Computational Analysis of an Irregular Slotted Waveguide as Radiating Element

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The recent review of electromagnetic (EM) software [1] has shown that there are several simulators on the market, which are suitable for modelling of processes and systems of microwave (MW) heating. QuickWave-3D (QW3D) (www.qwed.com.pl), the 3D full-wave conformal FDTD simulator has been identified as a particularly useful tool due to a number of implemented specific extensions and beneficial functions (field envelopes, energy coupling, basic heating module, and others). The heating intensity in the food loads in a MW oven computed with QW3D has been presented in [2]. In [3], the software has been utilized to find characteristics of a 915 MHz water load and especially those ones which cannot be measured. This successful experimentally verified computational analysis has suggested that many existing MW systems and elements developed on the basis of extensive experimentations and simplified calculations could be carefully studied with the use of this computational tool in order to characterize EM processes in these devices more precisely and to get the ideas on possible ways of their modification or optimization.

The present paper pursues a similar goal in the study of a special radiating element (RE) [4], which reportedly provides relatively uniform field distribution on the surface of an irradiated dielectric layer in the near-field zone. Rigorous analysis of this structure appears to be extremely difficult, so it has been synthesized by its authors from an admittance integral equation and with the use of the perturbation theory under a number of assumptions. A RE with the claimed capability would be of high value for many MW heating applications (particularly, in wood processing). However, the method used for its design doesn’t allow engineers to figure out characteristics of the system in detail, and experimental options here are either limited, or expensive. We show that valuable and reliable information about this RE can be generated by accurate simulation with the use of QW3D and modest computational resources.

Applicator. The irregular (tapered) rectangular waveguide with non-linear longitudinal radiating slot cut in its broad wall (Fig. 1) has been proposed in [4] for heating of sheet and band materials. The radiation from the RE is supposed to be uniform when the amplitude of the transverse current induced by the TE_{10} mode is constant with respect to the z-coordinate. The RE’s authors suggest that this amplitude primarily depends on the waveguide narrow wall, the distance from this wall to the slot, and the fundamental mode’s attenuation constant. From this observation, the slot was found to be of curvilinear profile (Fig. 1).

Paper [4] also describes an experimental verification of the synthesized RE at 2.45 GHz. However, since the authors do not provide complete information about the experiment (material parameters of the irradiated plate are not specified, presence of other objects near the RE is not mentioned, etc.), direct comparison between the experimental data and our simulation is not possible. Our goal, therefore, has been to create a parameterised computer model wherein all structure dimensions, materials parameters and excitation can easily be changed, and independently validate with this model the principle of the RE operation.

Model. The synthesized RE has been modelled by QW3D as an open structure: the slotted waveguide and the wood plate were considered surrounded by the surfaces imitating the near-to-far field transformation and the absorbing boundary conditions. The slot profile \( x_0(z) \) has been approximated by two straight-line segments. In computations, the length of the slotted waveguide was 1000 mm; \( a \times b = 90 \times 45 \) mm and \( a \times b_0 = 90 \times 9 \) mm were the input and output cross-sections respectively; the width of the slot \( d \) was constant (2 mm). The rectangular wood plate of the 1000 mm length (\( w = 150 \) mm, \( h = 20 \) mm) was placed at a distance of 15 mm from the waveguide.
mm) was placed in parallel to the waveguide (with \( l = 100 \) mm). Dielectric constant \( \varepsilon' \) and loss factor \( \varepsilon'' \) of the wood plate were taken as 3.8 and 0.87 respectively. Simulation with the pulse excitation has been used to compute return loss in the slotted waveguide and the radiation pattern of the RE. Sinusoidal excitation at 2.45 GHz (TE\(_{10}\) mode) has been applied to get field and SAR patterns. Non-uniform mesh (cell sizes from 2 x 4 to 10 x 10 mm, about 1 million cells total) has requested the use of about 90 MB of RAM. It took a P III 850 MHz PC near 3 h to get steady state results. The developed model is flexible in terms of dimensions and media modifications, so we can use it for further studying of the structure to find its more advanced characteristics and to explore the ways of optimisation of its performance with specific materials.

**Results.** In the experimental validation [4], the field radiated from the RE was measured in the presence of the matched load in the tapered end of the waveguide. Our simulation shows that in this case, the return loss at 2.45 GHz is -19.7 dB that means that about 1% of power is reflected to the source. However, without the load, the return loss is -1.8 dB, i.e., only 34% of EM power leaves the waveguide for the outer space. From the field pattern in the \( yz \)-plane (Fig. 2, top), we find that the field magnitude inside and outside the waveguide differs by at least the order of two. This suggests that the considered slotted waveguide is characterized by low radiation efficiency and cannot be used in high power applications without the matched load.

The pattern of the electric field in the horizontal plane on the top surface of the wood plate (Fig. 2, bottom) reveals the increased field amplitude towards the plate’s edges. In the longitudinal direction, the field distribution is characterized by standing wave maxima and minima. Since the standing wave pattern depends on material parameters, we conclude that the experiment in [4] dealt with a different medium. Computations also show that the EM power dissipates in the wood also non-uniformly forming the “hot spots” generally following the pattern of the electric field.

The radiation pattern of the considered RE in the \( yz \)-plane is characterized by a strong and narrow main lobe rotated at approximately 45° from the waveguide longitudinal direction (Fig. 3, left). In the \( xy \)-plane (Fig. 3, right), the radiation is more uniform. The presented angle distributions seem to be well matched with the horizontal field pattern in Fig. 2 showing a higher concentration of the field along the plate’s edges and on the part of the plate located above the tapered end of the slotted waveguide.

**Conclusion.** This paper provides engineers with specific data to help them decide to what extent the considered slotted waveguide proposed in [4] could be used as a radiating element in microwave heating applications. The described computer model can be used for optimisation of the system performance towards the improvement of heating uniformity and radiation efficiency.