IJIREEICE

ISSN (Online) 2321-2004
ISSN (Print) 2321-5526

International Journal of Innovative Research in
Electrical, Electronics, Instrumentation and Control Engineering

Vol. 6, Issue 11, November 2018

Review of Wireless Power Transfer Techniques

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Abstract: Wireless transfer refers to any of a number of methods by which electrical power is transferred from a source device or circuit to a sink device or circuit, using electromagnetic waves. Numerous techniques abound in the domain of wireless power transfer technology. The current paper carries out a brief review of the most salient concepts, with a special focus on far-field techniques.

Keywords: Wireless Power Transfer Technology, Magnetic Coupling, Travelling Waves, Near-Field, Far-Field, Coupled-Mode Theory

I. INTRODUCTION

The need for wireless power transfer has increased in recent years due to a number of potential commercial and military uses of such techniques for transferring power in situations where it is not practical and sometimes entirely not possible to maintain a wired power transmission scheme. Wireless power transfer techniques can be loosely grouped into near and far field techniques. Near-field power transmission normally uses inductive coupling to transfer power from source to load. Examples of near-field wireless power transmission applications are wireless chargers for phones and continuous wireless power transfer circuits for electric vehicles. Far-field techniques on the other hand employ microwaves or laser beams to transfer power. Potential applications range from wireless power supply for drone aircraft to industrial applications. The current paper reviews the different schemes with special focus on far-field techniques. The paper is organized in the following manner. Section II surveys the recent literature on wireless power transfer. Section III describes near-field schemes with a special focus on magnetic coupling. Section IV reviews far-field techniques with specific emphasis on coupled-mode theory. Section V concludes the paper with a discussion on the scope for research in this domain.

II. LITERATURE SURVEY

Near-field techniques of wireless power transfer are mostly reliant on magnetic coupling between resonator circuits (such as paired antennas coupled in the near-field domain) [1]. Researchers such as Keskin and Liu have worked on analysis of such near-field phenomena and their application in antenna-based power transfer systems [2]. Power transfer using sheet-like waveguide structures [3], coherent enhancement of microwaves for wireless power transfer [4] and design of high-Q flat resonator structures for 2D wireless power transmission [5] are some of the methods and structures investigated.

Magnetic coupling and resonant coupling have been most thoroughly investigated for wireless power transfer in recent years, along with coupling energy to multiple receivers. Research has focused on determination of the limiting values of efficiency of resonant coupling considering multiple receivers [6], the effects of strong magnetic resonance [7], adjustable power distribution among multiple receivers [8], analysis of efficiency of transmission for resonantly coupled modal propagation [9], and analysis of resonant loops and dipoles according to the figure of merit [10]. The goal of the present research is to review the mathematical as well as the empirical relationship between the input and output power in coupled microwave waveguide-based systems.

III. NEAR-FIELD TECHNIQUES

The example of a near-field resonance-based coupling circuit is shown in Figure 1 below [1]. Researchers such as Keskin and Liu have focussed on design of unit antenna array systems that are tunable and can transfer power at around 13.56 MHz. The system is shown in Figure 2. These systems generally work on the principle of magnetic coupling. Near-field techniques have been generally found by researchers to be efficient only at comparatively lower frequencies (a few tens of MHz) and incur significant power losses if antennas are used in the coupling.

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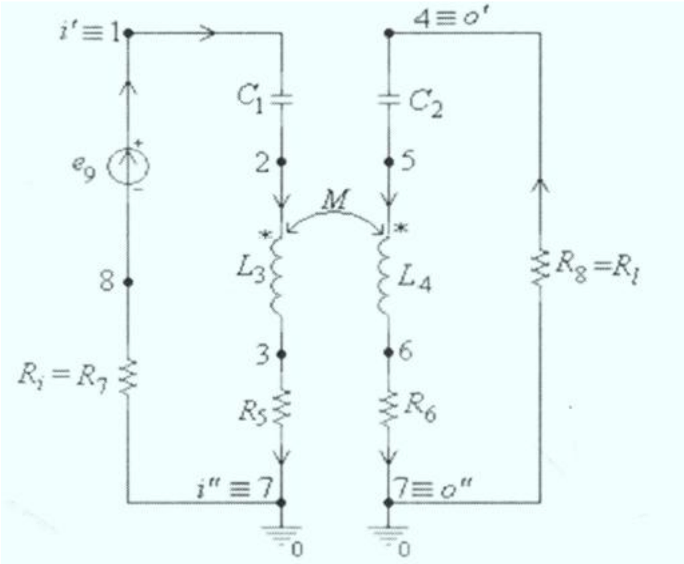

Fig. 1 Series-Series Resonators Driven by voltage source

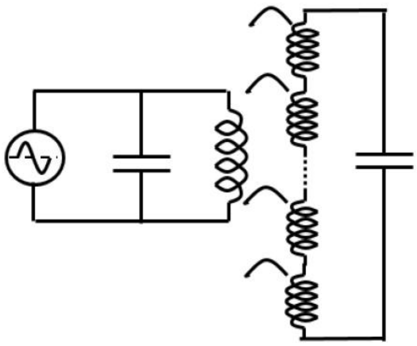

Fig. 2 Unit Array-based antenna structure

IV. FAR-FIELD TECHNIQUES

In the microwave domain, a combination of waveguides can also bring about effective coupling, as shown in Figure 3.

Fig. 3 Forward coupling of microwaves

Using mathematical tools, different far-field techniques have been proposed and evaluated by researchers in recent years. The analysis of these systems can be effectively carried out using Coupled-Mode Theory. Considering multimodal propagation when 'n' modes propagate in a coupled manner through a waveguide the total power obtained from the waveguide is given by the following equation 1.

$$P^{w}(z) = \sum_{m}^{n} P_{m}^{w}(z) = \frac{1}{4}\sum_{m}^{n} N_{m}^{w}|a_{m}^{w}(z)|^{2} \quad \ldots(1)$$

Here N_m is the norm of the m-th mode and a_m is the modal amplitude, with P_m being the modal power. Hence, the power for coupled modes can be calculated from the VSWR data experimentally obtained at the output. The aim of current research is to increase this available power.

CONCLUSION

The current work accomplished in this paper comprised of the review of near-field and far-field techniques with representative examples. In future, the researchers aim to formulate mathematically as well as examine empirically the relationship between the input and output power in coupled microwave waveguide-based systems, and to devise a novel method to effectively couple power between waveguides. The waveguide coupling experiment and mathematical formulations are to be tallied through comparison of the simulation results with the empirical results obtained to enable the researchers in proposing a novel method of coupling to enhance wireless power transfer for suitable far-field applications, to increase the microwave power available at the output through efficient coupling combinations based on mathematical calculations using coupled-mode theory.

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DOI 10.17148/IJIREEICE.2018.6113