

Efficiency Optimization for Microwave Thermal Processing of Materials with Temperature-Dependent Media Parameters

Ethan K. Murphy and Vadim V. Yakovlev

Department of Mathematical Sciences, Worcester Polytechnic Institute
Worcester, MA 01609, USA

Abstract— Microwave heating of materials is known to be the technology capable of substantial improvement in the efficiency and quality for a variety of applied thermal processes. However, corresponding industrial implementations are still quite limited because, as a physical phenomenon, microwave heating is hard to control. Several years ago, it was suggested that, with the remarkable progress in efficient numerical techniques allowing for quite accurate computer simulation of complex microwave systems, the problem of optimization of microwave thermal processing can be approached through modeling-based techniques [1]. One crucial aspect of this type of optimization, namely, optimization of microwave energy coupling interpreted as a numerical characteristic of system efficiency, has been discussed and conceptualized, for the first time, in [1]. Then in [2] an artificial neural network (ANN)-based finite-difference time-domain (FDTD)-backed algorithm has been introduced as an optimization procedure suitable for viable multi-parameter optimization of energy efficiency for microwave heating systems.

Recently, the critical upgrade of the algorithm proposed in [2] has been reported [3, 4]. The revised version of the optimization technique deals now with a new objective function and features a principal improvement of dynamic training of the RBF network by Constrained Optimization Response Surface (CORS) technique — global response surface type algorithm designed to minimize the number of function evaluations in the process of finding the global minimum. It has been shown [3, 4] that the new technique substantially outperforms its predecessor [2] by getting optimal solutions of better “quality” and substantially reducing the number of FDTD analyses (and thus dramatically cutting the optimization’s computational cost) for such systems as a waveguide band-pass filter, a dielectric resonator antenna, and a loaded microwave oven.

In this contribution, we demonstrate how the CORS-RBF optimization procedure [3, 4] can be applied for efficiency optimization of the systems of microwave heating of materials whose media parameters (the dielectric constant ε' and the loss factor ε'') change in the course of heating. The considered scenario is concerned with a microwave oven (with the dimensions and feed location of *Sanyo EM-N105W*) containing a glass shelf and a cylindrical sample of processed material on it. The optimization problem is formulated as follows:

Given:

- (1) the processed material with temperature characteristics $\varepsilon'(T)$ and $\varepsilon''(T)$ for the working temperature range, and
- (2) the fixed dimensions of the cylinder (diameter D and height H);

Find:

- (a) thickness of the glass shelf t ,
- (b) diameter of the shelf d ,
- (c) the position of the shelf above the bottom h , and
- (d) the position of the cylinder on the shelf with respect to its center, d_x and d_y

such that the reflection coefficient of the entire system is guaranteed to be less than 0.3 (i.e., less than 9% of microwave energy is reflected back to the magnetron) in 75% of the frequency range from 2.4 to 2.5 GHz.

The 5-parameter optimization problem is solved for a particular pair of $(\varepsilon', \varepsilon'')$ corresponding to a certain temperature; the optimization is then repeated, for the same space of design variables, for the values of the dielectric constant and the loss factor at a number of other temperatures. In the considered illustration, we work with experimentally determined values of ε' and ε'' of resin R498 at $T = 30, 80, \text{ and } 120^\circ\text{C}$ [5]. The underlying FDTD model developed for the 3D conformal FDTD simulator QuickWave-3D [6] consists of 166,000 to 189,000 cells (16 to 18 MB RAM), so one analysis of the system involving 20,000 time-steps takes 2.2 to 2.5 min of CPU time on Xeon 3.2-GHz PC operating under Windows XP. It turns out that the CORS-RBF procedure requires as little as 177, 160, and 185 simulations (i.e., about 10 h total) for each of these temperatures, respectively, to find an optimal solution satisfying the 75% frequency band

constraint. (For comparison, the best solution found by the previous version of this optimization algorithm [2] corresponds to 52% bandwidth, and it needs 462 analyses to get this solution.) Finally, the optimal configuration for each temperature is tested for two other pairs of (ϵ', ϵ'') , and the one demonstrating best bandwidth is chosen as overall optimal.

Due to a fully parameterized underlying FDTD model, the optimization problem can be instantly formulated for any other set of parameters in accordance with the practical need of the system designer. Thanks to its computational effectiveness, the presented optimization tool may assist in fairly practical CAD projects in microwave power engineering easily dealing with several design variables and performing optimization of regular widely available PCs.

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