MICROWAVE ENGINEERING PROBLEMS IN THE MICROWAVE OVEN

John M. Osepchuk
Raytheon Research Division
Waltham, Massachusetts 02154

Abstract

A general review of microwave engineering problems of the microwave oven is presented. Of central importance is the continuing improvement of the microwave magnetron in efficiency and stability. The goal of uniform heating is discussed with reference to measurement techniques and efforts at standardization. Advances in door-seal techniques are presented with reference to leakage and RFI requirements. Lastly the relevance of the basic microwave problems in the microwave oven to other ISM applications is discussed.

Summary

The microwave oven has become a major appliance[1,2] (over one million annual sales) in the United States following an impressive engineering and market effort by several appliance manufacturers in the last decade. In this paper we will review microwave engineering problems in the microwave oven. There have been several general reviews[3,4] of the basic microwave oven design problem. It is appropriate now to review progress since these reviews and the challenging microwave problems to be resolved in future advances in microwave oven design.

The magnetron remains the universal choice as the microwave power source for microwave ovens because of low cost (less than $30 for 700 watts), good efficiency (50-70%), simple power supply requirements and good reliability (as much as 3000 hours MTTF). It is perhaps ironic that the magnetron, oldest of microwave tubes, now is the highest-volume microwave component. This ubiquitous device, however, still presents some challenging problems not completely resolved despite over thirty years of R&D. Some of these are:

a. Transients: Most microwave ovens use a half-wave doubler 60 Hz voltage supply by which the magnetron is subjected to a cold start. Under these conditions several types of potentially damaging voltage transients[5] can be generated. These can be classified as due to (1) inrush currents, (2) moding transitions as emission builds up, (3) random voltage breakdown phenomena and (4) on anomalous "cold"-cathode mode. The first is solved by special input circuit modifications to limit inrush current. The second is controlled by the not-completely understood "clamping" action of higher magnetron modes. The third is minimized by cold cathode aging techniques but is not completely understood. The last type is minimized by control of cathode end-shield emission. Because types (3) and (4) are not completely understood it is generally necessary to provide clamping action against transients by means of a specified avalanche reverse breakdown characteristic in the rectifier diode. The theories of the various mechanisms will be reviewed and in particular evidence will be presented in support of the identification of the fourth type as a Farnsworth-type[6] cold-cathode interaction involving the π-mode and axial electron flow.

b. Spurious oscillations: Cooker magnetrons produce spurious sideband signals and associated low-frequency signals that have been identified[7] as the result of a relaxation oscillation of the large signal state and an inherent result of a.c. space-charge forces. This is reflected in the finding[8] in sophisticated digital computer calculations that the magnetron generally does not exhibit a steady state in electron flow patterns. A review of experimental studies suggests a strong relation of this phenomenon to that in M-type backward-wave oscillators.[8] This in turn suggests that analysis of magnetrons in terms of a backward-wave model[9] could yield some fruitful results.

c. Other problems: These include a better understanding of basic phenomena such as efficiency limitations, pulling, pushing and moding. It is probable that advances in all these areas can be made to improve the efficacy and reliability of microwave ovens.

A basic and certainly continuing microwave problem is the achievement of a desired "cooking pattern" or the desired degree of uniformity in heating or cooking of foods. Although there has been some theoretical[10] study of heating patterns in microwave ovens they have been restricted to idealized unrealistic load shapes and restricted type of oven feed. Because of the overwhelming complexity of the practical oven-food configuration as an object for theoretical study involving Maxwell's equations most design for "cooking patterns" remain a black art. Even the means for evaluating the heating pattern characteristics has presented engineers with much controversy and debate. A variety of techniques involving use of sheet loads, separated water samples and actual foods have been studied.[11,12,13] These involve gross temperature measurements and qualitative assessments - particularly when foods are used. It appears that practical tests involving assessment of foods by home economists remains the best way of assessing this quality although standardization efforts[14] by trade and standards organizations are continuing.

The use of thermographic mapping of external and internal heating patterns has been somewhat limited due to the high cost and complexity of such techniques. In some studies with such equipment some interesting nonuniformities are portrayed. These will be reviewed with a discussion of the compatibility of such findings with the apparent effectiveness as a consumer product despite these imperfections. The sources of heating imperfections will be reviewed and some promising solutions discussed. The latter include the use of power sources at two different ISM frequencies.

It is clear that randomization in microwave field patterns is an important basis for achieving uniformity. Means of randomization include the "mode stirrer".

The browning problem is briefly reviewed with some discussion of the most popular solution - that of the browning dish.[15]

The control of power level or power scheduling has been provided in microwave ovens by means of some ingenious solid-state circuitry to control timing and duty cycle of the magnetron. Little or no use is made of microwave techniques in this area till now, however. The development of non-perturbing probes[16] in microwave bioeffect research suggests useful application to the microwave cooking problem if it could be made to work at higher temperature, be more rugged and drastically reduced in cost.

The design of door seals is an important area of microwave oven design because of its relevance to minimizing leakage to meet HEW requirements and satisfy public concern as well as to suppress out-of-band radiation to meet the RFI requirements of FCC. The basic theory of leakage suppression or "choking" principles is reviewed. Some important distinctions arise from the point of view of leakage suppression in contradistinction with the classical viewpoint of minimizing VSWR in waveguide joints etc. The factors in practical oven leakage are reviewed including screen transmission and door resonance phenomena. Techniques[17] to control multimode propagation in door seal areas are reviewed. Theory and data are presented on a most simple and effective solution - that of the "slotted" choke.[16]

Data on the nature of leakage field propagation is presented and a relationship[18] between potential exposure of oven users and oven leakage emission is established. Such calculations are important in demonstrating to the general public the high degree of safety against potential microwave hazards when using a microwave oven. Such calculations could be refined but are justified only if public concern over leakage grows. A comparison of potential microwave exposure near operating ovens with that of broadcast television shows that the microwave oven is even below broadcast television as a potential source of speculative low-level microwave effects.

In concluding this review one can point out the commonality of problems in microwave oven heating, medical diathermy and other industrial applications. It is not unlikely that studies of propagation and heating in lossy dielectric objects done with respect to one application will benefit all these areas.

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