Low-cost impedance approach using AD5933 for sensing and monitoring applications

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Abstract. The use of electro-materials such as piezoelectric, thermoelectric and pyroelectric has gained popularity due to their unique properties and can be deployed in a system for sensing and monitoring applications. Due to advancement in technology, Analog Devices has introduced in the market the first integrated impedance device, AD5933. The AD5933 is relatively inexpensive compared to an impedance analyzer such as HP 4192A, portable and has a 1MSPS sampling rate, fast enough for frequency sweeping. A sensing technique known as impedance approach has been commonly used to utilize the coupling property of the electro-materials by measuring their electrical impedance directly. The changes in the impedance response signals at certain frequencies can be used to detect changes in the integrity of a structure. However, there is still need for a feasibility study to investigate the use of low-cost impedance approach and it is necessary to carry out an experimental validation of a proposed system for sensing and monitoring applications.

1. Background and Recent Studies
The technology breakthroughs in electro-materials have a direct impact on some of today’s most challenging global problems. The use of electro-materials such as piezoelectric, thermoelectric and pyroelectric has gained popularity due to their unique properties. Many researchers e.g. [1-3] have taken advantage of the coupling property of these electro-materials by measuring their electrical impedance directly via a sensing technique known as impedance approach. At high frequencies (typically > 30 kHz), changes in integrity of a structure can be detected via the changes in impedance response signals of the electro-materials. To date, development of impedance measuring devices has allowed a sensing system that can be adapted in various fields. Furthermore, they are low cost, portable and easily used.

Na and Baek [4] applied multiple monitoring approach using piezoelectric transducers via AD5933 evaluation board [5]. The researchers successfully showed the advantage of the low-cost impedance technique to monitor adhesive defects of a glass-fiber epoxy plate.

Al-Ali et al. [6] designed and implemented a low-cost, portable impedance analyzer which can be used to measure impedance up to 100 kHz and from 10 Ω to 100 kΩ. The proposed system was used to monitor growth of fruits at different ages by using bio-impedance data.

Tambara and Bulhões [7] introduced a low-cost impedance analysis system that can be used to estimate the electrode-electrolyte parameters. The proposed system, which can be carried out using frequency sweep, allowed the resistance and capacitance of the equivalent model to be measured using...
only voltage outputs. The system is also flexible in application that it can be easily modified to suit user’s requirements. Their results showed good accuracy for a system that is lower in price and smaller in size.

Meanwhile, Potdar et al. [8] adapted the AD5933 for determining respiration rate by transmitting current via two electrodes and then measuring the output impedance signals through two other electrodes. The impedance signals can be calculated using the magnitude and phase shift at different frequencies from 0.1Hz to 100KHz. Using signal processing technique, the impedance can also be converted into voltage and can be separated into real and imaginary parts using the Discrete Fourier Transform (DFT) algorithm.

2. Impedance Measurement and Proposed Setup

There are a number of methods that can be chosen to measure impedance. Each of the method has its own advantages and disadvantages and in order to choose the most suitable method depends on the measurement requirements and factors such as frequency range, bandwidth, accuracy and ease of use [9] i.e. it is not possible to consider all these with only one method. Conventionally, impedance can be measured with the use of an impedance analyzer. However, the conventional impedance analyzers in the market are very expensive and not suitable for field applications since they are bulky [10]. Due to advancement in technology, Analog Devices has introduced in the market the first integrated impedance device, AD5933. The AD5933 is relatively inexpensive compared to an impedance analyzer such as HP 4192A. It is also portable and fast enough for frequency sweeping at a 1MSPS sampling rate. It is easy to use with any computer using a USB cable.

The low-cost impedance method with a AD5933 evaluation board is shown in Figure 1. The electrical impedance can be measured by the frequency domain ratio of the voltage to the current. Impedance is a complex number consist of real part or resistance, R and imaginary part or reactance, X. The R and X parameters can be converted into desired parameters such as impedance magnitude, |Z|; phase, θ; admittance magnitude, |Y|; conductance, G; and susceptance, B.

3. Data Analysis

There are a number of methods that can be chosen to measure impedance. Each of the method has its own. There are three commonly used statistical metrics for quantifying the changes in response signals, namely, root mean square deviation (RMSD), mean absolute percentage deviation (MAPD) and correlation coefficient deviation (CCD):
RMSD = $\sqrt{\sum_n [\text{Re}(Z)_i - \text{Re}(Z^o_i)]^2 / \sum_n [\text{Re}(Z^o)_i]^2}$  \hspace{1cm} (1)

MAPD = $\sum_n |[\text{Re}(Z)_i - \text{Re}(Z^o_i)]/\text{Re}(Z^o_i)|$  \hspace{1cm} (2)

$\text{CCD} = 1 - \text{CC}$, where $\text{CC} = \frac{1}{\sigma_X \sigma_Z} \sum_n [\text{Re}(Z)_i - \text{Re}(\bar{Z})], [\text{Re}(Z^o_i) - \text{Re}(\bar{Z}^o)]$  \hspace{1cm} (3)

In the equations, $\text{Re}(Z)_i$ and $\text{Re}(Z^o_i)$ represents real part of the reference or baseline and the corresponding impedance signals, respectively, $N$ is the total number of signals and symbols $\bar{Z}$ and $\sigma_Z$ signifies mean values and standard deviations, respectively. The statistical metrics yield a numerical value that represents changes in frequencies and changes in amplitudes of the reference signal as a sign that damage has occurred to a structure.

4. Conclusions

The idea is to propose an impedance system that is low cost, portable and easy to be used for field applications, hence to replace the bulky and expensive conventional impedance analyzers. In recent years, several researchers have used AD5933 applied to electro-materials and gained recognition by the research communities for their contribution in advancing the low-cost impedance approach. However, there is still need for a feasibility study to investigate the use of low-cost impedance approach due to its limited frequency range (up to 100 kHz), and it is necessary to carry out an experimental validation of a proposed system for sensing and monitoring applications.

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