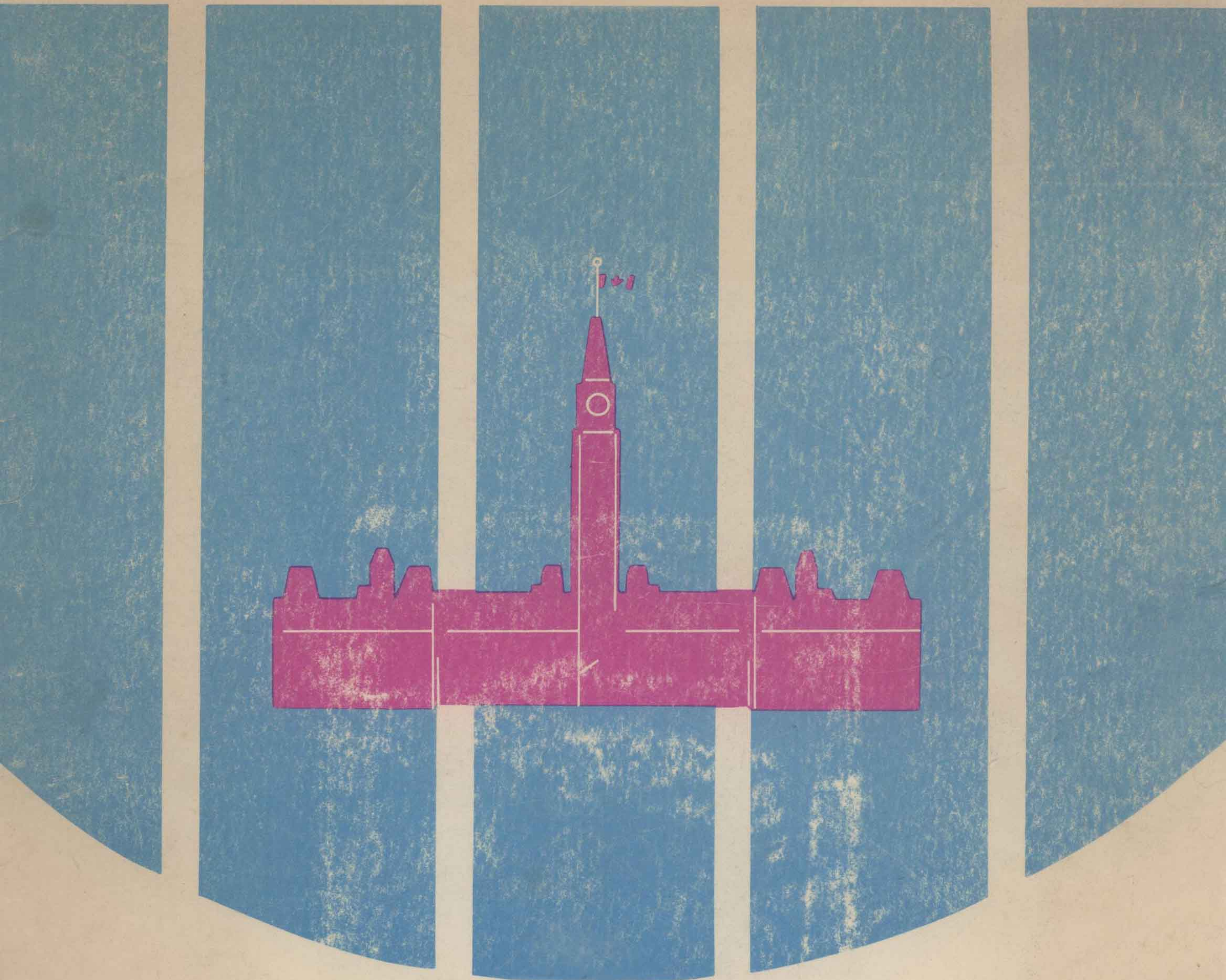

DIGEST

Microwave Power Symposium 1978

OTTAWA, ONTARIO, CANADA JUNE 28–30

MICROWAVE POWER SYMPOSIUM 1978

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and

TABLE OF CONTENTS

Wednesday, June 28, 1978
Parallel Sessions

Opening Ceremonies: 8:30 a.m. - 9:00 a.m.
Convention Hall

9:00 a.m.

10:30 a.m. - Coffee

9:00 a.m.

10:30 a.m. - Coffee

Wednesday, June 28, 1978

Thursday, June 29, 1978

Thursday, June 29, 1978

2:00 p.m.

Session 9: MICROWAVES IN CHEMICAL INDUSTRY

Chaired by: *R. G. Bosisio*, Ecole Polytechnique, Montreal, Que., Canada

3:30 p.m. - Coffee

4:00 p.m. Annual General Meeting of IMPI

2:00 p.m.

Panel Discussion: PACKAGING AND UTENSILS FOR DOMESTIC MICROWAVE OVENS - STATE OF THE ART

Moderator: *R. H. Olson*, Consumer Products, Mobil Chemical Co., Masedon, NY, 14502, U.S.A.

3:30 p.m. - Coffee

Friday, June 30, 1978

9:00 a.m.

Session 11: MICROWAVE POWER GENERATION

Chaired by: *W. C. Brown*, Raytheon Co., Waltham, MA, U.S.A.

10:30 a.m. - Coffee

11:00 a.m.

Session 12: MICROWAVE POWER GENERATION

Chaired by: *H. Takahashi*, Toshiba Co., Kawasaki, Japan

12:30 p.m. - L U N C H

9:00 a.m.

Session 13: MICROWAVE INSTRUMENTATION

Chaired by: *J. T. Senise*, Escola de Engenharia Mauá, São Paulo, Brazil

10:30 a.m. - Coffee

11:00 a.m.

Session 14: MICROWAVE INSTRUMENTATION

Chaired by: *M. Kent*, Torry Research Station, Aberdeen, Scotland

12:30 p.m. - L U N C H

INDEX OF AUTHORS

cont'd.

Session 1

MICROWAVE OVENS

Chaired by:

John Gerling
Gerling Moore, Inc.
Santa Clara, CA, 95051
U.S.A.

9:00 a.m.
Wednesday Morning
June 28, 1978

HIGH PERFORMANCE DOOR SEAL FOR MICROWAVE OVEN

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ABSTRACT

A novel choke structure for microwave oven doors which does not require absorbing materials and metal contact is described. By utilizing periodic square wave shaped metal sheets inserted into a groove of a choke, it is possible to suppress the maximum leakage power density below 0.02mW/cm² in the closed door position, and below 0.1 mW/cm² in the slightly opened door position(about 4mm of gap between the door and the oven), for a microwave oven designed for 500W level using the standard load of 275ml of water. With no load, the maximum leakage power density is 0.1mW/cm² in the closed position and 0.5mW/cm² in the slightly opened door position.

Introduction

An ordinary door seal for a microwave oven is made up of a quater wavelength choke based on the transmission line theory, absorbing materials and metal contact. In the absence of absorbing materials or in the cace of roughly metal contact, the leakage level abrupIy increases. However we have developed a novel door seal which does not require absorbing materials and metal contact. This new door seal is characterized by low level leakage power density even with a fairly large gap between the door flange and the oven flange, for example, a level of 0.1mW/cm² with a 3mm uniform gap. We have named it "Wavy Door Seal".

Theoretical Investigation of Wavy Door Seal

A sketch of Wavy Door Seal geometry is shown in Fig.1. Periodic square wave like metal sheets play an important part in this door seal. Wavy Door Seal has a paticularly complicated structure that we will not analyze rigorously here. Thus we will proceed to the analysis under the following assumptions:

(1) A periodic square wave like metal sheet is mounted in parallel plate waveguide, as shown in Fig.2, and is not coupled with the door flange, the sash plate etc.

(2) The incident wave to a wavy metal sheet is a uniform plane wave. That is,

$$E_i(\mathbf{r}) = j V_0 (pa)^{-1/2} \exp(-j\alpha_0 x - j\kappa_0 z) \tag{1}$$

$$\kappa_0 = (k_0^2 - \alpha_0^2)^{1/2}, \quad \alpha_0 = k_0 \sin\theta \tag{2}$$

where k_0 is a phase constant of free space.

(3) The secondary electromagnetic fields induced by the incident wave have no y-component in the magnetic field.

(4) All components of a Wavy Door Seal are perfect conductors.

(5) Utilizing the transmission line[1] representation for electromagnetic fields whose direction of transmission line are selected in z-direction, the fields are expanded into E-type modes.[1,2]

Boundary conditions are zero tangential components of electric field on surface S_0, S_1 and S_2. From these conditions we can obtain the simultaneous integral equations of unknown electric current distribution J_0, J_1 and J_2, on the surface S_0, S_1 and S_2, respectively. After some modifications these equations yield variational expressions of equivalent circuit parameters of a wavy metal sheet. It is too difficult to find out accurate forms of unknown functions, J_0, J_1 and J_2. Thus employing the following forms, we can make up approximate solutions.

$$\mathbf{J}_1(\mathbf{r}) = \mathbf{J}_2(\mathbf{r}) = \gamma_0 \{1-(y/c)^2\}^{1/2}\{1-(2z/d)^2\}^{-1/2} + \gamma_1 (2z/d)\{1-(2z/d)^2\}^{-1/2}\{1-(y/c)^2\}^{1/2} \tag{3}$$

$$\nabla \cdot \mathbf{J}_0(\mathbf{r}) = \beta_0 + \beta_1 (2z/d) \tag{4}$$

where β_0, β_1, γ_0 and γ_1 are unknown constants.

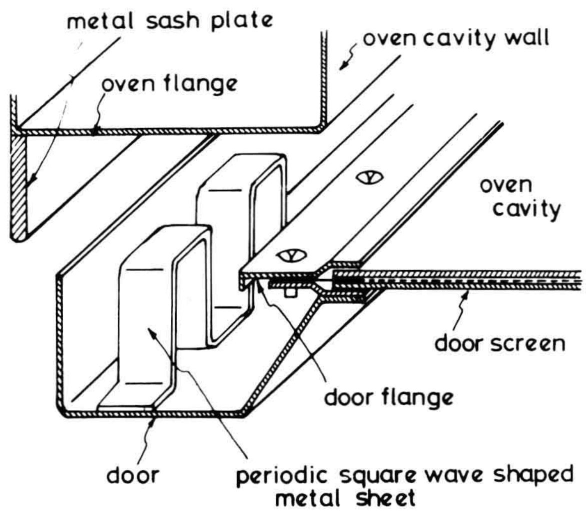

Fig.1 Sketch of "Wavy Door Seal" geometry in microwave oven.

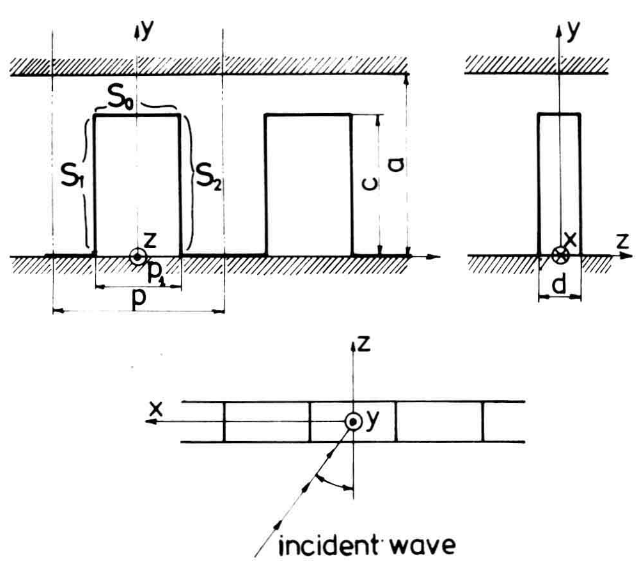

Fig.2 A Wavy Metal Sheet mounted in parallel plate waveguide and coordinate system.

Equivalent circuit parameters of a Wavy Metal Sheet

Under the above assumptions, we can obtain the equivalent circuit parameters of a Wavy Metal Sheet for a T-type circuit shown in Fig.3, as follows:

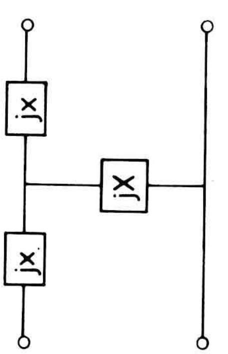

Fig.3 Equivalent circuit of a wavy metal sheet.

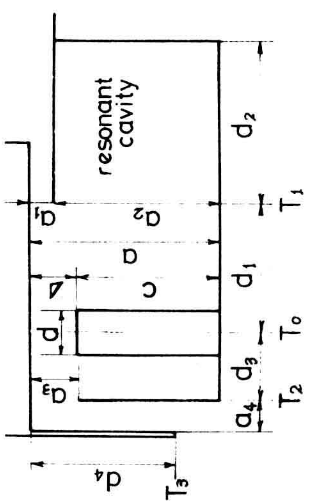

Fig.4 Analytical model of wavy door seal.

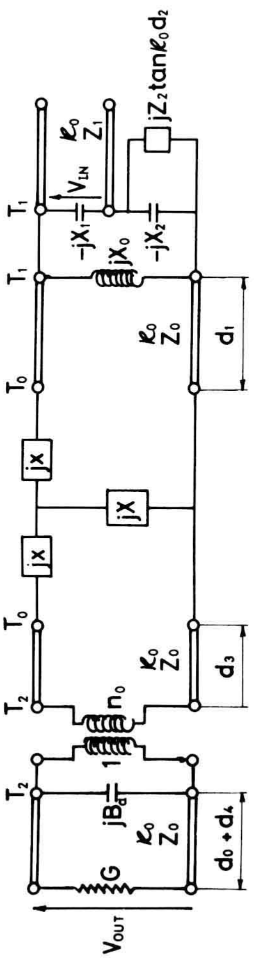

Fig.5 Equivalent circuit of wavy door seal.

$$j\left(X+\frac{x}{2}\right)=jZ_0\left[\frac{k_0 p}{4\pi}\left\{\frac{1}{J_0^2(k_0 d/2)}\ln\left(\frac{p}{\pi d}\,\mathrm{cosec}\frac{\pi p_1}{p}\right)+\frac{2\pi d}{3p}\left(\frac{k_0 d/2}{\sin(k_0 d/2)}\right)^2\right\}+\frac{k_0 p a p_1 d\{2c^2/[c^2+(p_1/2)^2]\}}{4\pi^2 k_0^2\Delta\{c^2+(p_1/2)^2\}}-\frac{k_0 p}{(k_0^2 a)^2}\cdot\frac{\pi\tau/2}{4J_0^2(k_0 d/2)\ln(\frac{2a}{\pi\Delta})}-\frac{k_0 d}{12}\right] \quad (5)$$

$$j\frac{x}{2}=jZ_0\frac{J_1^2(k_0 d/2)}{8\sqrt{2}\left(\frac{a}{\pi c}\right)^2\frac{k_0 p}{(k_0 a)^2}\frac{2a}{\pi^2 c}S-\frac{k_0 p}{2\pi}} \quad (6)$$

$$S=\sum_{n=1}^{\infty}\frac{\ln(\sqrt{2}n\tau)\cos^2\left(\frac{n\pi c}{a}-\frac{3\pi}{4}\right)}{\sqrt{2}n^2\tau} \quad (7)$$

$$Z_0=\frac{\omega\mu_0}{k_0},\quad k_0=(k_0^2-\alpha_0^2)^{\frac{1}{2}},\quad k_0^2=\omega^2\epsilon_0\mu_0,\quad \tau=\frac{\pi d}{2a}$$

Whole equivalent circuit of Wavy Door Seal

Fig.4 shows an analytical model of a Wavy Door Seal which is infinitely long into or out of the plane of Fig.4. In this model three other discontinuities, i.e., E-plane bifurcation, E-plane step and E-plane corner of parallel plate waveguide exist in addition to a Wavy Metal Sheet. Utilizing the results given in "WAVEGUIDE HANDBOOK" for these, we can construct the whole equivalent circuit, as shown in Fig.5.[3] Each of the equivalent circuit parameters corresponds to the following discontinuities:

G: Radiation conductance looking outward from the tip of sash plates.

jB_d: Capacitance caused by E-plane step of parallel plate waveguide.

jX_0, jX_1, jX_2: Reactances of E-plane bifurcation of waveguide.

$1:n_0$: Ideal transformer corresponds to the jump of characteristic impedance of waveguide.

$jZ_2\tan k_0 d_2$: Input impedance looking to the right from terminal T_1.

In this circuit we define the attenuation by the following equation.

$$\text{ATTENUATION}= -20\log_{10}(\text{Vout/Vin}) \quad (\text{dB}) \qquad (8)$$

Behavior of Wavy Door Seal

The cutoff effect of Wavy Door Seal appears as the superposition of two effects. The first effect is caused by a Wavy Metal Sheet. In the equivalent circuit jx is always capacitive, but jX varies from capacitance to inductance in prportion as the gap Δ decreases. If Δ is selected properly, jX yields zero and then output voltage Vout becomes zero by this series resonance. The second effect is caused by resonant cavity, i.e., the parallel resonant circuit made of $jZ_2\tan k_0 d_2$ and $-jX_2$ also makes Vout zero.

Numerical results

Attenuation as a function of frequency of Wavy Door Seal is shown in Fig.6, and its dimensions of the analyzed model is nearly equal to those of one and one third times Fig.4. In this figure lower resonant frequency F_s corresponds to series resonance, and higher resonant frequency F_p corresponds to parallel resonance, and cooperation of the two resonances results in a large attenuation above 50dB over wide frequency range. In proportion to the gap a_1 between the door flange and the oven flange, the series resonant frequency moves to a higher frequency and the parallel resonant frequency moves oppositely, and at 5mm of gap a_1 the difference between both resonant frequency becomes no more than 50MHz. At this point the two effects of attenuation operate on the same frequency range, and in consequence the Wavy Door Seal keeps a lower leakage level for the fairly large gap a_1, compared with a conventional quater wavelength choke. This effect becomes clearer in oven tests.

In Fig.7 attenuation as a function of incident angle is shown. Its dimensions of the analyzed model is the same as Fig.6, however frequency F and gap a_1 are fixed(2.45GHz and 1mm, respectively). It can be seen that in the usual quater wavelength choke the leakage level increases in proportion to the angle of incident wave. For example, if choke has a wave of incident angle 45 deg., it operates effectively at 70% of designed frequency, and its frequency deviation corresponds to 700MHz in a microwave oven operated at 2450MHz. However the Wavy Door Seal's leakage level is in reciprocal proportion to the incident angle. This feature is very important, because in actual microwave ovens which make use of a stirrer or a turning table for uniform heating many modes exist and the angle of incidence is distributed between 0 and 90 deg..

It shoud be noted that results given by Fig.7 do not provethe existance of a stop band due to the Wavy Door Seal in x-direction. Because we treated the problem as the power flow of z-direction, we can conclude only that incident power from the oven cavity is reflected into the cavity by Wavy Door Seal and consequently leakage power through the door yields a very low level.

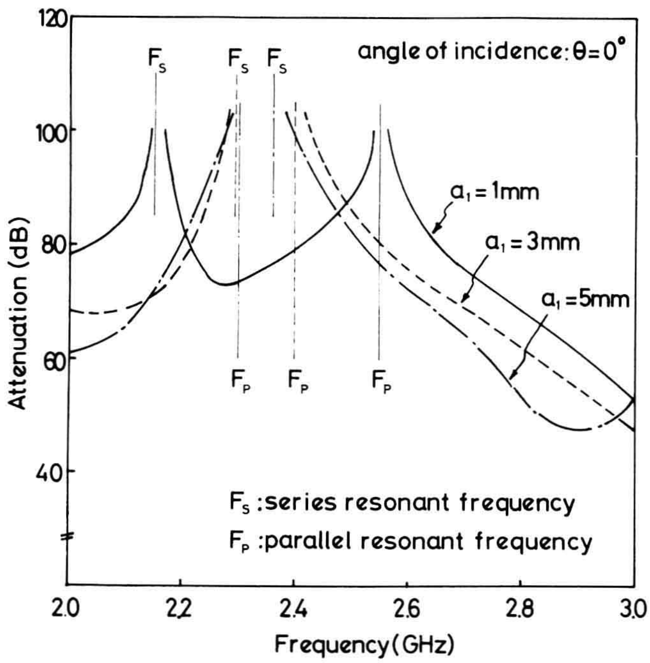

Fig.6 Frequency characteristics of Wavy Door Seal
Dimensions: p=30.0, p_1=15.0, d=7.5, c=25.0, d_1=19.45, d_2=28.0, d_3=11.75, d_4=25.0, a_2=29.0, $a_3=a_1+5.0$, a_4=3.0

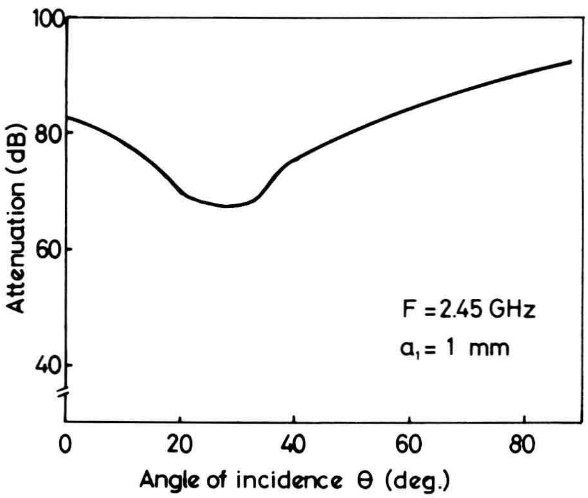

Fig.7 Attenuation vs. angle of incidence.
Dimensions: p=30.0, p_1=15.0, d=7.5, c=25.0, d_1=19.45, d_2=28.0, d_3=11.75, d_4=25.0, a=30.0, a_2=29.0, a_3=6.0, a_4=3.0

Oven Tests

In Fig.8 the maximum leakage power density vs. gap a_1 is for a new model, MRO-5100, which employs the Wavy Door Seal and which is now on sale only in Japan. The most important feature of this seal is that a low leakage level is maintained even though a fairly large gap exists between the door flange and the oven flange. This feature makes a latching mechanism unnecessary in our model. In Fig.8 interlock switches are short-circuited to show the actual performance of preventing leakage power; however actual products are adjusted so that these switches operate and and turn off the power supply below 4mm of gap a_1. In this position leakage level is about 0.1mW/cm². With no load the maximum leakage power density is 0.1mW/cm² and 0.5mW/cm², in the closed door position and the opened door position (about 4mm of gap), respectively.

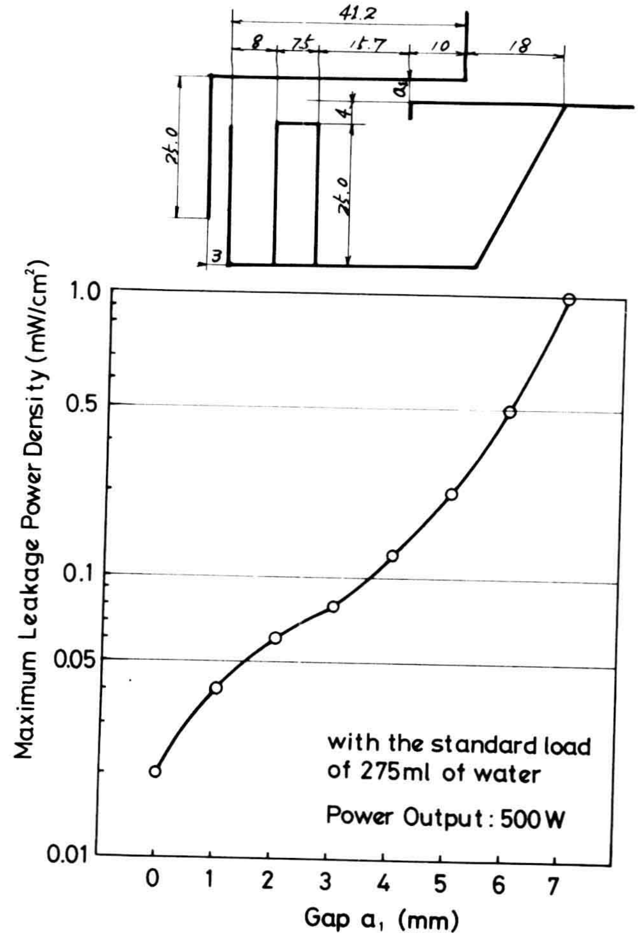

Fig.8 Maximum leakage power density vs. gap a_1.
Measured conditions: (1) Absorbing materials such as ferrite absorbers are not employed.
(2) When adjusting the door to the oven, 1mm of spacers are inserted between the door flange and the oven flange.
(3) Therefore upon opening the door gradually, gap a_1 on the door handle side(which corresponds to the gap a_1 in Fig.8) inceases: however the gap a_1 on the door hinges side is kept about 1mm.
(4) Latching mechanism is not employed.

Conclusion

Wavy Door Seal is designed under presupposed condition of floating the door from the oven. Its advantages in comparison to other door seal techniques are:
(1) Wavy Door Seal has yielded not only a very low leakage level but one that has proved consistently low in production, thus showing no marked sensitivity to dimensional tolerances caused when fitting up the oven with a door;
(2) it prevents the increase of leakage caused by the loosening of the door hinges or latching mechanism with age.

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1. L.B.Felsen and N.Marcuvitz:"Modal Analysis and Synthesis of Electromagnetic Fields", Research Report R-446(a) and (b), PIB (1957.2).
2. H.M.Allshuler and L.O.Goldstone:"A Class of Alternative Modal Representation for Uniform Waveguide Resions", Research Report R-557-57, PIB-485(1957.2)
3. N.Marcuvitz:"Waveguide Handbook",Chap.4 and Chap.6, McGraw Hill, New York(1951).

USE OF A REVERBERATING CHAMBER IN MICROWAVE OVEN CHOKE DESIGN

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A reverberating room has been used to measure total oven leakage over a wide frequency range to aid in choke seal design. Choke improvements observed using the reverberating room are also seen in the HEW leakage test results.

Introduction

In the testing of microwave oven choke designs there is a need for a rapid means of assessing a choke's effectiveness. A system for testing the leakage over a wide band of frequencies is desired so that a design can be quickly tuned for best performance in the ISM band. The reverberating chamber is well suited to these measurements and has the additional advantage that test personel are not exposed to high level leakage should the choke design prove to be faulty.

Measurement System

The reverberating chamber has the ability to measure the total power emitted by a device placed inside.[1,2] The average received field strength is nearly independent of the position of the radiating structure within the chamber unless the structure is placed close to a wall (say less than one wavelength). This has been confirmed with the reverberating room shown in Fig. 1 using a variety of radiating devices in many positions inside the chamber.

The measurement system shown in Fig. 1 actually measures the average value of the attenuation in decibels between the radiating device and the pick up antenna inside the room. The test bed consists of an oven cavity opening into a 0.5 inch thick wrought aluminum tool plate. Chokes may be built up on the plate's surface or built into the doors which are laid upon the plate for test. The system is calibrated by removing the door from the test bed. The received signal is then recorded several times as a function of frequency; each time with a different network analyser gain setting.

The door to be tested is placed on the test bed and a frequency scan recorded. The process is repeated for a variety of gaps between the tool plate and the door. The resulting graphs clearly show the frequencies at which the choke is most effective. The size of the choke or amount of dielectric loading can be changed to tune the choke to 2450 MHz. Of course, the measured attenuation vs. frequency characteristics do not satisfy current HEW leakage test proceedures; hence that test must also be performed. Experiments indicate that reverberating room results are reflected in the outcome of the standard HEW leakage test.

Results

The results of a reverberating room leakage test on one door with choke before and after modification are shown in Fig.2. The modification has reduced the total leakage by about 7dB in the ISM band. Using the standard HEW leakage test, the door had a maximum leakage level 5.4dB lower after modification; thus confirming the measurements made in the reverberating room.

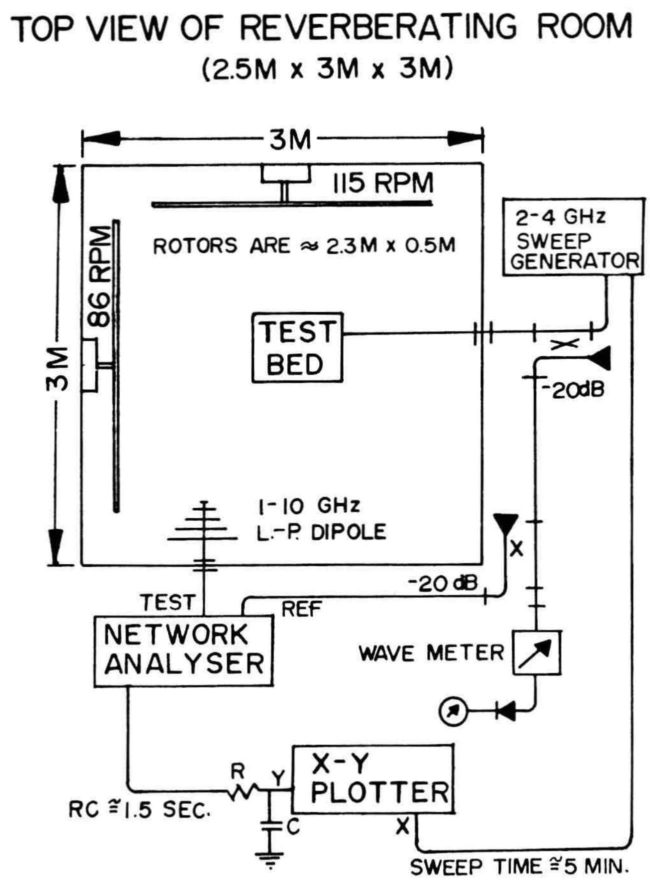

Fig. 1. Experimental Configuration for Choke Tests

Conclusion

The swept frequency, total leakage measurements made in the reverberating room provide a very useful choke seal design aid.

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1. Corona, P.; Latmiral, G.; Paolini, E.; and Piccioli, L., "Use of a Reverberating Enclosure for Measurement of Radiated Power in the Microwave Range," I.E.E.E. Transactions on E.M.C., Volume 18, No.2, May 1976.

2. Okamura, M. and Miyajima, S. "Experimental Evaluation of a Reverberating Enclosure to be used for Making Measurements of Radiated Power in the Microwave Region," International Electrotechnical Commission and International Special Committee on Radio Interference (CISPR) meeting October 1977, Dubrovnik, Yugoslavia.