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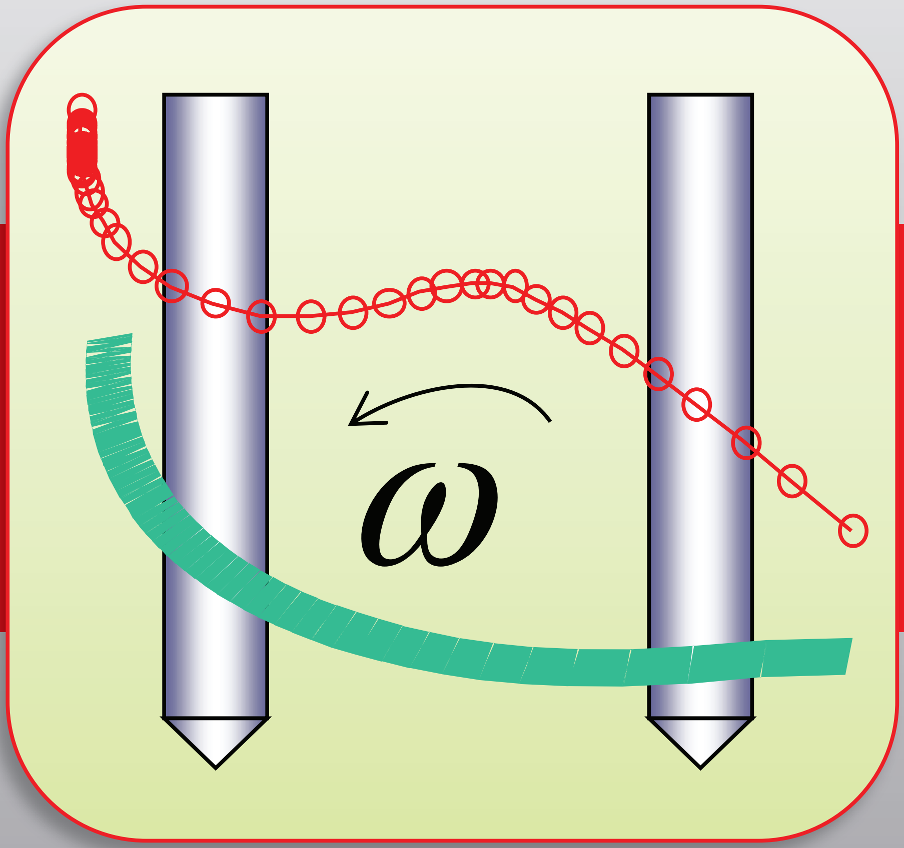

Lecture Notes on Impedance Spectroscopy

Measurement, Modeling and Applications

Editor: Olfa Kanoun

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LECTURE NOTES ON IMPEDANCE SPECTROSCOPY

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Measurement, Modeling and Applications

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Preface

Impedance Spectroscopy is a powerful measurement method used in many application fields such as electrochemistry, material science, biology and medicine, semiconductor industry and sensors. Using the complex impedance at various frequencies increases the informational basis that can be gained during a measurement. It helps to separate different effects that contribute to a measurement and, together with advanced mathematical methods, non-accessible quantities can be calculated.

Dealing with Impedance Spectroscopy in general requires competences in several fields of research, such as measurement technology, electrochemistry, modeling, mathematical and physical methods and nonlinear optimization. Depending on the specific challenges of the considered application there are generally more efforts to be done in one or two specific fields. The scientific dialogue between specialists of Impedance Spectroscopy, working with different applications, is therefore particularly profitable and inspiring.

The International Workshop on Impedance Spectroscopy has been launched already in June 2008 with the aim to serve as a platform for specialists and users to share experiences with each other. Since 2009 it became an international workshop addressing more fundamentals and application fields of impedance spectroscopy. The workshop is gaining increasingly more acceptance in the scientific and industrial fields.

This book is the first in the series Lecture Notes on Impedance Spectroscopy. It includes the proceedings of the International Workshop on Impedance Spectroscopy (IWIS'09). The proceedings are a set of presented contributions of world-class manuscripts describing state-of-the-art research in the field of impedance spectroscopy. It reports about new advances and different approaches in dealing with impedance spectroscopy including theory, methods and applications. The book is interesting for research and development in the field of impedance spectroscopy.

I thank all contributors for the interesting contributions, for confidence and for having patience with us during the preparation of the proceedings.

Prof. Dr.-Ing. Olfa Kanoun

Modeling of impedance spectra

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Impedance of nonlinear current or voltage dependent devices

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ABSTRACT: Many real devices such as batteries are nonlinear and their impedance values depend on either current or voltage. However, impedance analysis is based on the assumption of a linear system. If certain conditions such as sufficiently small excitation amplitude to ensure quasi-linearity and measurements at several operating points are fulfilled, also the impedance of a nonlinear system can be interpreted. Equations to calculate the large signal impedance from small signal impedance measurements of current, voltage and mixed dependent devices are derived and analyzed.

Keywords: component, nonlinear, large signal impedance, small signal impedance, negative resistance, negative capacitance, inductive semicircle, inductive behaviour

1 INTRODUCTION

Impedance spectroscopy is a powerful and widely used tool for the parameterization of simulation models. From a single impedance spectrum of a linear device, both the structure of its equivalent circuit and the parameter values can be extracted. For nonlinear devices, the same information can be obtained, but measurements at several operating points are necessary to obtain the complete behavior. Besides the dependency on the operating point, which means the bias current or voltage, the impedance of a nonlinear device also depends on the excitation amplitude. In order to guarantee quasi-linear conditions and thus usable spectra, the amplitude has to be kept small enough (Barsoukov and Macdonald 2005). Furthermore it has to be considered that—in contrast to the linear case—the measured (small signal) impedance of a nonlinear device is not equal to the large signal impedance which is needed for a time domain simulation model.

There are several publications dealing with nonlinear circuits; already in the 1950s, 1960s and 1970s, researchers focused on the mathematical description of polarized electrodes (Macdonald and Brachman 1954; Macdonald 1954; Macdonald 1955), nonlinear capacitors (Macdonald and Brachmann 1955) and nonlinear networks (Popov and Paltov 1963; Chua 1969; Chua and Lin 1975). Those researchers had to face the problem that they could not employ their theory on a grand scale because of the limitations in computing power. The focus of these works was to calculate current and voltage behaviour of a circuit with given nonlinearities, while the focus in this work is to determine the nonlinearities from current and voltage measurements. More recent publications deal with this problem by the usage of impedance spectroscopy, but they typically only determine the small signal impedance in the frequency domain, e.g. (Darowicki 1994; Darowicki 1997; Darowicki 1998).

In a previous paper by the authors, a procedure was developed to determine the large signal impedance of a voltage dependent device from its small signal impedance (Kowal and Sauer 2009). Starting from the differential equation of the current-voltage relationship, the equation is linearized after an AC and DC perturbation. The resulting AC part is transformed into the frequency domain giving differential equations for the small signal impedance elements. In this paper, the method is applied to current and mixed dependency.