a shielded cable). Most of the read-out circuits suggested so far for remote grounded capacitive sensors have the limitation that either a continuous auto-calibration (that measures the offset parasitic capacitance caused by the devices and tracks) is required, or a capacitor of the circuit must be adjusted to the value of this offset capacitance [3]. In order to cope with that limitation, a novel AC bridge with a floating voltage source providing an ultra-low offset capacitance and a high linearity was presented in [4]. A simplified version of that circuit is presented herein.

2. Materials and Methods

This work proposes the novel front-end circuit for remote grounded capacitive sensors depicted in Figure 1a. This circuit relies on a transformer to generate a floating voltage source and applies the concept of active shielding to the interconnecting cable, as in [4], but it has three main differences and contributions: (1) it employs a square excitation (v_{ref}) instead of a sinusoidal excitation, which makes the design simpler since the generation and reading are more straightforward; (2) the reading of the sensor signal is carried out through a charge amplifier instead of a transimpedance amplifier so as to guarantee a square signal at the output; and (3) it requires a single supply voltage instead of a split supply voltage; this is achieved by connecting the non-inverting input of the operational amplifier to half of the supply voltage (V_{CC} = 3.3 V), which is generated by a voltage follower and a couple of equal resistors (R_1 and R_2). The capacitor (C_d) placed in series with the generator is intended to block any DC component.

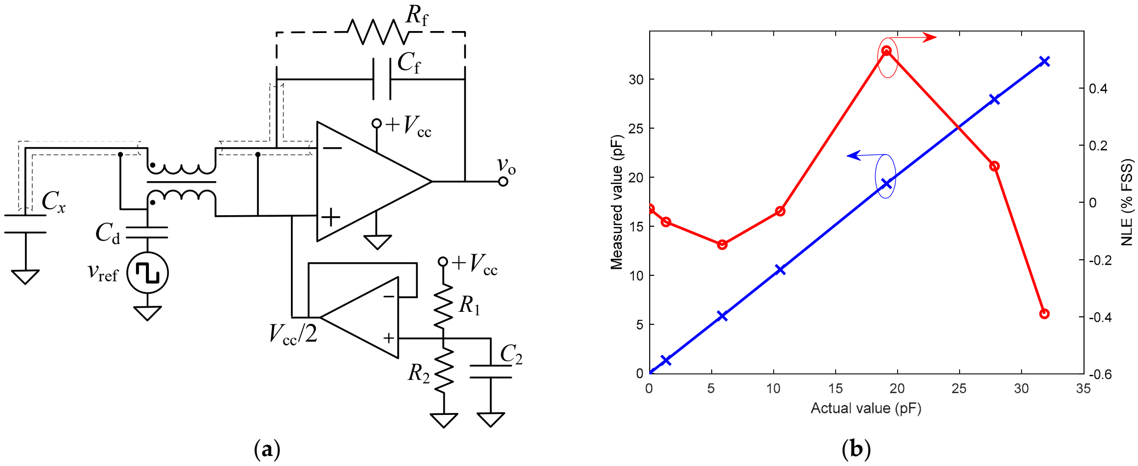

Figure 1. (**a**) A transformer-based circuit for grounded capacitive sensors (C_x) with a square excitation. (**b**) Experimental results (in blue, the measured value of capacitance, and in red, the NLE) obtained when characterizing the circuit in (**a**).

3. Experimental Results and Discussion

The circuit in Figure 1a was experimentally tested with a square excitation at 40 kHz using off-the-shelf components. The capacitance C_x, between 0 and 33 pF, was connected to the circuit via a 45 cm shielded cable. The higher the value of C_x, the higher the amplitude of the square signal at the output (v_o in Figure 1a), as expected. Note, however, that the output signal was not perfectly square due to the high-pass filter effects caused by the output resistance of the signal generator (50 Ω) and the magnetizing inductance (9 mH) of the transformer; this response will be improved in the future work by reducing the output resistance. The peak-to-peak voltage of the output signal ($V_{o,pp}$) was measured and then C_x was estimated as $V_{o,pp}/V_{ref,pp} \cdot C_f$, where $V_{ref,pp}$ is the peak-to-peak voltage of the reference signal (v_{ref}) and C_f is the feedback capacitance in Figure 1a. The resulting input-output characteristic is represented in Figure 1b, where the actual value of C_x was measured by an LCR meter. The corresponding non-linearity error (NLE) calculated by means of the least-squares method and expressed as a percentage of the full-scale span (FSS), i.e., 33 pF, is also represented in Figure 1b, with a maximum NLE of 0.5% FSS. Experimental results with different lengths of the shielded cable and also using a lock-in amplifier at the output will be provided in the extended version of this work.

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