Optimization of the Energy Transfer in Microwave Ovens using a Wave-Guide with Sloped Slits

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***Abstract* — The present paper proposes the optimization of the energy transfer in microwave ovens for the drying process of thin materials, in order to choose a basic radiant element, easy to be reproduced and that ensure a good uniformity of the radiant power. The proposed solution consists in realizing a network of serial and parallel slits on a single wave-guide, in order to optimize the energy transfer.**

I. INTRODUCTION

The length of a resonant slit is theoretically chosen so that the perimeter of the slit equals to λ_0. The width of the slit is chosen in order to remains below the level of the destruction tension of the maximum radiated power.

The length l of the slit will be chosen so that: $2 \cdot l = \frac{\lambda_0}{2} - \varepsilon$. For a determined wave-guide this length is determined experimentally, by measuring the impedance of the circuit formed by a wave-guide that contains a slit.

The considerations of energetic nature allow an easier computation of the real part of the slits impedances [2], [6], [7].

Knowing that the difference between the energetic flux from the upstream and the downstream of the slit must equals the radiated power (computed as the power of the half-wave dipole), we obtain:

$$R_e\left(\frac{1}{\beta - 1}\right) = 1 - \frac{73}{60\pi \cdot \gamma \cdot |f|^2} \tag{1}$$

For the serial and parallel slits, we compute the conductance G of the serial slit and the resistance R of the parallel slit [8]:

$$\frac{1}{G_s} = R_p = \frac{73}{120 \cdot \pi \cdot \gamma \cdot |f|^2} \tag{2}$$

Replacing the expression of f, we obtain the expression of the conductance of a central serial slit, sloped under a θ angle:

$$\frac{1}{G} = \frac{120 \cdot \pi^3 \cdot \gamma}{73 \cdot k^2 \cdot L^2}\left(U \cdot L \cdot \sin\theta \cdot A(p,q) + \pi \cdot \cos\theta \cdot B(p,q)\right)^2 \tag{3}$$

The resistance expression of a parallel slit shifted proportionally with the edge of the wave-guide is:

$$\frac{1}{R} = \frac{480 \cdot \pi}{73} \gamma \cdot k^2 \cdot L^2 \cdot \cos^2 \frac{\pi \cdot U}{2k} \cdot \cos^2 \frac{\pi \cdot d}{L} \tag{4}$$

In practice, the used slits must be resonant.

II. THE SIMPLIFIED EXPRESSIONS OF THE EQUIVALENT IMPEDANCES CORRESPONDING TO THE RESONANT SLITS

a) A *longitudinal slit* (figure 1) shifted with a d distance, in comparison with the wave-guide axis, behaves like a conductance with the following value:

$$G = 2{,}09 \cdot \frac{L}{l} \cdot \frac{\lambda_g}{\lambda_0} \cdot \cos^2\left(\frac{\pi \cdot \lambda_0}{2 \cdot \lambda_g}\right) \cdot \sin^2\left(\frac{\pi \cdot d}{L}\right) \tag{5}$$

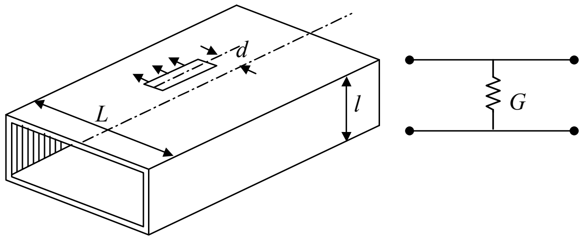

Figure 1. Longitudinal slit and its equivalent circuit.

b) A *slit sloped* under a angle θ in comparison with the vertical axis of the narrow side of the wave-guide (figure 2) behaves like a parallel conductance with the following value:

$$G = 0{,}13\left(\frac{\lambda_g}{\lambda_0}\right) \cdot \left(\frac{\lambda_0^4}{L^3 l}\right) \cdot \left(\frac{\sin\theta \cos\left(\frac{\pi\lambda_0}{2\lambda_g}\sin\theta\right)}{1 - \left(\frac{\lambda_0}{\lambda_g}\right)\sin^2\theta}\right)^2 \tag{6}$$

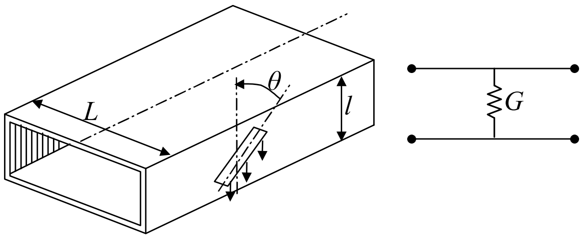

Figure 2. Sloped slit and its equivalent circuit

These expressions allow the positioning of the slits on the wave-guides, especially of the resonant serial or parallel slits, knowing the resistance of each slit [3, 4].

The synthesis of a radiant slits network resumes to

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the computation of the equivalent slit resistances, positioned on the wave-guides, that are considered as transmission lines [1], [5], [6], [9].

Generally, this synthesis may be made in each case, by defining a bidimensional power profile and a radiation surface. Such a synthesis implies the space determination between slits in order to take into account the phase angle of the waves in different wave-guides, the radiated serial powers or the parallel slits conductance.

III. EXPERIMENTAL RESULTS

In order to achieve an optimal functioning of the microwave ovens for the drying process of thin materials we must choose a basic radiant element, easy to be reproduced and that ensure a good uniformity of the radiated power.

In our case, the basic radiant element of the system is represented by a rectangular wave-guide that contains centered sloped (serial) slits on the short side of the wave-guide.

In order to radiate all the incident power on a distance *d*, we must determine the number, the position and the slope of the serial slits. It is obvious that, energetically, the linear network of the slits must be adapted.

The method generally used for the microwave antennas is to make the wave-guide to function in progressive wave mode.

The closer we are by the adapted load, the more connected to the wave-guide the slits must be, the available power being lower and lower. Thus, we must compute the resistance of each slit compared to the precedent one, in order to obtain an identical radiated power for all slits. A part of the energy is lost in the adapted load or is radiated by a slit from the extremity of the wave-guide that doesn't take part at the product processing. The advantage of this method is that it allows functioning in a wide frequency band. The direction of the maximum of radiated power forms an angle with the wave-guide axis.

In order to obtain the most efficient energy transfer into the product, the loss of one part of this power in an adapted load should be avoided. The product being disposed under the antenna, it is preferably that the maximum of the radiated power to be orthogonal on the antenna plan.

These considerations lead to the adoption of the second synthesis method of linear networks. Thus, a resonant system of narrow band is obtained, because the slits position determines a significant radiated energy, that is important only for the frequencies for which the distance between them is: $\frac{n\cdot\lambda_g}{2}$.

In the case of the serial slits, the slits are distanced at integers of the short-circuit semi-wave and thus, they are distanced with $n\cdot\lambda_g/2$. In the case of parallel slits the short circuit must be at $(2n+1)\cdot\frac{\lambda_g}{4}$, because the distances at $m\cdot\frac{\lambda_g}{2}$ (*m* being an integer) always coincide with the point of the maximum of the electrical field.

In order to obtain a sufficient band-width, we will not be interested to realize slits with a too high supra-voltage coefficient, i.e. in practice the slits should not be too narrow.

Using the formulas (5) and (6) that are expressing the serial resistances (equivalent to the slits) we have realized a MATLAB program that calculates the slope depending on the number of slits, at a given frequency (2.45 GHz as well as for 433 MHz, 915 MHz, 24.125 MHz) and we have represented the corresponding curves (figure 3), for the centered sloped slits.

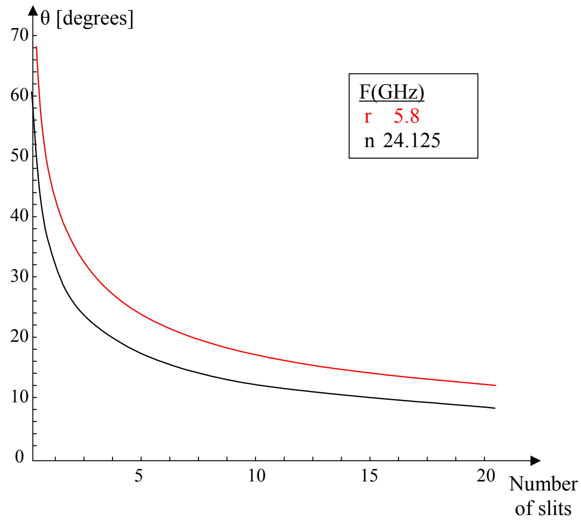

Figure 3. The slope θ, depending on the number of slits, for a centered slit sloped on the large side of the wave-guide (for different frequencies).

We have also calculated the slope versus the number of slits for different frequencies (figure 4), for the slits sloped with a θ angle in comparison with the vertical axis of the small side of the wave-guide.

We notice that increasing the number of slits, the energy radiated by each slit is decreasing, while the slope decreases. This confirms the theory: a centered slit with null slope (that is a slit that doesn't cross current lines) doesn't radiate.

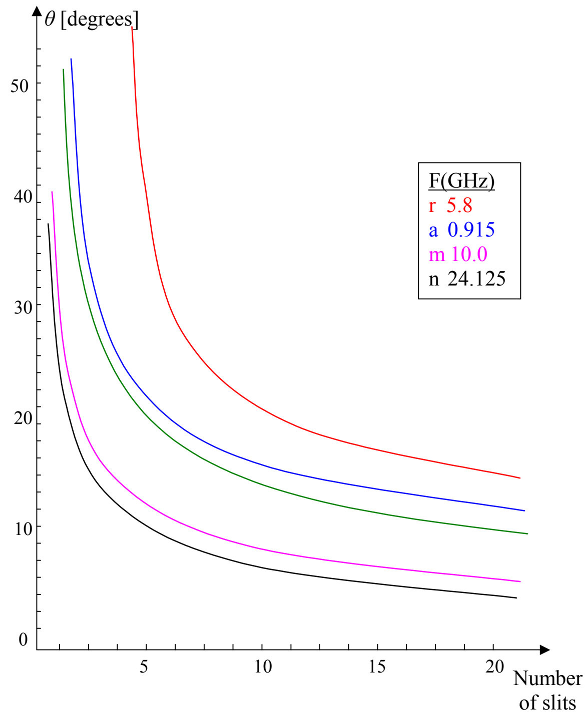

Figure 4. The slope θ, depending on the number of slits, for a centered slit sloped on the small side of the wave-guide (for different frequencies).

In the case of heating treatment in continuous regime, the shifting of the product under antenna allows to take into account the power density variations of the incident microwaves on the condition that the point of the maximum of power density to be high enough, regularly distributed and having comparable intensities.

Although, when the shifting speed of the product is too low compared to the sensibility of the product at treatment inhomogeneities, it is necessary to design a shifting method of the stationary waves reported to the product.

In order to obtain a uniform radiation profile, the following condition should be respected:

$$\sum_{i=1}^{m} Z_i = 1 \text{ and } \sum_{i=1}^{n} Y_i = 1$$
$$m \cdot Z = 1 \text{ and } n \cdot Y = 1 \quad (7)$$

IV. Conclusions

This method is applicable in the heating treatments when the risk of the packing up of the energy is appearing (the energy absorption of the product increases very quickly with the temperature), as well as in the case of heating treatments in static regime.

The proposed solution consists in shifting the stationary wave system in the middle of a mobile reflector in front of the antenna.

The proposed device made up of a network of serial and another one of parallel slits on a single wave-guide, the distance between a serial and a parallel slit being $n \cdot \lambda g / 2$.

The results are good on the condition that the drying process be sufficiently slow, in order to avoid the apparition of internal stress that may decrease the quality of the product.

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