CITY UNIVERSITY OF HONG KONG
香港城市大學

Electrical and Electromagnetic Modeling, Analysis and Design of Planar Contactless Battery Charging Platform
平面無接觸式充電平臺的電氣與電磁建模、分析和設計

Submitted to
Department of Electronic Engineering
電子工程學系
in Partial Fulfillment of the Requirements
for the Degree of Doctor of Philosophy
哲學博士學位

by

Liu Xun
劉遜

August 2007
二零零七年八月

ABSTRACT

This thesis describes an investigation into the universal contactless planar charging platform based on the 'perpendicular flux' approach. Two kinds of winding structures, namely 'multilayer planar winding array structure' and 'hybrid winding structure' are studied theoretically and practically. With the help of a patented electromagnetic shield, the flux of each structure flows vertically into and out of the charging surface like a "water fountain". Such feature is very suitable for slim design of the energy-receiving element because it allows the energy transfer over the entire surface on which the electronic equipment (to be charged) is placed.

An equivalent circuit model of the multilayer planar winding array structure has been derived and presented. The model includes the mutual effects of partial overlaps and non-overlap of planar windings in the multilayer structure. The equivalent circuits of three different platforms have been successfully simulated with PSpice and practically confirmed with measurements. The model parameters are important in facilitating the optimal design of the resonant operation and estimating the power loss of the universal battery charging platform. This circuit model forms the basis of an overall system model of the planar charging platform.

Finite-element (FE) simulation and practical tests have been carried out for the multilayer planar winding array structure in full-excitation mode and selective-excitation mode, respectively. The FE simulation confirms the feasibility and flexibility of the localized charging principle of the multilayer winding array structure for use as planar battery charging platform.

Although the multilayer winding array structure does provide flexibility of selective excitation based on columns or windings, it still has the problem of added cost in terms of control and manufacture. A new and simple hybrid winding structure which consists of a coil and a spiral winding has been proposed for improving uniform magnetic field distribution. To implement multi-load application, besides the uniform magnetic flux generated by the hybrid structure, the circuit topology, especially the resonant compensation tank has been designed carefully for efficient power transfer. A design procedure has also been proposed and verified by experiments. The efficiency of the coupling structure reaches about 80% when four loads are placed on the platform simultaneously.

Besides the winding structure of the platform, the electromagnetic (EM) shield at the bottom of the platform is also an important part. A theoretical analysis and practical evaluation of a double-layer EM shielding structure have been presented. This analysis is based on the extended transmission line theory and can generate fast and reasonably accurate solutions without using the time-consuming finite-element methods. Both calculated and measured results agree well and have confirmed the good shielding effectiveness of this double-layer structure (>40dB) in the working frequency range of the planar battery charging platform, from 100 kHz to 500 kHz.

TABLE OF CONTENTS