Simulation of Electromagnetic Leakage from a Microwave Oven

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Abstract

The optimum door seal configuration to prevent radiation leakage from a microwave oven is still a concern of the manufacturing units. Here we propose a numerical code to simulate the radiation propagation along a door seal structure using the finite-difference time domain method which is suitable for *a priori* shielding efficiency tests. The first computations are in agreement with experimental data. The code is quite flexible to admit different dimensions, geometries or filling materials.

Keywords: electromagnetic leakage, microwave oven, finite-difference time domain method

1. Introduction

A microwave oven have necessarily a door for placement and retrieving of foods to be heated. This door should be projected for preventing electromagnetic leakage. The most probable leakage path is the gap between the microwave oven body and the door itself, thus the best size and geometric configuration of such gap is still a research issue.

The first used seal structures had pressure latch systems that provided close contact between the two metal surfaces: door and frontal panel of the microwave oven. This system soon showed to be inefficient for long-time functioning due to metal deformation, latch misalignments or accumulation of food residues. The alternative system, which are nowadays commonly used by several microwave ovens manufacturers, consists on a choke structure of $\lambda/4$ in length usually accompanied by periodic slits (Fig. 1(a)).

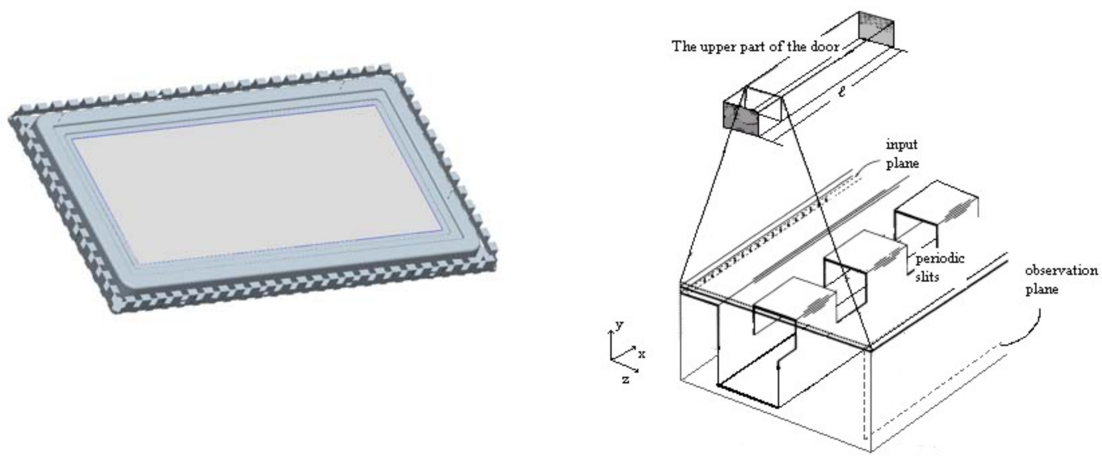
The $\lambda/4$ length would theoretically produce total reflection of the leakage wave. However, this wave should have a complicated wavelength since it consists of a mixture of modes depending on the input wave from the oven body and on the door seal configuration itself. Thus, in order to increase the shielding effect the choke structure is usually interrupted by periodic slits in the longitudinal direction.

A further complication of the door seal design arrives whenever the λ/4 length is neglected or modified in order to have thinner doors. Then, the manufacturing practice ends in repeated sequences of constructing and measuring until the minimum admissible leakage is attained.

Here, we propose a computational method capable of calculating the electromagnetic leakage for a certain door seal structure. The method uses a 3D finite-difference time domain method FDTD [8][7][8] which was also used in similar studies[1][2][3][5]. The article is organised in the following way. In section 2, we describe the typical door seal choke and the numerical scheme. Section 3 is devoted to results and, finally, the conclusions are in section 4.

2. Door model and computation method

The initial door seal structure under study is showed in Fig. 1(a) as used by a microwave oven model manufactured by Teka Portugal S.A. Nevertheless, several technically possible changes may be numerically implemented in order to obtain better shielding effect.



(a) (b)

Fig. 1 - (a) Microwave oven door and (b) computational model of the door seal structure

The upper part of the door is considered and discretized in small cells of equally length sides $\Delta = 0.5mm$. Each cell is indexed by the triplet (*i*, *j*, *k*) with *i*, *j* and *k* being integers that relate to the cartesian coordinates (*x*, *y*, *z*). The metal surfaces are modelled by one cell in thickness. The electrical and magnetical constants of free space are assigned to each lattice cell except to the metal cells where we have used the electrical conductivity of stainless steel which is $\sigma_e = 10^6 \Omega^{-1} m^{-1}$.

The input field is introduced following the total field/scattered field formulation which was originally implemented in [5]. The space grid is divided in two regions separated by a nonphysical virtual *xy* plane at *k*=5. The region 1 which includes the choke structure is called the total field region. Here the FDTD algorithm operates on the total field vector components, which is the sum of the incident and scattered fields. The region 2 consists of a small part of the gap close to the microwave oven body. Here we operate only on the scattered field. At the interface plane *k*=5, we apply a connecting condition which ensures consistency and, simultaneously, introduces the incident field. We have chosen the incident field to be the TE_{40} mode because it is the higher mode inside the oven body.

Hence, the non-zero components of the incident electric and magnetic vectors are

$$E_y^{inc}(x,y,z_0,t) = -AE_{y0}\sin\frac{4\pi x}{l}\cos(2\pi f_0 t) \tag{1}$$

$$H_x^{inc}(x,y,z_0,t) = AH_{x0}\sin\frac{4\pi x}{l}\cos(2\pi f_0 t) \tag{2}$$

$$H_z^{inc}(x,y,z_0,t) = AH_{z0}\cos\frac{4\pi x}{l}\cos(2\pi f_0 t) \tag{3}$$

where $z_0 = 2.5mm$, A depends on the microwave power inside the oven (ranging from 780 to 820 W) and f_0 is the magnetron frequency.

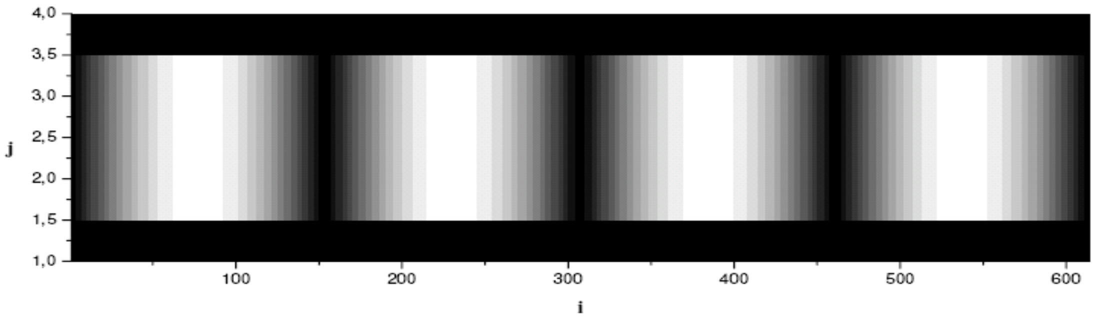


Fig. 2 – Example of the incident electric field profile on the gap

The Mur boundary conditions are adopted on the first and last *xy* planes, and in the right and left *yz* planes. The time step is $\Delta t = \Delta/\sqrt{3}c$ where *c* is the vacuum light velocity. The computation progresses in time until we reach a stationary state, for which 20 periods are usually sufficient. At this time stage, the intensity of the radiation leakage is computed using the field values at the *xy* observation plane, which is 5 cells away from the final plane.

In order to compute the intensity, we first calculate the Poyinting vector components using the electric and magnetic field components, namely

$$\begin{aligned}\vec{S}(x,y,z,t) &= S_x(x,y,z,t)\hat{x} + S_y(x,y,z,t)\hat{y} + S_z(x,y,z,t)\hat{z} = \\ &= \vec{E}(x,y,z,t)\times\vec{H}(x,y,z,t).\end{aligned} \tag{4}$$

Then, S_x, S_y and S_z are averaged over a period using the numerical integration defined below

$$\bar{S}_p(x,y,z) = \frac{\Delta t}{T}\sum_n S_p(x,y,z,n\Delta t), \qquad p = x,y,z$$

(5)

The intensity pattern is then given by

$$I(x,y,z) = \sqrt{\bar{S}_x^{\ 2} + \bar{S}_y^{\ 2} + \bar{S}_z^{\ 2}},$$

(6)

and the radiation power at each *xy* plane is the sum over the entire plane of the above intensity multiplied by Δ^2, namely

$$P(z) = \Delta^2 \sum_i \sum_j I(i\Delta, j\Delta, z).$$

(7)

Finally, the shielding effect is calculated as

$$SE = -10\log\frac{P_{out}}{P_{in}}$$

(9)

Where P_{in} and P_{out} are radiation powers used at the input plane and computed at the observation plane, respectively.

3. Results

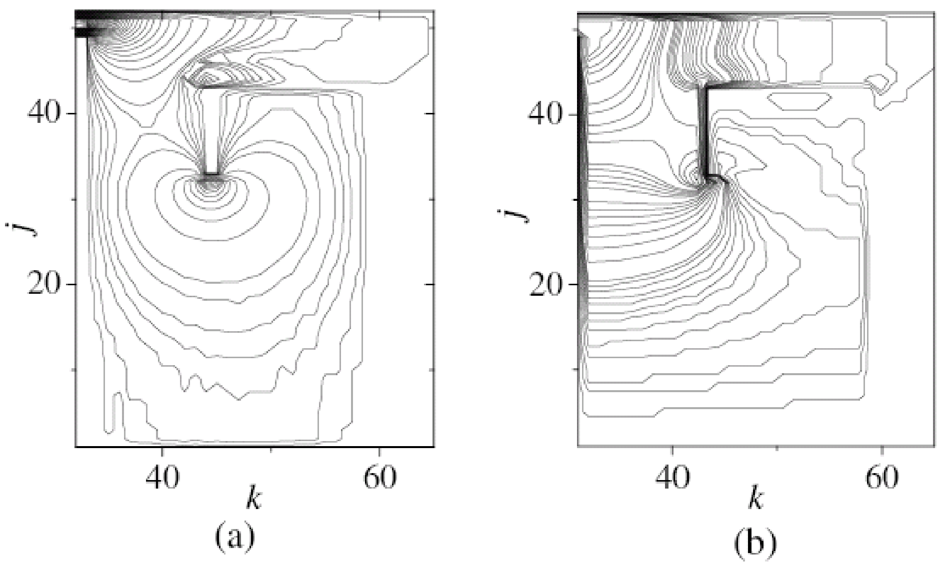


Fig. 3 – (a) Absolute value of the electric field and (a) radiation intensity inside the choke structure

The first simulations were performed using the door seal structure depicted in Fig. 1(a). Fig. 3(a) shows a contour plot of the electric field inside the choke structure and Fig. 3(b) the intensity in the same structure. Fig. 4 shows an example of the electric field profile on the observation plane, where the effect of the periodic slits is observable.

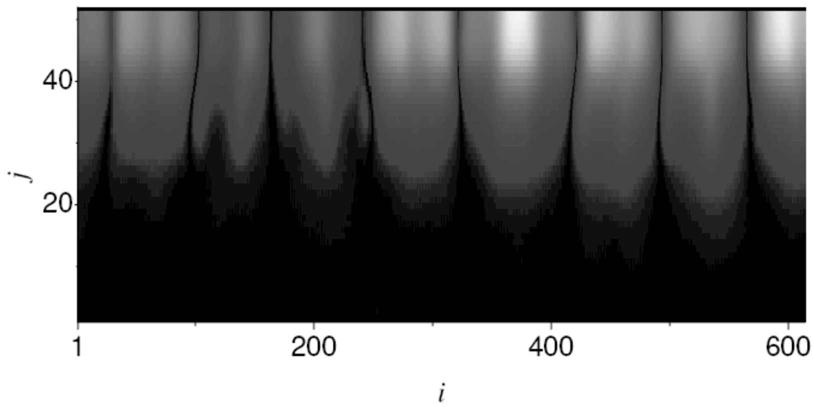


Fig. 4 – Example of the outgoing electric field profile in the observation plane.

The outside intensities were in good agreement with experimental data. Fig. 5(a) shows the intensity along a *z*-line that passes through the gap. The shielding efficiency was checked for structures with and without periodic slits. Fig. 5(b) shows that the high shielding was obtained for structures with periodic slits which confirms previous studies.

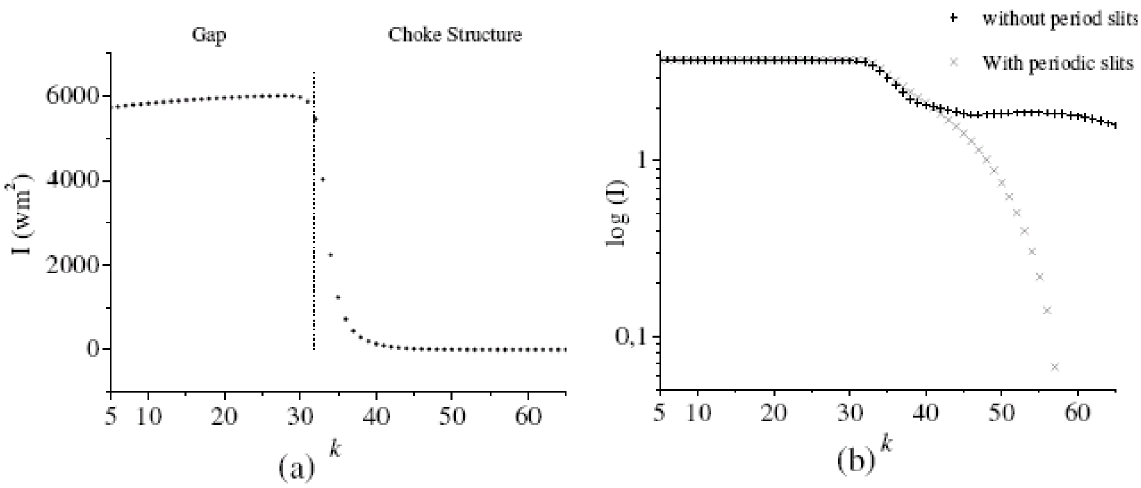


Fig. 5 – (a) Intensity along a *z*-line (b) logarithm of the intensity for structures with and without periodic slits

The project is still running, our aim is to study different door structures, changing the dimensions and the geometry, searching for a configuration with higher shielding efficiency.

4. Conclusion

A FDTD numerical scheme was implemented to study the radiation leakage across a door seal structure of a commercial microwave oven model. The results were in agreement with experimental radiation intensities. The numerical code is now being used to test shielding efficiency of other technically possible door seal structures. This *a* *priori* numerical simulation could reduce time and costs of the manufacturing process when compared with the actual practice of repeated sequences of construction and *a posteriori* measuring. Possible improvements of the computation model include widening the numerical range to enclose the gap and choke all around the door and using a hybrid input mode which should be closer to the actual input wave. In the current model all the seal structure is filled with air, however the introduction of materials with known electric constants is feasible.

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