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A Fully Differential Synchronous Demodulator for AC Signals

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***Abstract*— A novel fully differential (FD) demodulator is presented. Using different design strategies, the circuit can be used for processing amplitude-modulated (AM) signals obtained from impedance measurements or coming from modulating sensors with differential outputs where a high common-mode rejection ration (CMRR) and low noise are demanded. The circuit multiplies the AM input signal by a square wave with the same frequency and phase of the carrier of the input signal. This kind of wave is simpler to generate than a sine wave (homodyne detection) and narrow unit-amplitude pulses (synchronous sampling). The proposed circuit is not a perfect floating system, but yields a high CMRR if matched op-amps are used and does not depend on matched resistors. The system has been tested with off-the-shelf amplifiers; at 100 kHz, the CMRR is about 65 dB when fast and wide-bandwidth amplifiers are used. The spectral density of noise voltage obtained is lower than 55 nV/$\sqrt{\text{Hz}}$ at 1 kHz; for a bandwidth of 15 Hz, this results in a noise voltage (rms) of 213 nV. Provided the circuit is implemented with low value resistors, the main contribution of noise comes from the noise voltage of the op-amps used to implement the demodulator.**

***Index Terms*— Coherent demodulation, common-mode rejection ratio (CMRR), fully differential (FD), low-noise, synchronous demodulator.**

I. Introduction

RESISTIVE and variable reactance sensors supplied by an ac voltage or impedance measurements yield amplitude-modulated (AM) signals with very low amplitude, where the information is contained in the amplitude or the phase of the modulating component. For example, linear variable differential transformers (LVDT) are widely used sensors in industrial, even in medical applications for measuring physical quantities such as displacement, force, or pressure. These sensors must be unconditionally supplied by an alternating voltage (or current), where the physical quantity modulates the amplitude of the voltage (or current) supplied. One of the main advantages of LVDTs is that they provide a differential output that must be connected to a differential-input system in order to take out the information of interest (i.e., the modulating component). Another example is related to bioimpedance measurements, where the basal impedance of some tissues is AM by the dynamic activity of some physiological functions, for example, from the arterial blood circulation [1]. Variations of 500 mΩ have been reported, which demanded a fully differential (FD) demodulation in order to reduce the contribution of common-mode (CM) errors caused by the electrode impedance imbalances and the finite CM rejection ratio (CMRR) of the measurement system [2].

Phase-sensitive (synchronous or coherent) demodulation is the technique commonly employed to recover both the amplitude and phase from an AM signal, where the input signal is multiplied by a reference wave with the same frequency and phase of the carrier. A common method is the homodyne detection, where the reference signal is a sine wave, but it is necessary to use analog multipliers to recover the modulating component. Although these analog multipliers include differential inputs, the majority of the proposed methods work with single-ended (SE) signals, for example, as is presented in [3] and [4]. Alternatives approaches are the use of switched detectors that multiply the AM signal by a square wave or by a train of very narrow unit-amplitude pulses [5]. Also, there are available digital demodulators based on digital signal processors [6], field-programmable gate array [7], [8], and application specific integrated circuits, which have been implemented using FD synchronous demodulators [9]. The performance of digital demodulators depends on the quality of analog-to-digital conversion (ADC) and the sampling frequency. The amplitude errors are reduced by using reference sine waves computed with high accuracy [10], which requires complex programing language. For increasing the CMRR and the sensitivity of the measurement system, most of the digital demodulators are driven by differential or FD analog input amplifiers [9].

Analog synchronous demodulation has demonstrated to be a technique, not only cheap and robust but also effective [4]. They have demonstrated a good performance when the AM signals come from high-impedance sensors (capacitive) [4] or dry electrodes in bioimpedance measurements [2], also in high-resolution measurements in order to detect the cardiac activity [11], [12]. Different analog demodulator circuits have been proposed. There are those that rely on a switched-gain amplifier with SE input and output that uses an analog switch to synchronously change the gain from +1 to −1 [13], but a differential-to-single-ended conversion is needed in a previous stage. To address this, a differential synchronous

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