# Near Field approximation for Wireless Power Transfer by MoM

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***Abstract*—In wireless power transfer systems, to know the near field radiated by the antenna is of primary importance, since it is through it that the coupling and the transfer of power occurs. Commercial full-wave simulator are good references for near field calculation however, its evaluation on an arbitrary surface is not straightforward. In this paper, the computation of the field radiated in the Fresnel region by a transmitting antenna is performed, recurring to a numerical approach based on the Method of Moments. Results for both a single E-shape element and a 4×4 array are presented. Details of the calculations are also presented in the paper.**

***Index Terms*—Patch antenna, MoM, computational electromagnetics**

## I. INTRODUCTION

Wireless Power Transfer (WPT) using electromagnetic was developed by Nikola Tesla in 1891. Recently, researchers have sought to increase the efficiency of power supply for electronic devices. Near-field wireless power transfer systems are safer than other systems, which create large electric field energy densities in space, and this fact has contributed to spur the research activity in this area. To increase the field energy caught by the receiving antenna, it is necessary to know where is the largest concentration of the field in space and to locate the receiving antenna consequently.

A wireless transmission system consists of two main components: transmitter and receiver, as shown in Figure 1. The transmitter has the main function of converting DC power or alternating current into microwave power, and send it out into space via the transmitting antenna. The receiver consists of a receiving antenna and a circuit whose main function is to convert the microwave power received by the antenna into one-way DC power. Generally, the transmitter and the receiver are located quite close each other, and therefore the coupling takes place thank to the near field of the antennas. One of the key issues for wireless power transfer is therefore properly calculating the near field of the transmitting antennas, and from that information, properly locate the receiving antenna.

In the commercial software such as HFSS, near field calculations are implemented in spherical coordinates with only radius $R$ for one assessment and normally for a big array it takes a lot of time. When the receiving part of the system is placed as an arbitrary surface, obtaining correct results is not trivial since it requires to define a lot of spheres (including their radius) and match those data together with spherical angles $\theta$ and $\phi$. More details about this computation are discussed in Sect. III.

To determine the power transfer we used a finite element method partially based on the electromagnetic tool available in Matlab which uses the Method of Moments (MoM) with the RWG basis functions [3], [5].

Computational scheme follows the standard MOM, where RWG are used as basis function [1]. According to this approach, the impedance matrix elements are given by:

$$Z_{mn} = l_m[j\omega(A^-_{mn}.\frac{\rho^{c^-}_m}{2} + A^+_{mn}.\frac{\rho^{c^+}_m}{2}) + \Phi^-_{mn} - \Phi^+_{mn}] \quad (1)$$

Where:

$$A^\pm_{mn} = \frac{\mu}{4\pi}[\frac{l_n}{2A^+_n}\int_{T^+_n}\rho^+_n(r')g^\pm_m(r')dS' - \frac{l_n}{2A^-_n}\int_{T^-_n}\rho^-_n(r')g^\pm_m(r')dS'] \quad (2)$$

and

$$\Phi^\pm_{mn} = \frac{1}{4\pi j\omega\epsilon}[\frac{l_n}{A^+_n}\int_{T^+_n}g^\pm_m(r')dS' - \frac{l_n}{A^-_n}\int_{T^-_n}g^\pm_m(r')dS'] \quad (3)$$

The moment equation is written as:

$$Z.I = V \quad (4)$$

where $V$ is the voltage excitation vector given by:

$$V_m = l_m(E^+_m.\frac{\rho^{c^+}}{2} + E^-_m.\frac{\rho^{c^-}}{2}) \quad (5)$$

and $E^\pm_m$ is the incident electromagnetic signal.

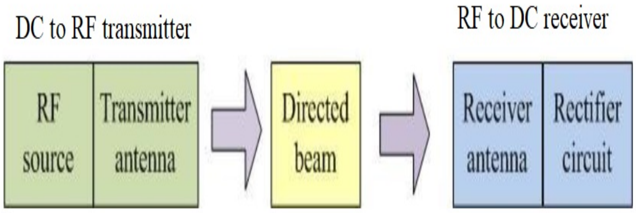

Fig. 1. Block diagram of wireless power transfer

## II. SINGLE ELEMENT DESIGN

To test the accuracy of the developed code, a single radiating element has been first considered, the input return loss has been computed and the obtained results compared with those calculated with HFSS. Figure 2 shows a proposed E- shaped antenna geometry: it has been obtained making two parallel slots, aimed to perturb the surface current path in a rectangular with length $L_1 = 61.22$ mm and width $W_1 = 59$ mm, printed on a dielectric substrate with thickness $h_{sub} = 3$ mm and $\epsilon_r \simeq 1$. The radiating element is probe-fed. The meshing is non- uniform with a with a reduced size of the unit-cells near the feeding point.

Figure 3 shows the antenna return loss with the developed code and with HFSS, : they are in good agreement. Moreover, these results prove that this antenna can operate well on the frequency band of 2.4 GHz to 2.5 GHz.

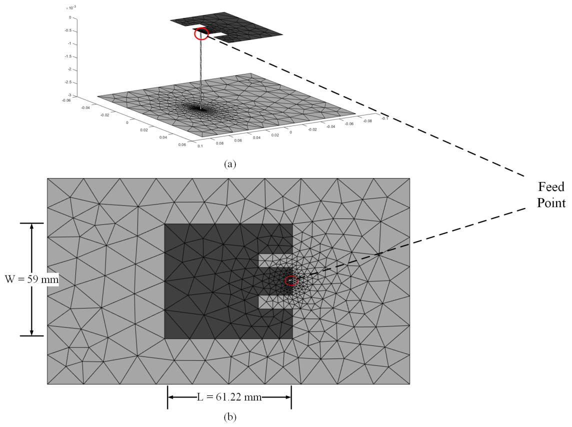

Fig. 2. Configuration of the considered antenna (a) Side view (b) Top view

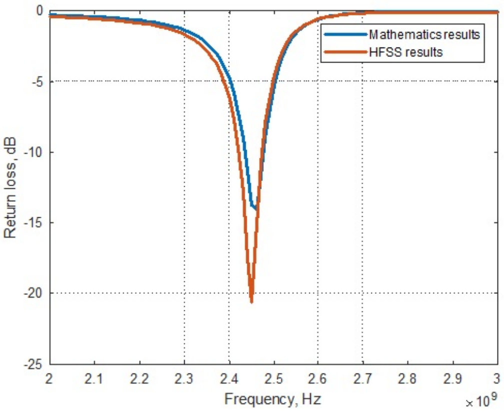

Fig. 3. Return loss of the E- shape patch antenna

## III. ARRAY DESIGN

In a second step, the E-shape patch introduced in the previous section, as been use for realizing an array of 4×4 elements, for which the near filed has been computed. Figure 4 shows the resulting array geometry based on the propose E-shaped antenna geometry. The spacing between two element is $dx = dy = 72.3\,\text{mm}$ that is equivalent to $0.6\lambda$ at the design frequency $f_0 = 2.45\,\text{GHz}$.

Two different methods are considered for the evaluation of the field radiated by the array.

The first method, is the most conventional one, according to which the array pattern is given by the product of the array factor $AF(\theta, \phi)$ and of the element pattern $EP(\theta, \phi)$ [6]

$$AP\left(\theta, \phi\right) = AF\left(\theta, \phi\right) * EP\left(\theta, \phi\right) \tag{6}$$

where

$$AF\left(\theta, \phi\right) = \sum_{n=1}^{N} \sum_{m=1}^{M} a_{mn} \times \left[ e^{j(m-1)(kd_x \sin\theta cos\phi + \beta x)} + e^{j(n-1)(kd_y \sin\theta \sin\phi + \beta y)} \right] \tag{7}$$

and $EP(\theta, \phi)$ is calculated by $E_{total}$ and $H_{total}$ on the plane, that is the set of "Observation Points" described in the following.

It is well know that this approach is fast but does not takes into account the mutual coupling between the elements. Moreover, the conditions that allow to write in this way the field radiated by the array of antennas are derived in far field, and strictly speaking they are no longer valid in near region. Therefore, the radiated field is evaluated summing up the contribution arriving from each element of the array, i.e. considering it as a single structure and analyzing it at the whole.

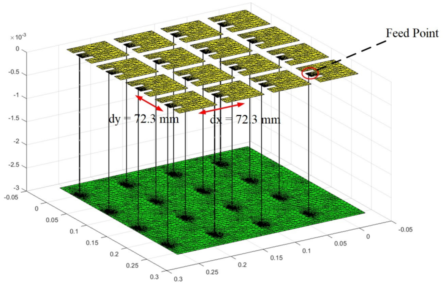

Fig. 4. Configuration of array antenna 4x4

Figures 5 and 6 show the normalized distribution field in the near field of the array computed with two methods. This field is considered on a planar surface at a distance of 3 m from the antenna. As expected, since the element of the array are all fed in phase, the radiation field energy concentrates in the broadside direction.

Using the first approach, the simulation of the entire array requires about 30 minutes while the accurate method takes more than 5 hours. Both of them are simulated on a computer configured as follows: Intel(R) Xenon(R) CPU E5520 @2.27GHz, RAM 32GB, Windows Sever 2008R2 64bit.

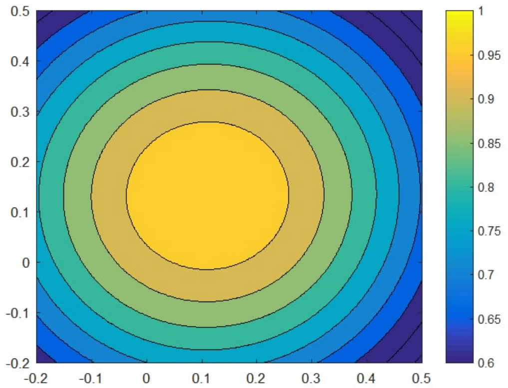

Fig. 5. Distribution E-field in the planar surface computed with the array-factor method

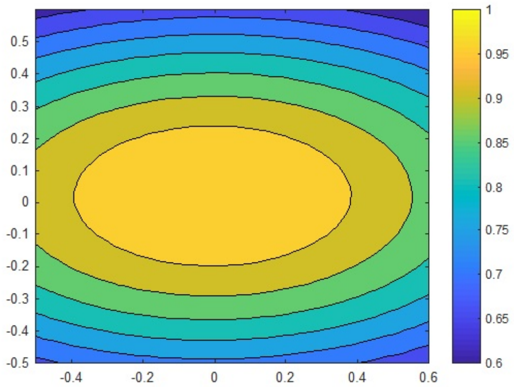

Fig. 6. Distribution E-field in the planar surface computed with the developed code.

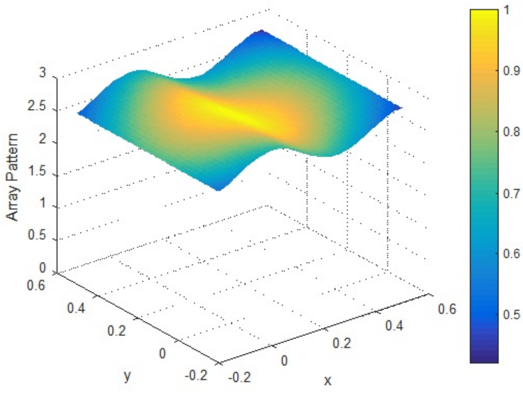

Fig. 7. Distribution E-field in the wavy surface computed with the developed code

As mentioned in the previous section the aim of this work is develop a code that directly allows the evaluation of the near field on a arbitrary shape surface, to overcome the limitation of commercial softwares, as HFSS; that compute the near field only on a plane or a sphere. As an example, a wavy surface is here considered. The surface is represented by a set of points, named ”observation Points” in correspondence of which the field is computed. The total filed on the surface is therefore given by the summ of the contribution in the Observation Points. While in the case of the planar surface considered before the ”Observation Points” are the nodes of a rectangular grid located at a constant distance (3 the m), the wavy surface is described by a set of points created by a ObservationX × ObservationY grid on an ObservationZ surface that is wavy, i.e. it is defined by the equation:

$$Z = 2.8 - 0.2 \times \left(\sin\left(2\pi X\right)^2 - \cos\left(2\pi Y\right)^2\right) \tag{8}$$

The resulting field distribution is shown in Fig. 7; as expected, the direction of maximum radiation is still bore sight.

## IV. CONCLUSION AND FUTURE RESEARCH

This paper presents some very preliminary results of the application of a developed code to the computation of the near field radiated by an antenna on an arbitrary shape surface. This is of particular interest in power transfer systems, where the coupling between the transmitter and the receiver is dominated by the near field and therefore it is necessary to properly know the field distribution of the antenna to properly locate them.

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