Microwave Oven Field Uniformity Analysis

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Abstract

The uniformity of the averaged field inside a microwave oven has been investigated using both the theoretical and experimental methods though the performance of the current oven is still not idea. In this paper, the field uniformity issue is studied by computer simulation, where a dyadic Green's function is employed. This approach is very efficient, especially compared with numerical methods, and some interesting results are obtained. To improve the field uniformity, a modified design is suggested.

1. Introduction

The microwave oven, as a well-known domestic electronic product, has been used for heating/cooking applications for more than 30 years. A brief history of microwave oven can be found in such as [1]. The growth of this field has been humped by a series of events questioning the safety of microwave exposure near high-power microwave systems. Although some of this has receded, the safety and interference issue remains a problem of wide interests. A lot of publications about this issue can be found from the public domain, the latest discussion seems to be focused on the interference of microwave oven to Bluetooth and UWB (Ultra-Wide-Band) systems [2].

The microwave oven is basically a rectangular conducting cavity with a turntable and microwave generator. The basic operation principle behind it is that the generator generates electromagnetic waves (normally at 2.45 GHz, license free ISM band) which make molecules/particles (such as electrons) move. This motion leads to friction, and friction leads to heating. The turntable is employed to generate a time-averaged uniform microwave field in order to achieve a good cooking uniformity. The field distribution inside a microwave oven, is one of the most important issues and has been investigated using various methods, most notably some numerical methods (such as FEM and FDTD) [3, 4]. Various experiments and measurements have been conducted to identify the field distribution and unevenness [5]. Despite of all these efforts, there has been a constant interest on how to improve the oven's performance, especially the uniformity as we all know that this is still a problem for the microwave oven we use.

2. Field Analysis

Field analysis is essential for us to understand how to generate a time-averaged uniform field inside the cooking area of a microwave oven. A reasonable knowledge has been accumulated over the years. Numerical methods are good to estimate the field inside the oven with or without food. Results are validated by some experiments. But how to improve the design of the microwave oven is still an open question. We are going to employ a different approach: dyadic Green's function method, to deal with the problem.

For a given chamber as shown in Fig. 1, the resonant wavelength λmnp for resonant (m n p) mode in an empty conducting rectangular cavity satisfies the following condition:

$$k_{mnp}{}^{2} = (\frac{m\pi}{a})^{2} + (\frac{n\pi}{b})^{2} + (\frac{p\pi}{c})^{2} \tag{1}$$

where k mnp $=2\pi/\lambda$mnp, m, n, and p are integers; a, b, and c are the dimensions of the chamber. The field inside a chamber with a source $\boldsymbol{J}$ can be expressed as

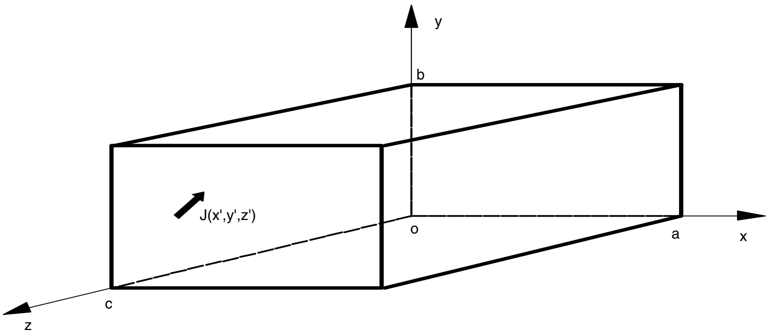


Figure 1 A chamber with an excitation J

$$\mathbf{E} = \frac{1}{j\omega\varepsilon} \int_{source} \underline{\mathbf{G}} \bullet \mathbf{J}(x',y',z')\, d'v \tag{2}$$

where $\underline{G}$ is the dyadic Green's function and defined by [6]:

$$\begin{aligned}
\underline{\mathbf{G}} = \sum_{m=0}^{\infty}\sum_{n=0}^{\infty}\sum_{p=0}^{\infty} & \frac{-4}{abc(k^2 - k_x^2 - k_y^2 - k_z^2)} \\
& \{(k_x^2 - k^2)\varepsilon_{0m} \cos k_x x' \cos k_x x \sin k_y y' \sin k_y y \sin k_z z' \sin k_z z \;\; \hat{x}\hat{x} \\
& + k_x k_y \varepsilon_{0n} \sin k_x x' \cos k_x x \cos k_y y' \sin k_y y \sin k_z z' \sin k_z z \;\; \hat{x}\hat{y} \\
& + k_x k_z \varepsilon_{0p} \sin k_x x' \cos k_x x \sin k_y y' \sin k_y y \cos k_z z' \sin k_z z \;\; \hat{x}\hat{z} \\
& + k_y k_x \varepsilon_{0m} \cos k_x x' \sin k_x x \sin k_y y' \cos k_y y \sin k_z z' \sin k_z z \;\; \hat{y}\hat{x} \\
& + (k_y^2 - k^2)\varepsilon_{0n} \sin k_x x' \sin k_x x \cos k_y y' \cos k_y y \sin k_z z' \sin k_z z \;\; \hat{y}\hat{y} \\
& + k_y k_z \varepsilon_{0p} \sin k_x x' \sin k_x x \sin k_y y' \cos k_y y \cos k_z z' \sin k_z z \;\; \hat{y}\hat{z} \\
& + k_z k_x \varepsilon_{0m} \cos k_x x' \sin k_x x \sin k_y y' \sin k_y y \sin k_z z' \cos k_z z \;\; \hat{z}\hat{x} \\
& + k_z k_y \varepsilon_{0n} \sin k_x x' \sin k_x x \cos k_y y' \sin k_y y \sin k_z z' \cos k_z z \;\; \hat{z}\hat{y} \\
& + (k_z^2 - k^2)\varepsilon_{0p} \sin k_x x' \sin k_x x \sin k_y y' \sin k_y y \cos k_z z' \cos k_z z \;\; \hat{z}\hat{z}\, \}
\end{aligned} \tag{3}$$

$where\ k_x = m\pi/a,\ k_y = n\pi/b,\ k_z = p\pi/c,\ and\ \varepsilon_{0n} = \begin{matrix} 1, when\ n = 0 \\ 2, when\ n \neq 0 \end{matrix}$. The wave number k is 2π over operational wavelength λ.

This means that the field inside the chamber is the summation of all modes weighted by the parameters such as the frequency, chamber dimensions and the source. But these modes consist of both the propagating and evanescent modes (whose resonant frequencies are greater than the operational frequency, i.e. $f < 150\sqrt{(\frac{m}{a})^2 + (\frac{n}{b})^2 + (\frac{p}{c})^2}$ MHz, cannot actually exist inside the chamber and will not make real contribution to the field within the chamber). A typical domestic microwave oven is of dimensions 342 (W) x 195 (H) x 357 (D) mm3 and the turntable diameter is about 325 mm. Thus the total possible number of propagating modes at 2.45 GHz is about [6]:

$$N = \frac{\pi}{3} abc(\frac{f}{150})^3 \approx 108$$

If a waveguide is assumed as the excitation of the oven, then the static field distribution within the cavity can be obtained as illustrated by Fig. 2, where the observation plan is at 100 mm above the cavity floor. Its contour plot is given in Fig. 3. The standing wave pattern (the dominant mode is (5 5 3)) is apparent and the field is not uniformly distributed inside the oven. The difference from one point to another can be more than 30 dB. However, when the microwave oven is on and the turntable is in operation, any observation point at the food will move around a circle, such as the one in red in Fig. 3. Hence the time averaged field becomes much more even, as shown in Fig. 4 where the difference among most places are within ±3dB.

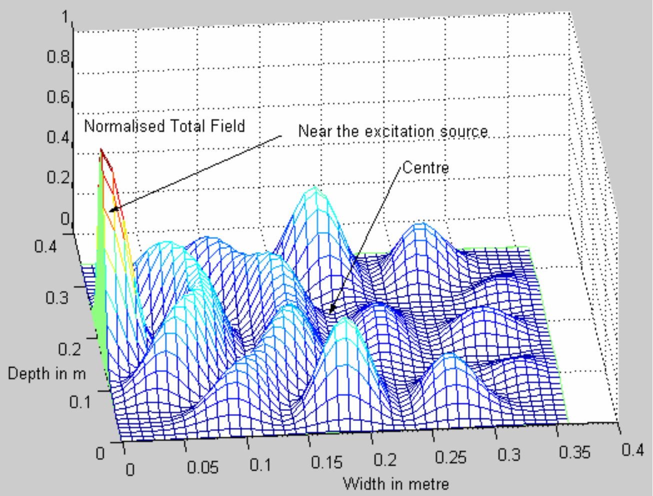


Figure 2 The calculated total field distribution inside a microwave oven at y = 0.1 m

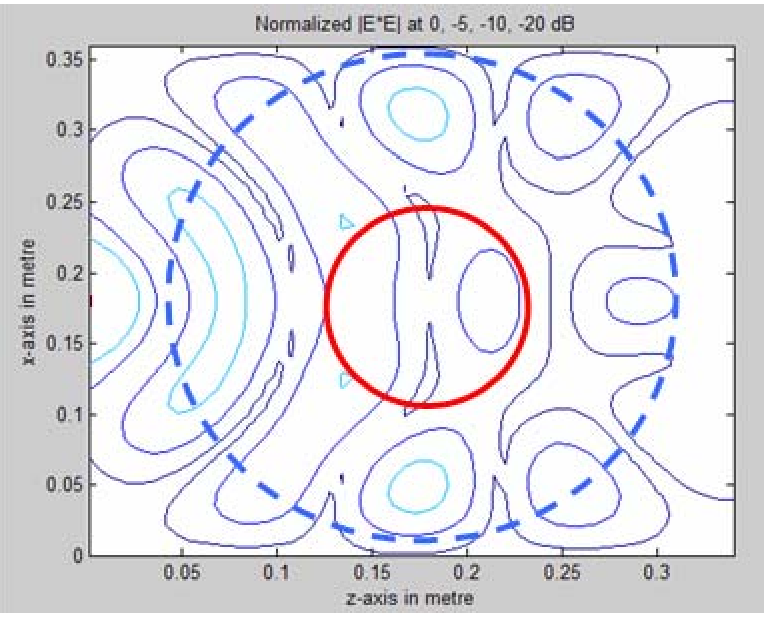
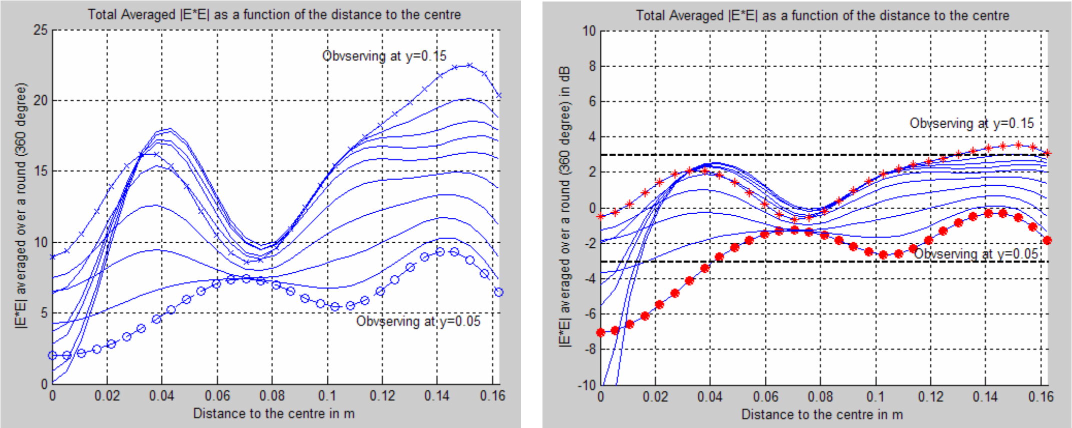


Figure 3 Contour plot of the calculated total field distribution inside a microwave oven

The major problem for this oven seems to be around the centre. The difference between the maximum and minimum is well over 10 dB, which is much larger than the variation expected from -3dB to +3dB. Similar results have been obtained for the fields at other observation planes in this and other microwave ovens. We therefore can conclude that the uniformity inside a microwave oven is not as good as that in a well designed reverberation chamber. This seems to be an inherent problem with the current oven design: field around the turntable centre is not stirred. The uniformity can be improved by introducing a stirrer. The drawback is that it may slight reduce the working space and increase the complicity of the oven. The detailed design and analysis will be reported in another paper.



a). |E*E| in $(V/m)^2$ b). |E*E| in dB (relative to 10)

Figure 4 The time averaged total field as a function of the distance to the turntable centre at various heights (from 0.05 to 0.15m).

3. Conclusions

We have compared the two very useful facilities: microwave oven and reverberation chamber. The focus has be the averaged field uniformity inside the chamber/cavity. A dyadic Green's function approach has been employed to aid the analysis. It has been demonstrated the field around the turntable centre is not adequately disturbed thus the averaged field uniformity is not as good as that inside a reverberation chamber. It has been suggested that the performance of a microwave oven can be improved by introduce a stirrer.

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