MODELING OF A CYLINDRICAL APPLICATOR WITH THE TM_{01l} MODE AND A SPHERICAL LOAD

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ABSTRACT
The paper presents the results of 3D FDTD modeling of a 915 MHz cylindrical structure with a spherical load (fruit). Three different configurations of the loops exciting the TM_{01l} mode are analyzed. The coupling is shown not to be sensitive to the load's temperature and to the type of the fruit.
KEYWORDS: coupling, cylindrical cavity, FDTD model, postharvest treatment of fruits, probe and loop excitation, spherical load, TM_{01l} mode.

INTRODUCTION

Cylindrical single-mode applicators with the TM_{01l} mode find practical use in microwave power engineering for treatment of optical fibers, liquid media, food stuff, biological tissues, etc. Empty and axially loaded cavities excited by a probe, a loop, and a waveguide aperture have been studied and described in literature (e.g., [1]) both analytically and experimentally.

It appears that because of the uniform electric field distribution along the axis of the cylinder, the TM_{01l} system can be beneficial for processing materials of other than coaxially symmetrical geometry and thus be of efficient use in other microwave power applications. For instance, it is well known that some practical technologies (particularly, microwave sterilization and pasteurization) deal with relatively low temperatures and thus do not require a high level of input energy. A postharvest treatment of fruits at temperatures of about 60°C [2] is one of the processes of this type. This suggests that one may wish to design a cylindrical single-mode applicator conveniently fed by a coaxial line and suitable for efficient processing of spherical food products. Such a design would be more efficient if supported by comprehensive modeling specifying appropriate parameters of the excitation system and monitoring the electric field and power distribution in the processed material.

The present paper outlines the results of the related modeling work. For the first time, we present the results of a systematic numerical analysis of the cylindrical 915 MHz applicator operating at the TM_{01l} mode and containing a spherical lossy load.

APPLICATOR MODEL AND DESIGN

We have developed a Finite-Difference Time-Domain (FDTD) model of a 915 MHz cylindrical applicator with a centered dielectric sphere and a coaxial excitation. The model built for the full-wave 3D conformal FDTD simulator *QuickWave-3D* (http://www.qwed.com.pl) employs a non-uniform mesh with cells becoming smaller around the dielectric object and near the coax-cylinder junction. The number of rectangular cells varies from 180,000 to 215,000 depending on the diameter of the sphere and the size of the excitation structure.

It is well known that for efficient excitation of the TM_{01l} mode in a cylindrical applicator one may use either a probe oriented along the longitudinal axis (to generate the electric field with the same orientation), or a loop placed in the longitudinal plane (to generate the magnetic field perpendicular to this plane) [1]. Initially, we have examined a coupling efficiency and the electric field distribution inside the cavity excited by the coaxial feed's probe centered on the shorting wall.

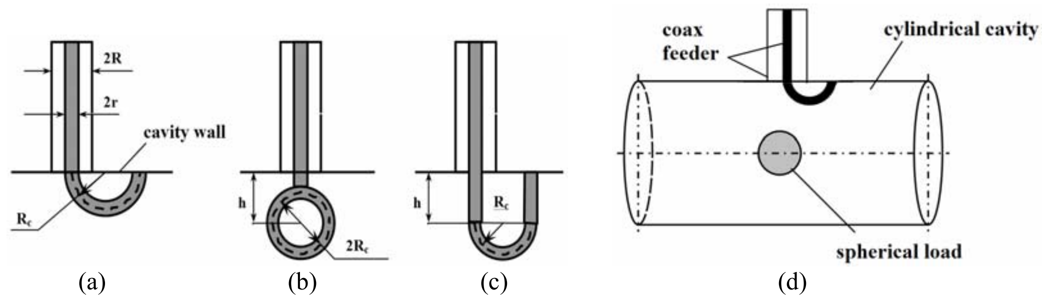


Fig. 1. Three configurations of the considered loop – Type 1 (a), Type 2 (b), Type 3 (c) and design of the chosen cylindrical applicator with a spherical load (d).

Modeling of a series of configurations has clearly shown the presence of the field of the TM_{01l} mode. However, we also observed very high electric field around the probe's tip that may be problematic because it may lead to arcing or limiting the level of microwave power handled by the applicator. In addition, the location of the probe on (or near) the central axis of the cylinder may be inconvenient in conveyor-type applicators.

Because of this, further study of the structure with the probe excitation was not found viable. Instead, we have focused on the loop excitation and considered various configurations of the coax-cylinder junction (Fig. 1, a-c) which are free from the drawbacks associated with the probe. The cavity was filled with a centered spherical load possessing the dielectric properties of an orange, a grapefruit and a red apple in accordance with Table 1. To choose the geometry of the loop, we have modeled the cylindrical structure with the diameter D = 169.5 mm and the length L = 350 mm; for the load, we took the typical diameter to be d = 70 mm and temperature T = 40°C.

It has been found that for the loops with the parameters given in Table 2 the magnitude of the reflection coefficient $|S_{11}|$ is characterized by resonances located very closely to 915 MHz. The graphs shown in Fig. 2 suggest that the best coupling is achieved with the loop of Type 1. In the next section, we therefore outline the characteristics of the cylindrical applicator schematically depicted in Fig. 1, d.

MODELING RESULTS

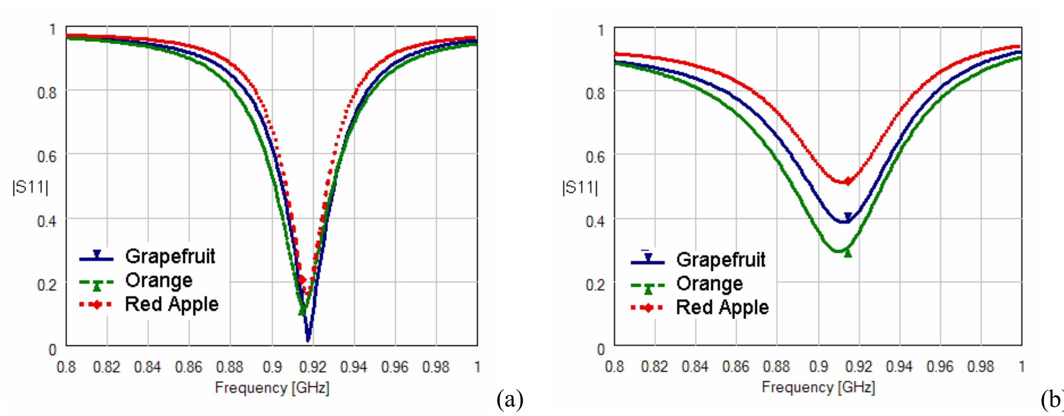
The cylindrical applicator with a spherical fruit and the loop of Type 1 was modeled for the same fixed D and L and variable R_c, d, and T. As one can see from Fig. 3, a, a minor change in the loop's radius notably affects the coupling by shifting the resonance away from the operating frequency regardless of the type of fruit in the cavity. Variation of the fruit's size (Fig. 4) also influences the position of the

Table 1. Dielectric Properties of Fruits at 915 MHz (From [3])

T, °C	Orange		Grapefruit		Red Apple	
	ε′	ε′′	ε′	ε′′	ε′	ε′′
20	72.9	16.5	72.7	12.1	77.0	10.0
40	68.0	18.7	68.5	13.3	71.5	10.0
60	63.2	18.4	63.7	15.5	67.1	8.9

Table 2. Configurations of the Loops Providing the Best Coupling

Coaxial feeder		Type 1	Type 2		Type 3	
R, mm	r, mm	R_c, mm	R_c, mm	h, mm	R_c, mm	h, mm
8	3.5	35	11	14	10	25



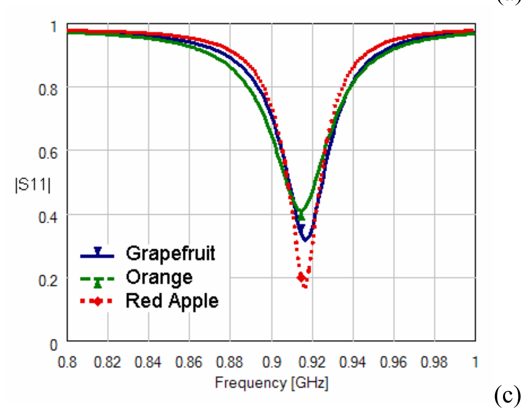


Fig. 2. Coupling in the cavity loaded with a spherical fruit and fed by the loop of Type 1 (a), Type 2 (b), and Type 3 (c).

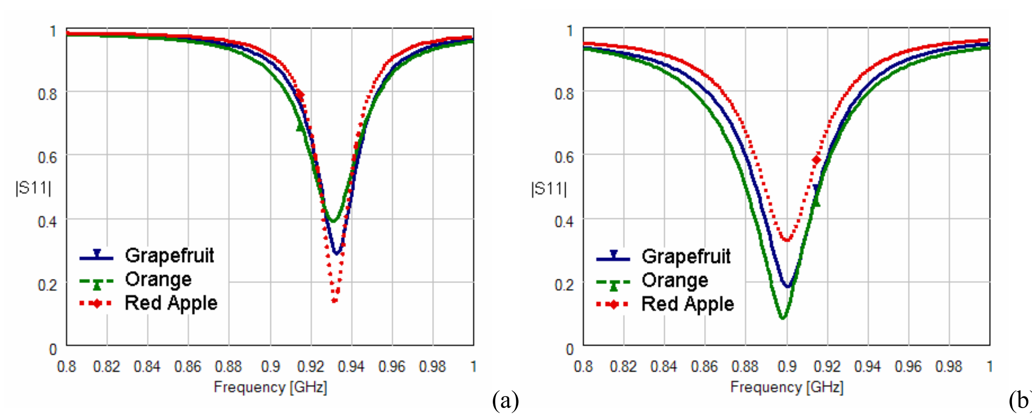


Fig. 3. Coupling in the cavity loaded with a spherical fruit and fed by the Type 1 loop with R_c = 30 mm (a) and 38 mm (b).

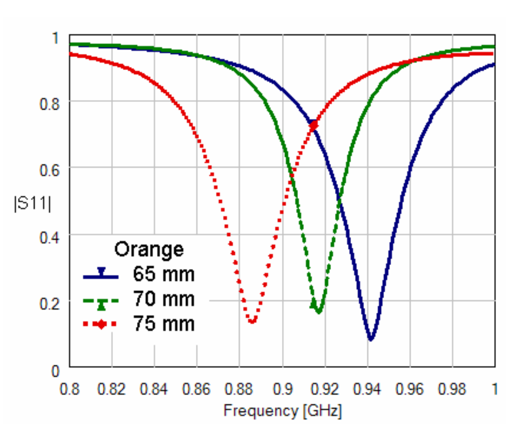
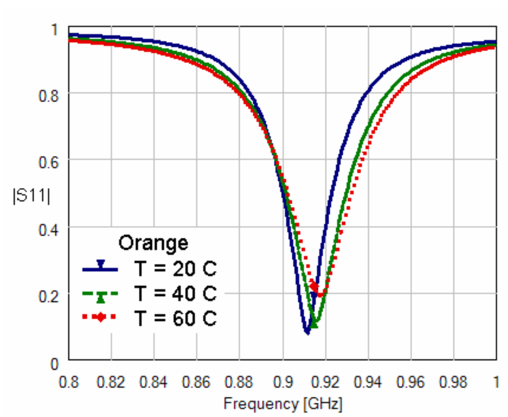
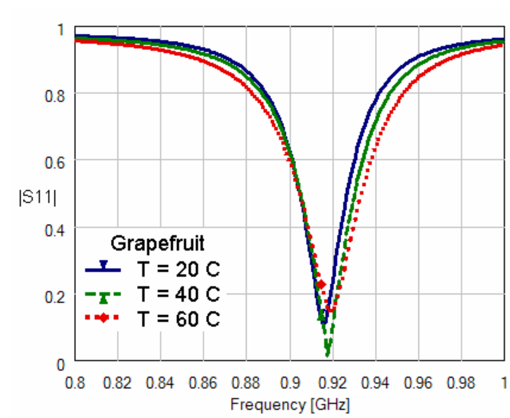


Fig. 4. Coupling in the cavity loaded with spherical orange of different d and fed by the Type 1 loop with R_c = 35 mm.





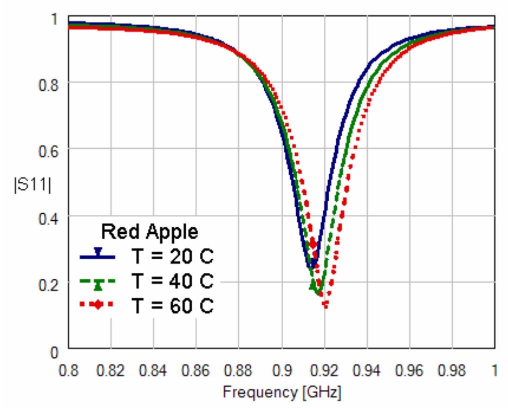


Fig. 5. Coupling in the cavity loaded with a spherical fruit (d = 70 mm) at different temperatures and fed by the Type 1 loop (R_c = 35 mm).

resonance (and thus may remarkably worsen the coupling) while the fruit's temperature leaves the resonances virtually intact (Fig. 5).

We have also observed that in the coordinate planes perpendicular to the loop's plane the dissipated power is characterized by a remarkable focusing effect for all the considered diameters, temperatures, and fruits.

CONCLUSION

In this paper we have presented the original results of comparison of three types of the loop exciting the TM_{01l} mode in the cylindrical applicator with a spherical fruit load. We have shown that the 915 MHz applicator of the proposed design (Fig. 1, d) is well suited for efficient thermal processing of various spherical fruits in the temperature range at least from 20° to 60°C if they possess approximately the same diameter. The paper presents the example of the use of advanced modeling for computer-aided design of systems and components of microwave power engineering.

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