Noise-Rejection Techniques for Impedance and Dielectric Spectrometers Using Ubiquitous Test and Measurement Equipment

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Abstract

This work encompassed the development for a frequency-domain impedance and dielectric spectrometer using ubiquitous test and measurement equipment, i.e., signal generators and digital oscilloscopes. Various methods of amplification, noise-rejection, and computations were employed to achieve the desired goals. The frequency range of 100 mHz to 1 MHz was tested using air capacitors of 3.7 and 14.5 pF and an applied voltage range of 10 to 300 mV. The multi-channel instrument produced a stable and reproducible dual-phase (real and imaginary or magnitude and phase) current sensitivity of 250 fA with an average phase stability of less than 0.5° ($\tan\delta < 10^{-2}$), and a single-phase (magnitude only) current sensitivity of 60 fA.

Introduction

Impedance spectroscopy is an important technique used to study the electrical characteristics of electronic components. Similarly, dielectric spectroscopy is used to study charged-particle migrations, electric dipoles and multi-poles, and generalized electric charge distributions of polar materials or substances. Early work dates back to 1850 [1, 2] with the Clausius-Mossotti treatment of induced polarization of insulating materials by an applied electric field. In 1929, Peter Debye [3] associated the dielectric response with the molecular dipole moment providing insight into molecular structure and its effect on charge distribution.

The techniques have steadily progressed since the 1930s, advancing with the electronic technologies of the age. The advent of digital technology has inspired new approaches to scientific research. Prior to digitalization, electrical signals from sensors were processed with analog components, i.e., transistors, which were highly susceptible to environmental factors and nonlinearities. Digitalization has brought this realm closer to the sensor, thereby increasing the range and reliability of the measured signal.

In effect, the analog signal from the sensor may be amplified by an analog amplifier and then directly converted to a digital waveform using an analog-to-digital converter. Once in the digital realm, all further signal processing is performed computationally. This is the basis of digital-signal processing (DSP). The most common evidence of such advances is a comparison of the analog oscilloscope of the 1980s to those of the digital present. Other test and measurement devices have undergone similar evolution, i.e., lock-in amplifiers, spectrum and network analyzers, and even electrocardiograms.

The development presented herein employs standard test and measurement equipment, i.e., a function generator and a digital oscilloscope, to increase the sensitivity of the oscilloscope for use as a multi-channel dual-phase impedance and dielectric spectrometer. The configuration can also extend its capability as a multi-channel dual-phase lock-in amplifier. The goal of this work was to create a more reliable and sensitive instrument than the commercially-available impedance and dielectric spectrometers from Agilent, Solartron Analytical, and NovoControl Technologies.

Implementation **Results and Discussion** **Tables** **Figures** **References**	Intentionally removed from this document

Summary

The present work has reintroduced the art of developing impedance and dielectric spectrometers. In so doing, it has been found that the limits of common test and measurement equipment can be extended to the realm of impedance and dielectric analyzers and spectrometers. This work generated results comparable to and exceeding the capabilities of commercially-available systems. The present spectrometer demonstrated a technical feasibility for comprehensive research and development while providing a cost-effective solution linked to the ubiquitous nature of the equipment. Extensive testing of the prototype spectrometer has provided a means to reliably measure impedance and dielectric responses without inducing nonlinear dielectric effects within the frequency range of 100 mHz to 1 MHz. This work has demonstrated the basis for creating more reliable and sensitive instruments than currently available for commercial impedance and dielectric spectrometers. The limits of the present instrument are equivalent to the limits of the products available from the test and measurement industry.

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