Analysis of the induced voltages on the electrodes inside the low-frequency electromagnetic field experimental system

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Abstract

This work investigates the influence of low-frequency electromagnetic fields on the induced voltage in the tested conductors. For this purpose, an experimental system was used, which was designed and implemented by the author with the dimensions of the experimental space 50 × 50 × 50 cm. The homogeneity of the field in the analyzed space was verified by calibration measurements. The system allows placing an experimental conductor in a relatively homogeneous low-frequency EMF and investigating the influence on the induced voltage.

The aim of this paper is to quantify and analyze the induced voltage generated in conductors exposed to a defined low-frequency electromagnetic field. The experiment utilized single conductors with lengths of 52 cm, 58 cm, and 65 cm and a diameter of 1 mm, as well as two parallel conductors. The geometry of the conductors represented implanted pacemaker leads in unipolar and bipolar configurations. During measurements, the conductors were terminated with a typical impedance of 470 kΩ in parallel with a capacitance of 100 pF.

The first part of the paper presents measurement results obtained by using harmonic excitation currents at frequencies of 50 Hz, 1 kHz, and 10 kHz. During the measurement, a constant value of magnetic induction from 0.25 to 1mT was ensured for a given series of measurements.

The measured induced voltages were recorded and processed for graphical evaluation. The results demonstrated a linear increase in induced voltage with increasing magnetic flux density. The highest induced voltages were observed for parallel conductor configurations. Non-harmonic excitation produced higher peak induced voltages compared to harmonic excitation. The obtained results provide a basis for further investigation of the effects of low-frequency electromagnetic fields on objects placed within such environments. The results also contribute to the assessment of electromagnetic compatibility of sensitive electronic devices, particularly implantable cardiac pacemakers and their lead.

Index terms - low-frequency electromagnetic field, induced voltage, magnetic flux density, pacemaker leads, electromagnetic compatibility, pulse-width modulation, implantable medical devices.

I. INTRODUCTION

Implantable cardiac pacemakers are among the most widely used active implantable medical devices. Due to the increasing number of electrical installations and electronic systems operating in everyday environments, patients carrying such devices are continuously exposed to low-frequency electromagnetic fields. Ensuring the electromagnetic compatibility (EMC) of pacemakers has therefore become an important aspect of both device design and patient safety. The pacemaker lead acts as a conductor exposed to the electromagnetic field. A voltage may be induced on the lead, which can be falsely interpreted by the pacemaker electronics as intrinsic cardiac activity. Previous studies have investigated the effects of magnetic resonance imaging (MRI) [1], extra-high-voltage (EHV) power transmission lines [2] [3] and induction cooktops [4]. More recent studies have focused on electric vehicles [6] as sources of electromagnetic fields (EMFs) that may affect the functionality of sensitive implantable medical devices. In contrast, relatively little information is available regarding the effects of pulse-width modulation (PWM) power supplies and non-sinusoidal magnetic fields. [5] [6] [7]

The objective of this study is to experimentally investigate the induced voltage generated in conductors representing implanted pacemaker leads exposed to homogeneous low-frequency magnetic fields. Both harmonic and non-harmonic excitation conditions are considered in order to evaluate the influence of conductor geometry, magnetic flux density and excitation waveform on the induced voltage [8].

II. THEORETICAL BACKGROUND

A. Experimental Principle

The developed experimental setup generates a quasi-static electromagnetic field. Consequently, the induced voltage can be described using Maxwell's equations [9], in particular Faraday's law of electromagnetic induction

$$\nabla \times \mathbf{E} = \frac{\partial \mathbf{B}}{\partial t} \qquad (1)$$