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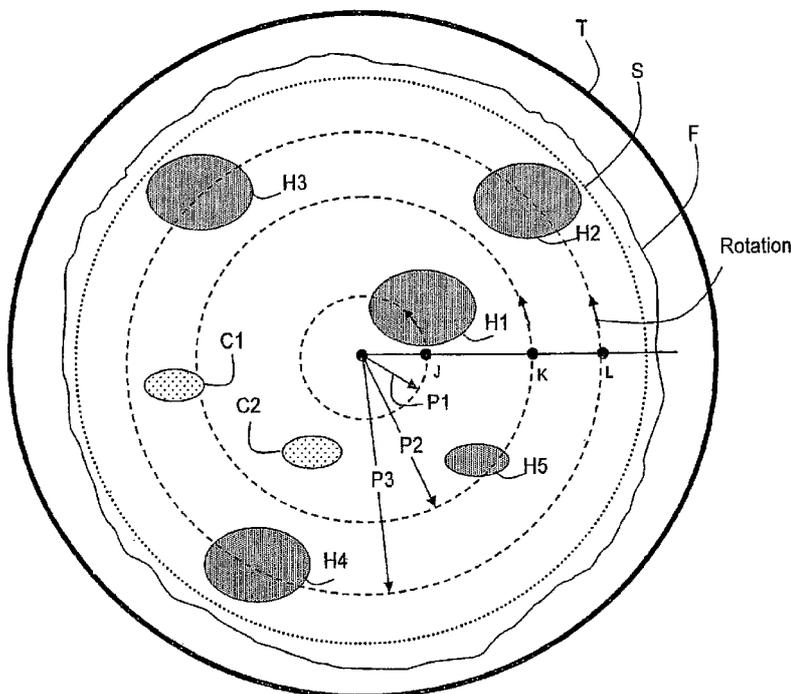
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(54) Title: FIELD DIRECTOR ASSEMBLY HAVING OVERHEATING PROTECTION



(57) Abstract: A field director assembly includes electrically conductive vanes positioned with respect to each other and to a planar support member to prevent overheating of the susceptor in an unloaded microwave oven.

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TITLE

FIELD DIRECTOR ASSEMBLY HAVING OVERHEATING PROTECTION

This application claims the benefit of U.S. Provisional Applications; 60/841,108 which was filed 29 August 2006, and 60/751,544, which was
5 filed 19 December 2005 and are incorporated as a part hereof for all purposes.

FIELD OF THE INVENTION

The present invention is directed to a field director assembly which resists overheating when used in an unloaded microwave oven.

CROSS-REFERENCE TO RELATED APPLICATIONS

Subject matter disclosed herein is disclosed in the following
10 copending applications filed contemporaneously herewith and assigned to the assignee of the present invention:

Arc-Resistant Microwave Susceptor Assembly
15 (CL-3624);

Field Director Assembly Having Arc-Resistant Conductive Vanes
(CL-3630); and

Microwave Susceptor Assembly Having Overheating Protection
(CL-3534).

BACKGROUND OF THE INVENTION

Microwave ovens use electromagnetic energy at frequencies that vibrate molecules within a food product to produce heat. The heat so generated warms or cooks the food. However, the food is not raised to a sufficiently high temperature to brown its surface to a crisp texture (and
25 still keep the food edible).

To achieve these visual and tactile aesthetics a susceptor formed of a substrate having a lossy susceptor material thereon may be placed adjacent to the surface of the food. When exposed to microwave energy the material of the susceptor is heated to a temperature sufficient to
30 cause the food's surface to brown and crisp.

The walls of a microwave oven impose boundary conditions that cause the distribution of electromagnetic field energy within the volume of

the oven to vary. These variations in intensity and directionality of the electromagnetic field, particularly the electric field constituent of that field, create relatively hot and cold regions in the oven. These hot and cold regions cause the food to warm or to cook unevenly. If a microwave
5 susceptor material is present the browning and crisping effect is similarly uneven.

To counter this uneven heating effect a turntable may be used to rotate a food product along a circular path within the oven. Each portion of the food is exposed to a more uniform level of electromagnetic energy.
10 However, the averaging effect occurs along circumferential paths and not along radial paths. Thus, the use of the turntable still creates bands of uneven heating within the food.

This effect may be more fully understood from the diagrammatic illustrations of Figures 1A and 1B.

15 Figure 1A is a plan view of the interior of a microwave oven showing five regions (H_1 through H_5) of relatively high electric field intensity ("hot regions") and two regions C_1 and C_2 of relatively low electric field intensity ("cold regions"). A food product F having any arbitrary shape is disposed on a susceptor S which, in turn, is placed on a turntable
20 T . The susceptor S is suggested by the dotted circle while the turntable is represented by the bold solid-line circle. Three representative locations on the surface of the food product F are illustrated by points J , K , and L . The points J , K , and L are respectively located at radial positions P_1 , P_2 and P_3 of the turntable T . As the turntable T rotates each point follows a
25 circular path through the oven, as indicated by the circular dashed lines.

As may be appreciated from Figure 1A, during one full revolution point J passes through a single region H_1 of relatively high electric field intensity. During the same revolution the point K passes through a single smaller region H_5 of relatively high electric field intensity, while the point L
30 experiences three regions H_2 , H_3 and H_4 of relatively high electric field intensity. Rotation of the turntable through one complete revolution thus exposes each of the points J , K , and L to a different total amount of electromagnetic energy. The differences in energy exposure at each of

the three points during one full rotation is illustrated by the plot of Figure 1B.

Owing to the number of hot regions encountered and cold regions avoided, points J and L experience considerably more energy exposure than Point K. If the region of the food product in the vicinity of the path of point J is deemed fully cooked, then the region of the food product in the vicinity of the path of point L is likely to be overcooked or excessively browned (if a susceptor is present). On the other hand, the region of the food product in the vicinity of the path of point K is likely to be undercooked.

Since non-uniform cooking due to the presence of hot and cold regions is undesirable it has been found advantageous to employ a susceptor assembly formed by the combination of a field director structure with a susceptor. The field director structure includes one or more vanes, each having a conductive portion on a paperboard support. The field director structure mitigates the effects of regions of relatively high and low electric field intensity within a microwave oven by redirecting and relocating these regions so that food warms, cooks and browns more uniformly. Use of the field director structure alone (i.e., without a susceptor) has also been found advantageous.

When a susceptor assembly is placed in an "unloaded" microwave oven (i.e., an oven without a food product or other article being present) and the oven is energized deleterious problems of overheating of the susceptor, and/or overheating of the field director structure, and/or arcing have been observed.

By "overheating of the susceptor" (or similar terms) it is meant heating of the lossy susceptor material to the extent that the susceptor substrate burns.

"Overheating of the field director structure" (or similar terms) means heating of the paperboard support of the vanes to the extent that it burns. Such overheating may be caused by either the heat generated by a lossy susceptor material or by arcing.

"Arcing" (or similar terms) is an electrical discharge occurring when a high intensity electric field exceeds the breakdown threshold of air. Arcing typically occurs in the vicinity of the electrically conductive portions of the vanes, particularly along the edges, and especially at any sharp corners. Arcing may cause the paperboard support of the vanes to
5 discolor, to char, or, in the extreme, to ignite and to burn.

Most common expedients to prevent arcing are impractical in microwave oven applications. These expedients are also not suitable for disposable packaging for convenience foods.

10 In view of the foregoing it is believed advantageous to provide a field director structure and a susceptor assembly incorporating the same that prevents the occurrence of arcing, the occurrence of overheating of the field director, and the occurrence of overheating of the susceptor.

15 SUMMARY OF THE INVENTION

The present invention is directed to a field director assembly that does not overheat when placed in an "unloaded" microwave oven, i.e., an oven without a food product or other article being present. The microwave oven is operative to generate a standing electromagnetic wave
20 having a predetermined wavelength.

The field director assembly includes a generally planar support member having one or more vanes mechanically connected thereto. Each vane has an electrically conductive portion thereon. The electrically conductive portion is generally rectangular in shape with a predetermined
25 length and width dimension and has a first end and a second end thereon. The electrically conductive portion of the vane may be formed from a metallic foil less than 0.1 millimeter in thickness.

The electrically conductive portion of each vane is disposed at least a predetermined close distance from the planar support member. The
30 predetermined close distance lies in the range from 0.025 times the wavelength to 0.1 times the wavelength. In the preferred instance the predetermined close distance is defined by a border of a lower

conductivity material on the vane between the conductive portion of the vane and the support member.

The first end of the conductive portion on each of the vanes is disposed at a distance at least a predetermined separation distance from the geometric center of the planar support member. The predetermined
5 separation distance is at least 0.16 times the wavelength.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be more fully understood from the following detailed description, taken in connection with the accompanying drawings,
10 which form a part of this application and in which:

Figure 1A is a plan view showing regions of differing electric field intensity within a microwave oven and showing the paths followed by three discrete points J, K, and L located at respective radial positions P_1 , P_2 and P_3 on a turntable;

15 Figure 1B is a plot showing total energy exposure for one full rotation of the turntable at each of the discrete points identified in Figure 1A;

Figure 2 is a pictorial view of a susceptor assembly with portions of the planar susceptor broken away for clarity and showing various edge
20 shapes of the vanes of the field director structure with the conductive portions of the vanes directly abutting the planar susceptor;

Figure 3 is a pictorial view similar to Figure 2 showing the vanes of the field director structure with the conductive portions of the vanes spaced from the planar susceptor;

25 Figures 4A through 4C are plan views respectively illustrating generally straight-edged, bent-edged and curved-edged of vanes extending generally transversely across the planar susceptor in directions offset from a generally radial line of the susceptor assembly;

30 Figures 4D through 4F are plan views respectively illustrating generally straight-edged, bent-edged and curved-edged of vanes extending generally transversely across the planar susceptor in a direction that intersects a generally radial line of the susceptor assembly;

Figures 5A and 5B are elevation views taken along view lines 5-5 in Figure 2 respectively illustrating a vane of the field director having a fixed connection to a planar susceptor and a flexible articulating connection, with the vane in the latter case shown in stored and deployed positions;

5 Figure 6 is a pictorial view illustrating the attenuating effect of a single transverse electrically conductive vane on the constituent field vectors of the electric field component in the plane of the planar susceptor;

10 Figure 7A is a plan view, generally similar to Figure 1A, showing the effect of the field director structure of a susceptor assembly of the present invention upon regions of high electric field intensity and again showing the paths followed by three discrete points J, K, and L located at respective radial positions P_1 , P_2 and P_3 on a turntable;

15 Figure 7B is a plot, similar to Figure 1B, showing total energy exposure for one full rotation of the turntable at each discrete point, with the waveform of Figure 1B superimposed for ease of comparison;

Figures 8A, 9A and 10A are pictorial views of various preferred implementations of a susceptor assembly in accordance with the invention, with portions of the planar susceptor broken away for clarity;

20 Figures 8B, 9B and 10B are plan views of the susceptor assembly shown in Figures 8A, 9A and 10A, respectively;

Figure 11 is a pictorial view of a field director structure in accordance with the invention implemented using a single curved vane;

25 Figure 12 is a pictorial view of a field director structure in accordance with the invention implemented using a planar vane with a single bend line therein;

Figures 13A and 13B are respective elevational and pictorial views of a field director structure in accordance with the invention implemented using a planar vane with two bend line therein;

30 Figures 14 and 15 are pictorial views of two additional implementations of a field director structure in accordance with the invention each having a plurality of vanes flexibly connected to form a collapsible structure;

Figure 16 is a pictorial view of a field director assembly in accordance with the present invention wherein at least one vane is supported on a non-conducting substrate;

Figures 17 and 18 are plots of the results of Examples 6 and 7,
5 respectively;

Figure 19 is a pictorial view showing various vane configurations of the field director structure with conductive portions having different shapes and positions;

Figure 20 is a plan view of a susceptor assembly incorporating a
10 six-vane field director structure used in Examples 9 through 23;

Figure 21 is an enlarged dimensioned view showing a vane configuration having a rectangular electrically conductive portion that occupies the entire vane area;

Figure 22 is an enlarged dimensioned view showing a vane
15 configuration having a generally rectangular electrically conductive portion having rounded corners and a surrounding non-conducting border portion;

Figure 23 is an enlarged dimensioned view showing a vane configuration having a generally rectangular electrically conductive portion having rounded corners;

Figure 24, 25 and 26 are an enlarged dimensioned views showing
20 vane blanks having two generally rectangular, spaced apart, electrically conductive portions, the conductive portions having rounded corners and having non-conducting borders surrounding each conductive portion;

Figure 27 illustrates typical overheating of the susceptor in
25 Examples 24–34;

Figure 28 is an enlarged view showing typical overheating of the susceptor and melting of the protective polymer coating on the susceptor;

Figure 29 shows the results of Examples 35–40; and

Figure 30 shows results of Examples 61–64.

30 DETAILED DESCRIPTION OF THE INVENTION

Throughout the following detailed description similar reference characters refers to similar elements in all figures of the drawings.

With reference to Figures 2 and 3 shown is a stylized pictorial view of a susceptor assembly generally indicated by the reference numeral 10 in accordance with the present invention. The susceptor assembly 10 has a reference axis 10A extending through its geometric center 10C. The susceptor assembly 10 is, in use, disposed within the resonant cavity on the interior of a microwave oven M. The oven M is suggested only in outline form in the Figures. In operation, a source in the oven produces an electromagnetic wave having a predetermined wavelength. A typical microwave oven operates at a frequency of 2450 MHz, producing a wave having a wavelength on the order twelve centimeters (12 cm)(about 4.7 inches). The walls W of the microwave M impose boundary conditions that cause the distribution of electromagnetic field energy within the volume of the oven to vary. This generates a standing wave energy pattern within the volume of the oven.

The susceptor assembly 10 comprises a conventional, generally planar susceptor 12 having a field director structure generally indicated at reference numeral 14 connected thereto. As will be developed herein the field director structure 14 is useful for redirecting and relocating the regions of high and low electric field intensity of the standing wave pattern within the volume of the oven. When used in conjunction with a turntable the positions of the redirected and relocated regions change continuously, further improving the uniformity of warming, cooking or browning of a food product placed on a susceptor assembly 10 that includes the field director structure 16.

In the embodiment shown in Figures 2 and 3 the field director structure 14 is disposed under the planar susceptor 12, although it should be appreciated that these relative positions may be reversed. Whatever the respective relative positions of the field director structure 14 and the planar susceptor 12, a food product (not shown) being warmed, cooked or browned or other article is typically placed in contact with the planar susceptor 12.

The planar susceptor 12 shown in the figures is generally circular in outline although it may exhibit any predetermined desired form consistent

with the food product to be warmed, cooked or browned within the oven
M. As shown in the circled detail portion of Figure 2 the planar susceptor
12 comprises a substrate 12S having an electrically lossy layer 12C
thereon. The layer 12C is typically a thin coating of vacuum deposited
5 aluminum.

The substrate 12S may be made from any of a variety of materials
conventionally used for this purpose, such as cardboard, paperboard,
fiber glass or a polymeric material such as polyethylene terephthalate, heat
stabilized polyethylene terephthalate, polyethylene ester ketone, polyethylene
10 naphthalate, cellophane, polyimides, polyetherimides, polyesterimides,
polyarylates, polyamides, polyolefins, polyaramids or
polycyclohexylenedimethylene terephthalate. The substrate 12S may be
omitted if the electrically lossy layer 12C is self-supporting.

The field director structure 14 includes one or more vanes 16. In
15 the embodiment illustrated in Figures 2 and 3, five vanes 16-1 through 16-
5 are shown. Figures 4A through 4F illustrate susceptor assemblies 10
wherein the field director structure 14 has a number N of vanes 16
ranging from two to six. In general, any convenient number of vanes 1, 2,
3 ... N may be used, depending upon the size of the planar susceptor,
20 and the edge length, configuration, orientation and disposition of the
vanes.

For purposes of illustration the vanes shown in Figures 2 and 3
exhibit a variety of edge contours, as will be discussed.

The front and back of each vane define a surface area 16S. In
25 Figures 2 and 3 the surface area 16S of each vane 16 is illustrated as
generally rectangular, although it should be appreciated that a vane's
surface area may be conveniently configured as any plane figure, such as
a triangle, a parallelogram or a trapezoid. If desired, the surface area 16S
of a vane may be curved in one or more directions.

30 At least a portion of the surface of the front and/or the back of each
of the vane(s) 16 is electrically conductive. Any region of drawing Figures
2 and 3 having hatched shading indicates an electrically conductive

portion 16C of a vane 16. An electrically non-conductive portion 16N of a vane 16 is indicated by the stipled shading.

Each vane has an edge 16F extending between a first end 16D and a second end 16E. The edge 16F of a vane may exhibit any of a variety of contours. For example, the edge 16F of a vane may be straight, as illustrated by the vanes 16-1 to 16-3. Alternatively, the edge 16F of a vane may be bent or folded along one or more bend or fold line(s) 16L as suggested by the vane 16-4. Moreover, the contour of the edge 16F of a vane may be curved, as suggested by the vanes 16-5 (Figures 2 and 3) and the vane 16-1' (Figure 3).

A vane may have its first end 16D and its second end 16E disposed at any predetermined respective points of origin and termination on the planar susceptor 12. The distance along the edge 16F of a vane between its first end 16D and its second end 16E defines the edge length of the vane. The vanes in the field director structure 14 may have any desired edge length, subject to the proviso regarding the length of the conductive portion 16C mentioned below.

The vanes 16 may be integrally constructed from an electrically conductive foil or other material. In such a case the entire surface 16S of the vane is electrically conductive (e.g., as shown in Figure 2 for the vane 16-1). The length and width of the conductive portion 16C thus correspond to the edge length and width of the vane.

Alternatively, a vane may be constructed as a layered structure formed from a dielectric substrate with an electrically conductive material laminated or coated over some or all of the front and/or back of its surface area. One form of construction could utilize a paperboard substrate to which an adhesive-backed electrically conductive foil tape is applied.

If provided over less than the full surface area of a vane the electrically conductive portion 16C may itself exhibit any convenient shape, e.g., trapezoidal (as shown for vanes 16-2 and 16-3) or rectangular (as shown for vanes 16-4 and 16-5 and vane 16-1' in Figure 3). The width dimension of the electrically conductive portion 16C of the vane should be about 0.1 to about 0.5 times the wavelength generated in

the oven. The conductive portion 16C of vane has a length that should be at least about a distance approximating about 0.25 times the wavelength of the electromagnetic energy generated in the oven. An edge length about twice the wavelength of the electromagnetic energy generated in the oven defines a practical upper limit.

Whatever the shape of the conductive portion it may be desirable to radius or "round-off" corners to avoid arcing, as will be developed in connection with Figure 19.

Selection of the shape and the length of the electrically conductive portion of the vane and the spacing of the conductor portion from the susceptor plane and other vanes permits the field attenuating effect of the vane to be more precisely tailored.

Wherever its points of origin and termination a vane may also be arranged to pass through the geometric center 10C. Figure 2 shows the path of a straight-edged vane 16-1 extending through the geometric center 10C from a first end 16d originating adjacent the periphery of the susceptor. Figure 3 shows the path of a curved-edged vane 16-1' extending through the geometric center 10C from a first end 16D originating in the vicinity of the geometric center 10C. All of the other vanes in Figures 2 and 3 have paths that originate at a point of origin in the vicinity of the geometric center 10C and extend outwardly therefrom.

The vanes 16 extend in a generally radial direction with respect to the geometric center 10C of the susceptor assembly 10. The vanes 16 may be angularly spaced about the center 10C at equal or unequal angles of separation. For example, the angle 18 between the vanes 16-1 and 16-2 may be smaller than the angle 20 between the vanes 16-2 and 16-3.

It should be appreciated that the term "generally radial" (or similar terms) does not require that each vane must lie exactly on a radius emanating from the center 10C. For example, vanes may be either offset or inclined with respect to the radius. Figures 4A through 4C respectively illustrate straight-edged vanes 16T, bent-edged vanes 16B and curved-edged vanes 16V that are offset with respect to radial lines R emanating from the geometric center 10C. Similarly, Figures 4D through 4F

respectively illustrate straight-edged vanes 16T, bent-edged vanes 16B and curved-edged vanes 16R that are inclined with respect to radial lines R emanating from the geometric center 10C. Other dispositions of the vanes may be used to achieve the transverse orientation of the vanes 16 with respect to planar susceptor 12.

Each vane 16 is physically (i.e., mechanically) connected to the planar susceptor 12 at one or more connection points. A connection between a vane 16 and the planar susceptor 12 may be a fixed connection or a flexible articulating connection.

A fixed connection is shown in Figure 5A. In a fixed connection a vane 16 is attached by a suitable adhesive 24 in a predetermined fixed orientation with respect to the planar susceptor 12. The orientation of the vane 16 is preferably at an angle of inclination in the range between about forty-five degrees (45°) and about ninety degrees (90°) degrees with respect to the planar susceptor, although smaller angular orientations may provide a useful effect. In the most preferred instance the vane 16 is substantially orthogonal to the planar susceptor 12.

A flexible articulating connection is shown in Figure 5B. In this arrangement a vane 16 is attached to the planar susceptor 12 by a hinge 26. The hinge may be made from a flexible tape. In an articulating connection the vane 16 is movable from a stored position (shown in dashed lines in Figure 5B) in which the plane of the vane is substantially parallel to the planar susceptor to a deployed position (shown in solid outline lines in Figure 5B). The hinge may be provided with a suitable stop so that, in the deployed position, the vane is held at a desired angle of inclination, preferably in the range between about forty-five degrees (45°) and about ninety degrees (90°) degrees with respect to the planar susceptor, and most preferably substantially orthogonal to the planar susceptor 12.

Whatever the form of construction, configuration of the vane's surface area, shape of the conductive portion, edge contour of the vane, edge length of the vane, length of the conductive portion on the vane, path of the vane with respect to the center of the susceptor, and the

orientation of the vane with respect to plane of the susceptor, the electrically conductive portion 16C of the vane 16 must be disposed no farther than a predetermined close distance from the electrically lossy layer 12C of the planar susceptor 12. In general the predetermined close distance should be no greater than a distance approximating 0.25 times the wavelength of the electromagnetic energy generated in the oven. It should be understood that so long as a food product or other article is present the predetermined close distance can be zero, meaning that the conductive portion 16C of the vane abuts electrically against the lossy layer 12C of the planar susceptor.

In a typical implementation, shown in Figure 2, the lossy layer 12C is supported on a dielectric substrate 12S, so that the edge of the conductive portion 16C of the vane is spaced from the lossy layer 12C by only the thickness of the substrate 12S. The vertical dimension of the non-conductive portions 16N may be used to control the height at which the planar susceptor 12 is supported within the oven M.

Alternatively, as seen from Figure 3 the non-conductive portions 12N of the vanes may be disposed adjacent to the planar susceptor 12. This disposition has the effect of spacing the conductive portions 16C of the vanes away from the lossy layer 12C at distances greater than the thickness of the substrate 12S. If desired, additional non-conductive portions 16N may be disposed along the opposite edge of the vanes to obtain the height control benefits discussed above.

The planar susceptor 12 and a surface area 16S of a vane 16 intersect along a line of intersection 12L extending in a generally transverse direction with respect to the planar susceptor 12. When intersected with the planar susceptor 12, a straight-edged vane 16 will produce a straight line of intersection 12L. A vane 16 having a bent edge or curved edge, when intersected with the planar susceptor 12, will produce a bent or curved line of intersection 12L, respectively. The magnitude of the bend angle or the shape of curvature of the line of intersection, as the case may be, will depend upon the angle of inclination of the vane to the planar susceptor. Whether the line of intersection is a

straight line, a bent line or a curved line, the extension of the conductive surface of the vane will lie along the line of intersection.

Having described the various structural details of a susceptor assembly 10 in accordance with the present invention, its effect on a standing electromagnetic wave may now be discussed.

Figure 6 is a schematic diagram representation in which an embodiment of a susceptor assembly 10 having a single straight-edged vane 16 is connected in a substantially orthogonal orientation with respect to the undersurface of a planar susceptor 12. A set of Cartesian axes is positioned to originate at the geometric center 10C of the assembly 10. The assembly 10 is arranged so that the planar susceptor 12 lies in the X-Y Cartesian plane and that the conductive portion 16C of the surface 16S of the vane 16 lies in the X-Z Cartesian plane. The line of intersection 12L defined along the connection between the vane 16 and the planar susceptor 12 extends transversely across the lossy layer 12C of the planar susceptor 12 and is oriented along the X axis, as illustrated. The conductive portion 16C of the surface 16S of the vane 16 lies a predetermined distance D in the Z direction from the lossy layer on the planar susceptor 12. The conductive portion 16C of the surface 16S has a thickness (i.e., its Y dimension) greater than the depth of the skin effect of a conductor at the frequency of microwave operation.

An electromagnetic wave is composed of mutually orthogonal oscillating magnetic and electric fields. At any given instant a standing electromagnetic wave includes an electric field constituent \vec{E} . At any instant the electric field constituent \vec{E} is oriented in a given direction in the Cartesian space and may have any given value.

The electric field \vec{E} is itself resolvable into three component vectors, viz., \vec{E}_x , \vec{E}_y , \vec{E}_z . Each component vector is oriented along its respective corresponding coordinate axis. Depending upon the value of the electric field \vec{E} each component vector has a predetermined value of "x", "y" or "z" units, as the case may be.

One corollary of Faraday's Law of Electromagnetism is the boundary condition that the tangential electric field at the interface surface between two media must be continuous across that surface. A particular example of such a media interface is that between a perfect conductor and air. By definition, a perfect conductor must have a zero electric field within it. Therefore, in particular, the tangential component of the electric field just inside the conductor surface must be zero. Hence, from the above asserted boundary continuity condition, the tangential electric field in the air just outside the conductor must also be zero. So we have the general rule that the tangential component of the electric field at the surface of a perfect conductor is always zero. If the conductor is good, but not perfect, then the tangential component of the electric field at the surface may be nonzero, but it remains very small. Thus, any electric field existing just outside the surface of a good conductor must be substantially normal to that surface.

The application of this physical law mandates that within that surface area of the vane 16 having the conductive portion 16C only the component vector of the electric field that is oriented perpendicular to that surface, viz., the vector \vec{E}_y , is permitted to exist. The component vectors of the electric field lying in any plane tangent to the surface of the vane, (viz., the vector \vec{E}_x and the vector \vec{E}_z) are not permitted. In Figure 6, the tangent plane is the plane of the conductive portion of the surface of the vane.

If the conductive portion 16C of the vane 16 were in electrical contact with the lossy layer 12C the value of the component vector \vec{E}_x lying along the line of intersection 12L and the value of the component vector \vec{E}_z would be zero, for the reasons just discussed. However, the conductive portion 16C is not in electrical contact with the lossy layer 12C, but is instead spaced therefrom by the distance D. The conductive portion of the surface of the vane nevertheless exerts an attenuating effect having its most pronounced action in the extension of the conductive portion of the surface of the vane.

Thus, the component vectors \vec{E}_x and \vec{E}_z of the electric field of the wave have only attenuated intensities " x_a " and " z_a ". The intensity values " x_a " and " z_a " are each some intensity value less than " x " and " z ", respectively. Attenuation of the electric field component of the
5 electromagnetic wave in the plane tangent to the surface of the vane results in enhancement of the component of the electric field oriented perpendicular to the conductive portion of the surface of the vane. Thus, the component vector \vec{E}_y has an enhanced intensity value " y_e " greater than the intensity value than " y ".

10 The degree of attenuation of the vector component \vec{E}_x is dependent upon the magnitude of the distance D and the orientation of the conductive portion 16C relative to the lossy layer 12C. The attenuation effect is most pronounced when the distance D is less than one-quarter (0.25) wavelength, for a typical microwave oven a distance of about three
15 centimeters (3 cm). At an angle of inclination less than ninety degrees the permitted field (i.e., the field normal to the conductive surface of the vane) will itself have components acting in the susceptor plane.

This effect is utilized by the susceptor assembly 10 of the present invention to redirect and relocate the regions of relatively high electric field
20 intensity within a microwave oven.

Figure 7A is a stylized plan view, generally similar to Figure 1A, illustrating the effect of a vane 16 as it is carried by a turntable T in the direction of rotation shown by the arrow. The vane is shown in outline form and its thickness is exaggerated for clarity of explanation.

25 Consider the situation at Position 1, near where the vane first encounters the hot region H_2 . For the reasons explained earlier only an electric field vector having an attenuated intensity is permitted to exist in the segment of the hot region H_2 overlaid by the vane 16. However, even though only an attenuated field is permitted to exist the energy content of
30 the electric field cannot merely disappear. Instead, the attenuating action in the region extending from the conductive portion of the vane manifests itself by causing the electric field energy to relocate from its original

location A on the planar susceptor 12 to a displaced location A'. This energy relocation is illustrated by the displacement arrow D.

As the rotational sweep carries the vane 16 to Position 2 a similar result obtains. The attenuating action of the vane again permits only an
5 attenuated field to exist in the region extending from the conductive portion of the vane. The energy in the electric field energy originally located at location B on the planar susceptor 12 displaces to location B', as suggested by the displacement arrow D'.

Similar energy relocations and redirections occur as the vane 16
10 sweeps through all of the regions H₁ through H₅ (Figure 1A) of relatively high electric field intensity.

The use of the present invention in a microwave oven having a mode stirrer apparatus will result in the same effect.

Figure 7B is a plot showing total energy exposure for one full
15 rotation of the turntable at each discrete point J, K and L. The corresponding waveform of the plot of Figure 1B is superimposed thereover.

It is clear from Figure 7B that the presence of a susceptor assembly 10 having the field director 14 in accordance with the present
20 invention results in a total energy exposure that is substantially uniform. As a result, warming, cooking and browning of a food product placed on the susceptor assembly 10 will be improved over the situation extant in the prior art.

Figures 8A and 8B, 9A and 9B and 10A and 10B illustrate preferred
25 constructions of a susceptor assembly in accordance with the present invention.

Figures 8A and 8B show a susceptor assembly 10² that includes a field director structure 14² having five straight-edged vanes 16²-1 through 16²-5. The five vanes 16²-1 through 16²-5 are attached to the underside
30 of a planar susceptor 12. The vanes lie substantially orthogonal to the planar susceptor 12 and are equiangularly arranged about the center 10C. The vane 16²-1 extends through the center 10C while the vanes 16²-2 through 16²-5 originate in the vicinity of the center 10C. The conductive

portion 16²C covers the entire surface of each vane. If desired the bottom edges of vanes of the field director 14² may be further supported on a non-conductive planar support member 32.

The support member may be connected to all or some of the vanes.

5 Figures 9A and 9B show a susceptor assembly 10³ that includes a field director structure 14³ having two curved-edged vanes 16³-1 and 16³-2. The two vanes 16³-1 and 16³-2 are attached to the underside of a planar susceptor 12. The vanes lie substantially orthogonal to the planar susceptor 12 and are equiangularly arranged about the center 10C. The
10 vanes intersect each other in the vicinity of the center 10C. The conductive portion 16³C covers the entire surface of each vane. Again, a non-conductive planar support member 32 may be further support the bottom edges of vanes of the field director 14³, if desired.

 Figures 10A and 10B show a susceptor assembly 10⁴ that includes
15 a field director structure 14⁴ having six straight-edged vanes 16⁴-1 through 16⁴-6. The six vanes 16⁴-1 through 16⁴-6 are attached to the underside of a planar susceptor 12. The vanes lie substantially orthogonal to the planar susceptor 12 and are equiangularly arranged about the center 10C. All of the vanes originate in the vicinity of the center 10C. The conductive
20 portion 16⁴C covers the entire surface of each vane. A non-conductive planar support member 32 may be used.

 If desired, the vanes 16⁴-1 and 16⁴-4 may themselves be connected by a length of a non-conductive member 16⁴N. The member 16⁴N is shown in Figure 10A in dashed outline with stipled shading.

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 In a second aspect, the invention is directed to various implementations of a collapsible self-supporting field director structure
30 embodying the teachings of the present invention.

 Figures 11, 12, 13A and 13B illustrate a field director structure formed from a single vane. In each implementation the vane has a zone of inflection whereby a planar vane may be formed into a self-supporting

structure oriented in a predetermined orientation with respect to a predetermined reference plane RP disposed within the oven M. The plane RP may be conveniently defined as a plane in which the surface of a turntable or the surface of a food product or other article disposed within
5 the oven.

In Figure 11 the field director structure 14⁵ is implemented using a single curved vane 16⁵. The vane 16⁵ may be curved or may have least one region of flexure or curvature 16⁵R defined between the first and second ends 16⁵D and 16⁵E. The conductive portion 16⁵C covers the
10 entire surface of the vane. In use, the vane 16⁵ may be formed into a self-supporting structure arranged in a predetermined orientation with respect to a predetermined reference plane RP.

In the field director structure 14⁶ shown in Figure 12 the vane 16⁶ has a single fold or bend line 16⁶L-1 herein. In use, the vane 16⁶ may be
15 folded or bent along the bend line 16⁶L-1 to define a self-supporting structure lying in a predetermined orientation with respect to a predetermined reference plane RP within the oven M. The same effect may be achieved by flexibly attaching two straight-edged vanes along a flexible line of connection in place of the fold or bend line.

Figures 13A and 13B are respective elevational and pictorial views of a field director structure 14⁷ implemented using a conductive planar vane 16⁷ with two bend lines 16⁷L-1 and 16⁷L-2. Bending the vane 16⁷
20 along the bend lines 16⁷L-1 and 16⁷L-2 forms ears 16⁷E-1 and 16⁷E-2 that serve to support the planar vane in a predetermined desired orientation with respect to the predetermined reference plane RP within the oven M.

Figures 14 and 15 are pictorial views of two additional implementations of a collapsible self-supporting field director structure in accordance with the invention. Each field director structure has a vane array that includes a plurality of vanes flexibly connected to form a
30 structure that may be made self-supporting.

In the field director structure 14⁸ shown in Figure 14 and 15 the vane array comprising vanes 16⁸-1 through 16⁸-5, each vane having an electrically conductive surface thereon. Each vane is flexibly connected at

a point of connection 16⁸F to at least one other vane. The flexibly connected vanes are able to be fanned toward and away from each other, as suggested by the arrows 16⁸J. In use, with the vanes in the array spread from each other the field director is able to be self-supporting with each vane in the array being disposed in a predetermined orientation with respect to a predetermined reference plane RP within the oven. In a modified embodiment a strut 16⁸S may be connected to the free end of each of at least three vanes. The struts are fabricated of any material transparent to microwave energy.

The field director structure 14⁹ shown in Figure 15 comprises a pair of vanes 16⁹-1 and 16⁹-2, each vane having an electrically conductive surface thereon. Each vane is flexibly connected at a point of connection 16⁹F to the one other vane. The flexibly connected vanes are able to be fanned toward and away from each other, as suggested by the arrows 16⁹J. In use, with the vanes in the array spread from each other the field director is able to be self-supporting with each vane in the array being disposed in a predetermined orientation with respect to a predetermined reference plane within the oven.

Although the vanes in each of the embodiments illustrated in Figure 11 through 15 are shown with the conductive portions extending over the entire surface of vane, it should be understood that the conductive portion of any of the vanes may exhibit any alternative shape.

It should also be appreciated that a field director structure of the present invention need not be made collapsible, but instead may be made self-supporting through the use of a suitable non-conductive support member. Figure 16 is a pictorial view of a field director assembly generally indicated by the reference character 31. The field director assembly 31 shown in Figure 16 comprises at least one vane 16 connected to a planar non-conductive support member 32 whereby the conductive surface of the vane is oriented in a predetermined orientation (shown as generally orthogonal to the support member). If additional vanes are provided, these additional vanes are supported on the same support member. The vanes may or may not be connected to each other,

as desired. The support member may be connected below or above the vane(s).

It should also further be appreciated that any embodiment of a field director structure falling within the scope of the present invention may be used with a separate planar susceptor (earlier described). It should also be appreciated that for some food products it may be desirable to place a second planar susceptor above the food product or to wrap the food product with a flexible susceptor.

EXAMPLES 1-8

The operation of the field director structure and a susceptor assembly in accordance with the present invention may be understood more clearly from the following examples.

Introduction For all of the following examples commercially available microwavable pizzas (DiGiorno[®] Microwave Four Cheese Pizza, 280 grams) were used in the cooking experiments.

A planar susceptor comprised of a thin layer of vapor-deposited aluminum sandwiched between a polyester film and paperboard was provided with the pizza in the package. This planar susceptor was used with various implementations of the field director structure of the present invention, as will be discussed. The edge of the paperboard provided was shaped to form an inverted U-shape cooking tray to space the planar susceptor approximately 2.5 cm above a turntable in the microwave oven. A crisping ring (intended for browning the edges of the pizza) provided with the pizza in the package was not used.

In all examples the planar susceptor was placed directly upon a turntable of a microwave oven. In all examples frozen pizzas were placed directly on the planar susceptor and cooked at full power for 5 minutes, except for Example 5, which was cooked in a lower power over for 7.5 minutes.

For comparison purposes one group of three pizzas was cooked using only the planar susceptor without a field director structure, and another group of three pizzas was cooked using the planar susceptor with a field director structure of the present invention.

The vanes of each field director were constructed using aluminum foil of 0.002 inch (0.05 millimeter) thickness, paperboard, and tape.

For Examples 1 through 7 the field director structure was placed in the space under the planar susceptor. For Example 8 the field director
5 structure was positioned above the pizza.

Browning and browning profile measurements The percent
browned and the browning profile of the pizza bottom crust were
measured following a procedure described in Papadakis, S.E., et al. "A
Versatile and Inexpensive Technique for Measuring Color of Foods," *Food*
10 *Technology*, 54 (12) pp. 48-51 (2000). A lighting system was set up and a
digital camera (Nikon, model D1) was used to acquire images of the
bottom crust after cooking. A commercially available image and graphics
software program was used to convert color parameters to the L-a-b color
model, the preferred color model for food research. Following the
15 suggestion from the referenced procedure the percent browned area was
defined as percent of pixels with a lightness L value of less than 153 (on a
lightness scale of 0 to 255, 255 being the lightest). Following the
methodology described in the referenced procedure the browning profile
(i.e., the percent browned area as a function of radial position) was
20 calculated.

The image of the bottom crust was divided into multiple concentric annular rings and the mean L value was calculated for each annular ring.

The following examples are believed to illustrate the improvements
in browning and browning uniformity that resulted from the use of different
25 field director structures of the present invention.

Example 1 A DiGiorno[®] Microwave Four Cheese Pizza was
cooked in an 1100-watt General Electric (GE) brand microwave oven,
Model Number JES1036WF001, in the manner described in the
introduction. When a field director was employed, the field director
30 structure in accordance with Figure 14 (without the struts 16⁸S) was used.
The vane 16⁸-1 had a length dimension of 17.5 centimeters, and a width
dimension of 2 centimeters. The vanes vane 16⁸-2 through 16⁸-5 each

had a length dimension of 8 centimeters and a width dimension of 2 centimeters.

After cooking an image of the bottom crust was acquired with the digital camera, as described. From the image data the percent browned area was calculated using the procedures described. The average percent browned area for the pizzas cooked without a field director was determined to be 40.3%. The average percent browned area for the pizzas cooked with a field director was determined to be 60.5%.

Examples 2 to 5 The experiment described in Example 1 was repeated in four microwave ovens of different manufacturers. The oven manufacturer, model number, full power wattage, and cooking time for each example are summarized in Table 1. The table reports the percent browned area achieved with and without a field director. It should be noted that the percent browned area was improved in all cases.

Table 1
Comparison of percent browned area with and without field director

Example	1	2	3	4	5
Oven brand	GE	Sharp	Panasonic	Whirlpool	Goldstar
Wattage	1100	1100	1250	1100	700
Model #	JES1036WF001	R-630DW	NN5760WA	MT4110SKQ	MAL783W
Cooking time	5 min	5 min	5 min	6 min	7.5 min
Percent Browned Area					
W/ field director	60.5%	70.7%	61.7%	60.7%	51.4%
w/out field director	40.3%	55.2%	50.3%	15.3%	31.5%

Example 6 A DiGiorno[®] Microwave Four Cheese Pizza, 280 gram, was cooked in an 1100-watt Sharp brand oven, Model R-630DW. When a field director structure was employed, the field director structure

in accordance with Figure 15 was used. The vanes 16⁹-1 and 16⁹-2 had a length dimension of 22.9 centimeters and a width dimension of 2 centimeters. The radius of curvature for each portion of a curved vane extending from the point of connection 16⁹F was approximately 5.3 cm and had an angle of arc of approximately 124 degrees.

After cooking an image of the bottom crust was acquired with the digital camera and the percent browned area was calculated, all as described.

The average percent browned area for the pizzas cooked without a field director was 55.2%. The average percent browned area for the pizzas cooked with the field director was determined to be 73.8%. The browning profile, was plotted and is shown in Figure 17.

Example 7 The experiment described in Example 6 was repeated using a 1300-watt Panasonic brand oven, Model NN5760WA. The average percent browned area for the pizza cooked without a field director was 50.3%. The average percent browned area for the pizzas cooked with a field director structure was determined to be 51.7%. The substantially uniform browning profile that follows from the use of the present invention may be observed from the plot shown in Figure 18. From observation of Figure 18 it can be appreciated that the browning profile along the radius was greatly improved with the use of a field director structure.

Example 8 The experiment described in Example 1 was repeated in a 700-watt Goldstar brand microwave oven, Model MAL783W. When a field director structure was employed, the field director structure in accordance with Figure 14 with the struts 16⁸S was used. The struts were 5 centimeters in height and were placed on the turntable to support the field director just above the pizza. The field director structure barely touched the top of the pizza after the pizza crust had risen.

After cooking (for 7.5 minutes at full power of the oven used) an image of the bottom crust was acquired with the digital camera and the percent browned area was calculated, all as described.

The percent browned area for the pizza cooked without a field director was 31.5%. The percent browned area for the pizza cooked with a field director was 65.1%.

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When a microwave susceptor assembly such as described above is placed in an "unloaded" microwave oven (i.e., an oven without a food product or other article being present) several deleterious problems have
5 been observed. The problems are particularly acute in high wattage ovens (i.e., ovens having power ratings typically greater than nine hundred watts). In some instances the microwave susceptor assembly may overheat even when an article is present.

As the lossy layer 12C of the planar susceptor 12 overheats,
10 melting or charring of the substrate 12S may occur. The susceptor may overheat to the extent that the susceptor substrate burns. The conductive portions of the vanes of the field director structure may arc, particularly along the edges and especially at the corners. The arcing causes the non-conductive (typically paperboard) support of the vanes to discolor, to
15 char or to overheat to the extent that it ignites into flames. Overheating of the field director structure may also be caused by overheating of the susceptor material.

Accordingly, it is believed advantageous to provide a field director structure and a susceptor assembly incorporating the same that is "abuse-
20 tolerant", that is, a structure that prevents the occurrence of arcing, and/or the occurrence of overheating of the field director, and/or the occurrence of overheating of the susceptor.

Figure 19 is a composite view of a susceptor assembly 10¹⁰ having a field director structure 14¹⁰ having. The vanes depicted in Figure 19
25 illustrate vanes that are used in the Examples 9-64 following herein.

The susceptor assembly 10¹⁰ includes a generally planar susceptor 12 having a substrate 12B with an electrically lossy layer 12C, as described earlier in connection with Figure 2.

The field director structure 14¹⁰ has at least one but preferably a
30 plurality of vanes 16¹⁰ each mechanically connected to the planar susceptor 12. Each vane 16¹⁰-1 through 16¹⁰-8 shown in Figure 19 is formed of a substrate 16¹⁰N of a non-conductive material. Each vane is generally rectangular in shape. The substrate 16¹⁰N is visible on some of

the vanes. The substrate 16¹⁰N may have a fire retardant composition applied thereto.

It should be understood that the field director structure 14¹⁰ may alternatively be used in combination with a planar non-conductive support member 32 to define a field director assembly generally indicated by the reference character 31.

Each vane 16¹⁰ has a surface 16¹⁰S which is identified for clarity of illustration only for the vane 16¹⁰-6. At least a portion 16¹⁰C of the surface 16¹⁰S of each vane is electrically conductive. As will be described the electrically conductive portion 16¹⁰C of each vane 16¹⁰ is positioned with respect to the planar susceptor 12 and configured in various ways to prevent overheating and arcing problems.

The conductive portion 16¹⁰C of each vane 16¹⁰ has a first end 15¹⁰D and a second end 15¹⁰E. Again for clarity the ends are indicated only on vane 16¹⁰-6. The distance between the first and second ends 15¹⁰D and 15¹⁰E defines a predetermined length dimension for the conductive portion 16¹⁰C. The conductive portion 16¹⁰C of each vane also exhibits a predetermined width dimension. As previously described (e.g., in conjunction with Figures 2 and 3) the length dimension should be in the range from about 0.25 to about two (2) times the wavelength of the standing electromagnetic wave produced generated in the oven. The width dimension should be in the range from about 0.1 to about 0.5 times that wavelength.

The vane 16¹⁰-1 has a conductive portion 16¹⁰C-1 that occupies the entire rectangular surface. The conductive portion 16¹⁰C-1 abuts the planar susceptor 12. The vane 16¹⁰-1 is typical of a vane structure that would overheat when used in an unloaded oven. A susceptor 12, when used with a field director structure having a vane 16¹⁰-1, may also overheat resulting in melting or charring of the susceptor substrate 12S. The conductive portion of the vane 16¹⁰-1 may arc along its edges or at its corners.

The conductive portion 16¹⁰C-2 of the vane 16¹⁰-2 is also rectangular in shape. This conductive portion 16¹⁰C-2 occupies only a

portion of the vane surface, leaving part of the substrate 16¹⁰N exposed to define a border 19L along the bottom edge. The conductive portion 16¹⁰C-2 abuts the planar susceptor 12. The structure of the vane 16¹⁰-2 has been shown to limit but not to eliminate overheating of the vane and susceptor when used in an unloaded oven (Examples 36, 39). When used with a field director structure having a vane 16¹⁰-2 the susceptor 12 may also overheat, resulting in melting or charring of the substrate 12S.

As will be developed the vanes 16¹⁰-3 through 16¹⁰-5, 16¹⁰-7 and 16¹⁰-8 exemplify various positions and/or configurations of the conductive portions 16¹⁰C in accordance with the present invention that the problems of overheating of the susceptor, and/or overheating of the field director, and/or arcing are prevented.

Vane 16¹⁰-3 is an example of a vane in which the substrate 16¹⁰N abuts the planar susceptor 12. In this instance the conductive portion 16¹⁰C-3 is positioned on the vane such that a top border 19T of non-conductive substrate material is exposed along the edge of the vane adjacent to the susceptor 12. The border 19T serves to space the conductive portion 16¹⁰C-3 of the vane 16¹⁰-3 a predetermined close distance 21D away from the susceptor 12. The dimension 21D, measured in a direction orthogonal to the plane of the susceptor 12, lies in a range from 0.025 to 0.1 times the wavelength of the standing electromagnetic wave produced in the microwave oven in which the susceptor assembly 10¹⁰ is being used. That is, the dimension 21D should be at least 0.025 times the wavelength. Further, the dimension 21D should be no greater than 0.1 times that wavelength (that is, the dimension 21D ≤ 0.1 times that wavelength). It should be noted that the maximum distance 17D referred to earlier and the maximum distance shown by reference character D in Figure 6 (i.e., 0.25 wavelength) is sized with the express understanding that the microwave oven in which that vane is used would be loaded.

The conductive portion 16¹⁰C-4 of the vane 16¹⁰-4 is sized such that part of its substrate 16¹⁰N is exposed to define radially inner and

outer borders 19D and 19E, respectively. In addition an upper border 19T and a lower border 19L of substrate material 16N are exposed.

Vane 16¹⁰-5 is an example of a vane in which the conductive portion 16¹⁰C-5 is generally rectangular (similar to the conductive portion 16¹⁰C-4) but with rounded corners. The corners may be rounded at a radius dimension 15R up to and including one-half of the width dimension of the conductive portion 16¹⁰C-5 (i.e., $15R \leq 0.5 \text{ width}$). When the corners are rounded the length of the conductive portion is defined by the radial extent of the conductive portion. The vane 16¹⁰-5 also has borders 19T, 19L, 19D, 19E (similar to those shown about the vane 16¹⁰C-4). The dimension of the lower border 19L is indicated by the reference character 21L.

Vane 16¹⁰-6 also exhibits a conductive portion 16¹⁰C-6 with rounded corners. However, the conductive portion 16¹⁰C-6 extends the full width of the vane and abuts the planar susceptor 12. It is not spaced a predetermined close distance away from the planar susceptor 12.

The vane 16¹⁰-7 is an example of a vane having an electrically conductive portion 16¹⁰C-7 made of a metallic foil that is folded as indicated at 16¹⁰C-7F to define at least a double thickness along its perimeter. Borders 19T, 19L, 19D, 19E (similar to those shown about the vane 16¹⁰C-4) are present along the perimeter of the conductive portion 16¹⁰C-7.

The vane 16¹⁰-8 has a conductive portion 16¹⁰C-8 that occupies its entire rectangular surface. For this vane the requisite spacing 21D of the conductive portion 16¹⁰C-8 from the susceptor 12 is achieved by using a mounting arrangement in which the vane is physically set apart from the susceptor.

Of course, it should also be appreciated that the requisite spacing 21D may also be achieved by the sum of the set apart distance from the susceptor and the border width of an appropriately sized bordered vane (i.e., vane 16¹⁰-3, 16¹⁰-4, 16¹⁰-5, or 16¹⁰-7).

As indicated in Figures 19 and 20, when a plurality of vanes are used the first end 15¹⁰D of the conductive portion of each of the vanes is

disposed a predetermined separation distance 21S from the geometric center 12C of the planar susceptor 12 or the geometric center 32C planar support member 32, as the case may be. The separation distance 21S, measured in a direction parallel to the plane of the susceptor 12 or the support member 31, should be at least 0.16 times the wavelength of the standing electromagnetic wave produced in the microwave oven in which the susceptor assembly 10¹⁰ is being used.

It has been found that disposing the first end 15¹⁰D of the conductive portion 16¹⁰C of each of the vanes at the predetermined separation distance 21S from the geometric center 12C of the planar susceptor 12 mitigates the occurrence of overheating of the susceptor in the vicinity of the susceptor center (Examples 18, 19, 20-22). Disposing the electrically conductive portion of the vane the predetermined close distance 21D from the electrically lossy layer of the planar susceptor (however that spacing is achieved) has also been found to mitigate the occurrence of overheating of the susceptor (Examples 35, 37). Further mitigation of the occurrence of susceptor overheating may be achieved by the provision of the lower border 19L (Examples 36, 39).

In accordance with the present invention the combination of the disposition of the conductive portions of the vanes at the predetermined separation distance 21S together with the disposition of the conductive portions of the vanes at the predetermined close distance 21D from the planar susceptor prevents the occurrence of overheating of the susceptor when used in an unloaded microwave oven.

Also in accordance with the present invention disposing the electrically conductive portion of the vane at the predetermined close distance 21D from the electrically lossy layer of the planar susceptor and rounding the corners of the conductive portion with the radius 15R prevents the occurrence of arcing when used in an unloaded microwave oven.

Further in accord with the invention the occurrence of arcing in an unloaded microwave oven is prevented by disposing the electrically conductive portion of the vane at the predetermined close distance 21D

from the electrically lossy layer of the planar susceptor and covering the conductive portion of any of the vanes 16¹⁰-3 through 16¹⁰-5, 16¹⁰-7, 16¹⁰-8 with an electrically non-conductive material such as a polyacrylic or a polytetrafluoroethylene spray coating or a polyimide tape.

5 Still further in accordance with the invention disposing the electrically conductive portion of the vane at the predetermined close distance 21D from the electrically lossy layer of the planar susceptor and increasing the thickness of the perimeter of a thin foil conductive portion (in the manner shown on the vane 16¹⁰-7) prevents the occurrence of
10 arcing when used in an unloaded oven.

EXAMPLES 9-23

The following examples describe experiments that were conducted to determine parameters that mitigate or eliminate the overheating and/or
15 arcing problems. A General Electric, model JES1456BJ01, 1100 watt microwave oven was used in Examples 9 through 23. The tests were conducted with the oven unloaded, i.e., no food product or other article was present in the oven. These Examples are summarized in Table 2 herein.

20 Example 9 was a control example with no borders and no rounding of corners of the conductive portion of a single vane.

Examples 10–13 and 14–17 tested the effect of a non-conductive covering on the conductive portion of a single vane. In Examples 10–13 the conductive portion was 3/4" (0.75"; 19 mm) wide with rounded
25 corners; in Examples 14–17 the conductive portion was 1" (25.4 mm) wide with rounded corners.

Examples 18–20 tested the effect of varying the center gap between radially opposite conductive portions on arcing and overheating.

30 Examples 21–22 tested alternate materials for the conductive portions. Example 23 tested the effect of fire retardant treatment of the paperboard on arcing and burning.

Example 9 In this example a single vane was configured and positioned with respect to the susceptor in accordance with vane 16¹⁰-1 of

Figure 19. An enlarged dimensioned view of such a vane is shown in Figure 21. A 3-1/2" (3.5") long by 1" wide (88.9 mm by 25.4 mm) adhesive-backed 0.002" (0.05 mm) thick aluminum foil conductive portion from the Merco Co., Hackensack, NJ, with square corners was applied to a cellulose paperboard of the same size. The paperboard was International Paper (Grade Code 1355, 0.017/180# Fortress Uncoated Cup Stock). The vane was then taped to the underside of a commercial susceptor arrangement supplied with DiGiorno[®] Microwave Four Cheese Pizza (280 grams) using 0.001" (0.025 mm) thick polyimide tape (Kapton[®] polyimide tape from E.I. DuPont de Nemours and Company). This configuration resulted in arcing in twenty-eight seconds when exposed unloaded in a microwave oven.

Examples 10–13 In these examples the single vane was configured and positioned with respect to the susceptor in accordance with vane 16¹⁰-5 of Figure 19. An enlarged dimensioned view of such a vane is shown in Figure 22.

Examples 10 through 12 provided a protective covering of an electrically non-conductive material over the aluminum conductive portion in an effort to prevent arcing. An uncovered version, Example 13, was also tested as a control.

Each vane had a conductive portion 3-1/2" (3.5"; 88.9 mm) long and 3/4" (0.75"; 19.2 mm) wide cut from the same adhesive backed 0.002" (0.05 mm) thick aluminum foil used in Example 9, applied to a 4" x 1" (101.6 by 25.4 mm) rectangle of the same cellulose paperboard as in Example 9. The conductive portion was 3/4" (0.75"; 19.2 mm) wide in order to insure the non-conductive covering covered all of the edges of the aluminum conductive portion. A top border of 1/8" (0.125"; 3.2 mm) of paperboard was exposed above the conductive portion. A 1/8" (0.125"; 3.2 mm) border dimension was about 0.025 times the wavelength. The conductive portion had all corners rounded at a radius of 3/8" (0.375"; 9.6 mm).

A lower border of 1/8" (0.125"; 3.2 mm) of paperboard was also exposed below the conductive portion and 1/4" (0.25"; 6.4 mm) border of paperboard was exposed on each end.

Different non-conductive materials were used as the coverings, as follows:

Example 10 - 0.001" (0.025 mm) thick by 1" (25.4 mm) wide polyimide tape (sold under the trademark Kapton® from E.I. DuPont de Nemours and Company)

Example 11 - polyacrylic spray from Minwax

Example 12 - polytetrafluoroethylene spray (sold under the trademark Teflon® from E.I. DuPont de Nemours and Company)

Example 13 – uncoated.

None of the vanes showed any arcing when exposed unloaded in a microwave oven for two minutes.

Examples 14–17 In these examples a single vane was configured and positioned with respect to the susceptor in accordance with vane 16¹⁰-6 of Figure 19. An enlarged dimensioned view of such a vane is shown in Figure 23.

Examples 14 through 16 evaluated the same non-conductive protective coverings disposed over the aluminum conductive portion as in Examples 10 through 12, respectively, but with the aluminum conductive portion being the same 1" (25.4 mm) width as the paperboard. Again, an uncovered version, Example 17, was tested as a control. In each of these examples the conductive portion was 3-1/2" (3.5"; 88.9 mm) long by 1" (25.4 mm) wide adhesive backed 0.002" (0.05 mm) thick aluminum foil applied to a 4" by 1" (101.6 mm by 25.4) rectangle of the cellulose paperboard as was used in Examples 10-13. The conductive portion had all corners rounded at a radius of 1/2" (0.5"; 12.7 mm) and had a 1/4" (0.25"; 6.4 mm) border of exposed paperboard on both of the ends.

Different non-conductive materials were used as the coverings, as follows:

Example 14 - 0.001" (0.025 mm) thick by 1" (25.4 mm) wide polyimide tape (sold under the trademark Kapton® from E.I. DuPont de Nemours and Company)

Example 15 - polyacrylic spray from Minwax

5 Example 16 - polytetrafluoroethylene spray (sold under the trademark Teflon® from E.I. DuPont de Nemours and Company)

Example 17 – uncoated.

10 In Example 14 the surface of the conductive portion was covered by the polyimide tape. The top and bottom edges were not covered by the polyimide tape.

In Examples 15 and 16 the surface of the conductive portion was covered by the polyacrylic or polytetrafluoroethylene spray coating, respectively. The top and bottom edges of the aluminum conductive 15 portion were covered only by incidental over-spray of the polyacrylic or polytetrafluoroethylene coatings.

In Examples 14, 16 and 17 the bottom edge of the conductive portion arced in the center. This arcing occurred very shortly after being exposed unloaded in the microwave oven. In Example 15 no arcing 20 occurred.

More particularly, the results of the experiments were as follows:

25 Example 14 – conductive portion of vane covered with 0.001" (0.025 mm) thick Kapton® tape, arced after 16 seconds of exposure

Example 15 - conductive portion of vane coated with polyacrylic spray, did not arc in 2 minutes

Example 16 - conductive portion of vane coated with polytetrafluoroethylene (Teflon®) spray, arced after 12 seconds of exposure

30 Example 17 - conductive portion of uncovered vane, arced after 17 seconds of exposure.

Figure 20 is a plan view of a susceptor assembly incorporating a six-vane field director used in Examples 18 through 23. It may be appreciated from Figure 20 that the end-to-end gap ("Gap") between conductive portions of diametrically opposed vanes is twice the separation distance 21S.

Example 18 In this example each of the six vanes of the field director of Figure 20 was configured with the conductive portions in accordance with vane 16¹⁰-5 of Figure 19.

As shown in Figure 24 three vane blanks each having conductive portions 3-1/2" (3.5") long by 3/4" (0.75") wide (88.9 mm by 19.2 mm) with all corners rounded at a radius of 3/8" (0.375"; 9.6 mm). The conductive portions were cut from the same adhesive backed 0.002" (0.05 mm) thick aluminum foil used for the previous Examples 9–17. Two of these conductive portions were placed on a by 8" by 1" (203.2 by 25.4 mm) rectangle of the cellulose paperboard used in Examples 9–17 so that there was a 1/8" (0.125"; 3.2 mm) border of paperboard exposed above and below the conductive portion and at the outside ends. A end-to-end gap of 3/4" (0.75"; 19.2 mm) was left between the inner ends of each conductive portion.

Each of three vane blanks was then bent in the middle to form a V-shape and positioned under a susceptor with the apex of each V at the center of the susceptor, thus defining a separation distance 21S (Figure 19) of 3/8" (0.375"; 9.6 mm). The V-shaped vane blanks were glued to the underside of the susceptor using a water soluble adhesive such as type BR-3885 from Basic Adhesives, Inc. The blanks were positioned such that the vanes were equally spaced in a radial spoke pattern. The fully assembled susceptor assembly was arranged so that pairs of conductive portions were directly opposed at an end-to-end gap of 3/4" (0.75"; 19.2 mm).

There was no discernible arcing when this susceptor assembly was exposed unloaded in the microwave oven, but the assembly did burst into flames when the paperboard substrate in the center overheated in forty-seven seconds.

Example 19 In this example each of the six vanes of the field director of Figure 20 was configured with the conductive portions in accordance with vane 16¹⁰-5 of Figure 19.

The vanes in this Example were constructed in the same manner as in Example 18 from vane blanks as illustrated in Figure 25. The vane blanks were 8" by 1-1/4" (203.2 mm by 31.7 mm) rectangles of the same cellulose paperboard. The conductive portions were 3-3/8" (3.375"; 85.7 mm) in length and 1" (25.4 mm) in width with all corners rounded at a radius of 1/2" (0.5"; 12.7 mm). The conductive portions were attached to the paperboard blanks to leave a 1/8" (0.125"; 3.2 mm) border of paperboard exposed above and below the conductive portion and at the outside ends. A end-to-end gap of 1" (25.4 mm) was left between the inner ends of each conductive portion.

As in Example 18 three of these V-folded vane blanks were glued to the underside of a susceptor defining a separation distance 21S (Figure 19) of 1/2" (0.5"; 12.7 mm).

Again, there were no discernible arcs when this susceptor assembly was exposed in the microwave oven unloaded, but the assembly did burst into flames when the paperboard vanes in the center overheated in one minute, eighteen seconds.

Example 20 In this example each of the six vanes of the field director of Figure 20 was configured with conductive portions in accordance with vane 16¹⁰-5 of Figure 19.

The vanes in this Example were also constructed in the same manner as in Examples 18 and 19 from vane blanks as illustrated in Figure 26. The vane blanks were 8" by 1-1/4" (203.2 mm by 31.7 mm) rectangles of the same cellulose paperboard. The conductive portions were 3-1/8" (79.4 mm) in length and 1" (25.4 mm) in width with all corners rounded at a radius of 1/2" (0.5"; 12.7 mm). The conductive portions were attached to the paperboard blanks to leave a 1/8" (0.125"; 3.2 mm) border of paperboard exposed above and below the conductive portion and at the outside ends. An end-to-end gap of 1-1/2" (1.5"; 38.1 mm) was left between the inner ends of each conductive portion.

As in Examples 18 and 19 three of these V-folded vane blanks were glued to the underside of a susceptor defining a separation distance 21S (Figure 19) of 3/4" (0.75"; 19.2 mm).

There was no arcing and no burning when this susceptor assembly was exposed in the microwave oven for five minutes Example 21 The test of Example 20 was repeated using conductive portions as shown in Figure 26. The conductive portions for this example were made with Avery-Dennison Fasson® 0817 adhesive backed 0.002" (0.05 mm) thick aluminum foil available from Avery-Dennison Specialty Tape Division, Painesville, OH.

There was no arcing and no burning when this susceptor assembly was exposed unloaded in the microwave oven for five minutes

Example 22 The test of Example 20 was repeated using conductive portions as shown in Figure 26. The conductive portions for this example were made with Shurtape AF973 adhesive backed 0.002" (0.05 mm) thick aluminum foil available from Shurtape, Hickory, NC.

There was no arcing and no burning when this susceptor assembly was exposed unloaded in the microwave oven for five minutes. The aluminum foil of this tape performed acceptably but the adhesive loosened.

Example 23 The application of a fire retardant composition to avoid spontaneous burning of the vanes was tested as Example 23. The fire retardant used was an aqueous based resin known as Paper Seal™ from Flame Seal® Products of Houston, TX. The susceptor assembly was constructed as in Example 18 with a 3/4" (0.75"; 19.2 mm) gap in the center between each pair of conductive portions as shown in Figure 24 thus defining a separation distance 21S (Figure 19) of 3/8" (0.375 "; 9.6 mm).

The paperboard blanks were dipped into a bath of the fire retardant liquid and allowed to dry for a day before adhering the conductive portions and assembling the susceptor assembly.

There were no arcs when an unloaded susceptor assembly was exposed in the microwave oven for five minutes. Unlike Example 18 the

assembly did not burst into flames, suggesting that a fire retardant treatment of the paperboard was sufficient to prevent burning.

The tests of Examples 9 through 23 are summarized in Table 2.

Table 2 Assessment of Arcing and Overheating (N/A indicates "Not

5 Applicable")

Example Number	Vane dimension	Conductive portion dimension	Rounded corner (radius)	Covering	Vane type ----- Border (Top and Bottom)	Separation Distance ----- Gap	Results
9	3.5"x 1"	3.5"x 1.0"	no	none	16 ¹⁰ -1 none	N/A	Arced 28 sec.
10	4"x 1"	3.5"x .75"	Yes .375"	Kapton®	16 ¹⁰ -5 0.125"	N/A	No arc 2 min.
11	4"x 1"	3.5"x .75"	Yes .375"	Poly-acrylic	16 ¹⁰ -5 0.125"	N/A	No arc 2 min.
12	4"x 1"	3.5"x .75"	Yes .375"	PTFE	16 ¹⁰ -5 0.125"	N/A	No arc 2 min.
13	4"x 1"	3.5"x .75"	Yes .375"	none	16 ¹⁰ -5 0.125"	N/A	No arc 2 min.
14	4"x 1"	3.5"x 1"	Yes .5"	Kapton®	16 ¹⁰ -6 none	N/A	Arced 16 sec.
15	4"x 1"	3.5"x 1"	Yes .5"	Poly-acrylic	16 ¹⁰ -6 none	N/A	No arc 2 min.
16	4"x 1"	3.5"x 1"	Yes .5"	PTFE	16 ¹⁰ -6 none	N/A	Arced 12 sec.
17	4"x 1"	3.5"x 1"	Yes .5"	none	16 ¹⁰ -6 none	N/A	Arced 17 sec.
18	4"x 1"	3.5"x .75"	Yes .375"	none	16 ¹⁰ -5 0.125"	0.375" 0.75"	No arc, Burned, 47 sec. Center overheated
19	4"x 1.25"	3.375"x 1"	Yes .5"	none	16 ¹⁰ -5 0.125"	0.5" 1"	No arc, Burned, 1:18 min, Center overheated
20	4"x 1.25"	3.125"x 1"	Yes .5"	none	16 ¹⁰ -5 0.125"	0.75 1.5"	No arc No burn 5 min.
21	4"x 1.25"	3.125"x 1" Avery/ Denison tape	Yes .5"	none	16 ¹⁰ -5 0.125"	0.75 1.5"	No arc No burn 5 min.
22	4"x 1.25"	3.125"x 1" Shurtape tape	Yes .5"	none	16 ¹⁰ -5 0.125"	0.75 1.5"	No arc, No burn, Adhesive loosened 5 min.
23	4"x 1" Fire retardant	3.5"x .75"	Yes .375"	none	16 ¹⁰ -5 0.125"	0.375 .75"	No arc No burn 5 min.

Observations from Examples 9 to 23 were:

1. The combination of rounded corners on the conductive portion and a border of paperboard (i.e., a lower conductivity material) of at least 1/8" (0.125"; 3.2 mm) (about 0.025

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wavelengths of the standing wave present in a microwave oven) completely surrounding an uncovered conductive portion of a vane prevented arcing. It should be noted that the border served to space the conductive portion of the vane from the susceptor by a predetermined close distance (Examples 18-23);

2. The combination of a border (predetermined close distance) of at least 1/8" (0.125"; 3.2 mm) and a separation distance of the inner ends of the conductive portions from the geometrical center of the susceptor of 3/4" (0.75"; 19.2 mm) (about 0.16 wavelength of the standing wave present in a microwave oven), i.e., a center gap of 1-1/2" (1.5"; 38.1 mm) between opposing conductive portions, prevented overheating and spontaneous combustion of the paperboard of a susceptor assembly when it was exposed in an unloaded microwave oven (Examples 20-22);

3. The combination of a border (predetermined close distance) of at least 1/8" (0.125"; 3.2 mm) and a non-conductive covering of the conductive portion prevented arcing (Examples 10-12). However, as may be seen from Examples 14-16, when the conductive portion was covered with a non-conductive covering and no border was present arcing occurred; and

4. Application of fire retardant to the paperboard prevented spontaneous combustion due to overheating with a separation distance from the geometrical center of the susceptor of 3/8" (0.375"; 9.6 mm) (about 0.08 wavelengths), i.e., a center gap of 3/4" (0.75"; 19.2 mm) between opposing conductive portions.

EXAMPLES 24-64

General Comments In the following Examples 24-64 a susceptor assembly similar to that shown in Figure 20 was used inside a microwave oven to cook DiGiorno[®] Microwave Four Cheese Pizza (280 grams). The results of these experiments are set forth in Tables 3, 4A, 4B and 5 below.

The Examples 24-50 and Examples 61-64 were conducted to assess the effect of various vane designs in eliminating overheating susceptor during pizza cooking in various microwave ovens. The remaining examples (viz., Examples 51-60) were conducted to assess the effect of various vane designs on browning of the pizza cooked in various microwave ovens.

As shown in Figure 20 each susceptor assembly included six identical vanes equally spaced sixty (60) degrees apart mounted onto a susceptor with a 3/8" (0.375"; 9.6 mm) separation distance 21S from each electrically conductive portion of a vane to the geometric center of the susceptor.

The susceptor assemblies tested had substrates formed from various materials. Four different susceptor substrate materials were tested in combination with two different thicknesses of metallization that formed the lossy conductive layer.

The conductive portion of each vane was made using an adhesive backed 0.002" (0.05 mm) thick aluminum foil applied to a cellulose paperboard vane from International Paper as described previously in connections with Examples 9-20. Each conductive portion was 3-1/2" (3.5"; 88.9 mm) in length but of different widths. Tables 3, 4A, 4B and 5 each contain a column of alphabetic designators indicating the "Vane type" tested. Each designator indicates a vane type as depicted in Figure 19 with the "Width" dimension of the conductive portion and "Border" as follows:

	<u>Designator</u>	<u>Figure 19</u>	<u>Vane type,</u>	<u>Width</u>	<u>Border</u>
5	A		Vane 16 ¹⁰ -1	1.0" (25.4 mm)	None
	B		Vane 16 ¹⁰ -3	0.75" 19T (19.2 mm)	0.25" (6.4 mm)
10	C		Vane 16 ¹⁰ -2	0.75" (19.2 mm)	19L 0.25" (6.4 mm)
	D		Vane 16 ¹⁰ -1	1.25" None (31.7 mm)	
	E		Vane 16 ¹⁰ -3	1.0" (25.4 mm)	19T 0.25" (6.4 mm)
20	F		Vane 16 ¹⁰ -2	1.0" (25.4 mm)	19L 0.25" (6.4 mm)
	G		Vane 16 ¹⁰ -3	0.875" 19T (22.2 mm)	0.125" (3.2 mm)
25	H		Vane 16 ¹⁰ -3	0.9375" 19T (23.8 mm)	0.0625" (1.6 mm)

Tables 3, 4A, 4B and 5 also contain a column of alpha-numeric designators indicating the "Oven" used for the test. Each designator corresponds to a particular microwave oven manufacturer and model, as follows:

<u>Designator</u>	<u>Oven Manufacturer, Model</u>
F-950	Frigidaire, FMV156DBA, 950 Watts,
35 GE-1100	General Electric, JES1456BJ01, 1100 Watts
GS-700	Goldstar, MAL783W, 700 Watts
S-1000	Sharp, R-1505F, 1000 Watts
S-1100	Sharp, R-630DW, 1100 Watts

Tables 3, 4A, 4B and 5 contain a column indicating the "Susceptor" (i.e., substrate 12S and layer 12C) used.

The Susceptor in some of the examples contained in Tables 3, 4A and 4B below is identified as "Control". The "Control" susceptor was that provided with the DiGiorno[®] Microwave Four Cheese Pizza (280 grams)

mentioned earlier. The "Control" susceptor included a paperboard substrate.

The "Susceptor" in some of the examples contained in Tables 3 and 5 below is identified by a reference designation comprising
 5 hyphenated first and second numeric values. The first numeric value represents the polymeric substrate material of the susceptor, while the second numeric value denotes the thickness of the susceptor lossy layer metallization (vacuum deposited aluminum) based upon its measured optical density.

10 The first numeric value denotes the polymeric substrate material, as follows:

	<u>First Numeric</u>	<u>Film substrate type</u>
15	10	polyethylene terephalate 300 gauge (no heat treatment) (sold under the trademark Melinex [®] S from E.I. DuPont de Nemours and Company)
20	12	polyethylene terephalate 300 gauge heat stabilized film (sold under the trademark Melinex [®] ST-507 from E.I. DuPont de Nemours and Company)
25	13	polyethylene naphthalene film (PEN) 2 mil sold under the trademark Teonex [®] Q51 from DuPont Teijin Films)

The second numeric value represents the optical density thickness measurement of the metallized coating of vacuum deposited aluminum, as follows:

	<u>Second numeric</u>	<u>Metallization thickness</u>
30	3	0.3 optical density
	4	0.4 optical density

35 Thus, for Example 29 in Table 3, a susceptor designated "12-3" indicates the susceptor had a substrate of 300 gauge polyethylene terephalate heat stabilized film (Melinex[®] ST-507 film) (as denoted by the first numeric "12") and that the aluminum vacuum deposited metallization had an optical density of 0.3 (as denoted by the second numeric "3").

Examples 24-34 A susceptor assembly with Type A vanes (as described above) was used to cook DiGiorno[®] Microwave Four Cheese Pizza (280 grams) in either the S-1000" or the F-950 oven. As may be seen in Table 3 four types of susceptor substrate materials were used.

5 The cooking time was varied from 5 to 6 minutes. All vanned susceptor assemblies consistently overheated in the center. The severity of the overheating increased with cooking time for each susceptor substrate material used. Examples of the overheating included burned and melted spots on the surface of the susceptor that in some cases resulted in
10 transport of the melted susceptor material to the bottom of the pizza, as may be seen in Figures 27 and 28.

Examples 35-40 In Examples 35 to 40 addition of a 1/4" (0.25"; 6.4 mm) border of paperboard on either top or bottom of the conductive portion of the vane was tested to assess its potential to eliminate the overheating in
15 the center of the susceptor. As summarized in Table 3 below, in this series of tests DiGiorno[®] Microwave Four Cheese Pizza was cooked an S-1000 microwave oven for 6 minutes using susceptors having 12-3 substrates. Field director assemblies exhibit different vane types A, B, C, D, E and F were tested. Example 35 utilized a type B vane; Example 36
20 utilized a type C vane; Example 37 utilized a type D vane; Example 38 utilized a type E vane; Example 39 utilized a type F vane; and Example 40 utilized a type A vane.

The results are summarized in Table 3.

Table 3 Assessment of Overheating of Susceptor

Example Number	Vane type	Susceptor	Oven	Cook time, min:sec	Result (to Susceptor)
24	none	Control	S-1000	6:00	No overheating
25	A	Control	S-1000	6:00	Overheating
26	A	Control	S-1000	5:00	Overheating
27	A	10-4	S-1000	6:00	Overheating
28	A	10-4	S-1000	5:00	Overheating
29	A	12-3	S-1000	5:30	Overheating
30	A	13-4	S-1000	5:30	Overheating
31	none	Control	F-950	6:00	No overheating
32	A	Control	F-950	5:30	Overheating
33	A	12-3	F-950	5:30	Overheating
34	A	13-4	F-950	5:30	Overheating
35	B	12-3	S-1000	6:00	No overheating
36	C	12-3	S-1000	6:00	Limited overheating
37	D	12-3	S-1000	6:00	Overheating
38	E	12-3	S-1000	6:00	No overheating
39	F	12-3	S-1000	6:00	Limited overheating
40	A	12-3	S-1000	6:00	Overheating

5

Table 3 illustrates that for vaned susceptors having a separation distance defined between the inner of the conductive portion and the geometric center of the susceptor the addition of a top border between the susceptor and the top edge of the conductive portion of the vane structure (vane Types B and E) consistently prevented overheating of the susceptor. Vaned susceptors without any border (vane Types A and D) consistently led to overheating in the center of the susceptor. Vaned susceptors having a lower border (but no top border) of non-conductive material along the conductive portion of the vane (vane Types C and F) somewhat reduced the severity of the susceptor overheating, but did not eliminate this problem completely. These results of Examples 35-40 are illustrated in Figure 29.

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Examples 41-60 A series of cooking tests were performed with five microwave ovens identified above. The tests used susceptors with vane types A and B to assess the effect of the addition of a top 1/4" (0.25"; 6.4 mm) wide paperboard border along the conductive portion of the vane. Examples 41-50 (summarized in Table 4A) and Examples 51-

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60 (summarized in Table 4B) respectively used the same test conditions. Examples 41-50 assessed overheating.

Examples 51-60 assessed the overall microwave cooking performance, specifically the ability of this configuration of the susceptor assembly to brown uniformly the bottom of a pizza. Percent browning ("% browning") of a pizza was measured in the same manner as described in connection with Examples 1 through 8. The measured % browning was averaged over three pizza samples.

10

Table 4A Assessment of Overheating

Example Number	Vane type	Susceptor	Oven	Cook Time, min:sec	Over-heating
41	A	Control	S-1100	5:00	Yes
42	B	Control	S-1100	5:00	No
43	A	Control	S-1000	5:00	Yes
44	B	Control	S-1000	5:00	No
45	A	Control	F-950	6:00	Yes
46	B	Control	F-950	6:00	No
47	A	Control	G-1100	5:00	Yes
48	B	Control	GE-1100	5:00	No
49	A	Control	GS-700	7:00	Yes
50	B	Control	GS-700	7:00	No

Table 4B Assessment of Cooking Performance

Example Number	Vane type	Susceptor	Oven	Cook Time, min:sec	Average % browning	Over-heating
51	A	Control	S-1100	5:00	53%	Yes
52	B	Control	S-1100	5:00	46%	No
53	A	Control	S-1000	5:00	42%	Yes
54	B	Control	S-1000	5:00	37%	No
55	A	Control	F-950	6:00	69%	Yes
56	B	Control	F-950	6:00	63%	No
57	A	Control	G-1100	5:00	42%	Yes
58	B	Control	GE-1100	5:00	26%	No
59	A	Control	GS-700	7:00	19%	Yes
60	B	Control	GS-700	7:00	22%	No

15

The results shown in Tables 4A and 4B indicated that for vanned susceptors having a separation distance defined between the inner of the conductive portion and the geometric center of the susceptor the addition of a top 1/4" (0.25"; 6.4 mm) paperboard border along the conductive portion of the vane (Type B) consistently prevented overheating in the

center of the susceptor. However, as seen in Table 4B the overall cooking performance of a susceptor with vane type B decreased (as evidenced by lower average percent browning).

5 Examples 61-64 Examples 61-64 evaluated the effect of the width of the top paperboard border between the susceptor and the top edge of the conductive portion of the vane on susceptor overheating. This series of tests was also performed with DiGiorno[®] Microwave Four Cheese Pizza cooked for 6 minutes in an S-1000 microwave oven. The susceptor
 10 assemblies had 12-3 substrate materials and vane types A, B, G and H.

These results of Examples 61-64 are illustrated in Figure 30 and summarized in Table 5.

Table 5 Assessment of effect of top borders on overheating

Example Number	Vane Type	Susceptor	Oven	Cook Time, min:sec	Susceptor Overheating
61	A	12-3	S-1000	6:00	Yes
62	B	12-3	S-1000	6:00	No
63	G	12-3	S-1000	6:00	No
64	H	12-3	S-1000	6:00	Yes

15

These test indicated that for vanned susceptors having a separation distance defined between the inner of the conductive portion and the geometric center of the susceptor a top paperboard border of at least 1/8" (0.125"; 3.2 mm) (i.e., vane types B and G) between susceptor and the
 20 top edge of the conductive portion of the vane structure was required to prevent overheating of the susceptor.

Overall, the conclusions drawn from Examples 24 through 64 for vanned susceptors having a separation distance defined between the inner
 25 of the conductive portion and the geometric center of the susceptor were:

1. A border of a width of at least 1/8" (0.125"; 3.2 mm) between the susceptor and the top edge of the conductive portion of a vane prevented overheating of the susceptor. It should be

noted that the border served to space the conductive portion of the vane from the susceptor by a predetermined close distance;

2. Regardless of substrate used, overheating in the center of the susceptor occurred for susceptor assemblies using vanes with a top border less than 1/8" (0.125"; 3.2 mm). This result was observed for all microwave ovens used.

3. Severity of the overheating (burning and melting) increased with increasing cooking time, higher metallization level of the susceptor substrate, or higher microwave oven power.

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Prevention of Arcing When a field director structure having one or more conductive portions is present in an energized microwave oven (either with or without the presence of a susceptor) the conductive portion(s) cause a disturbance of the standing wave electric field in the oven. The conductive portion(s) concentrate the electric field along their edges, producing local electric field intensities that are much higher than the base electric field within the oven, i.e., the field intensity before the introduction of the conductive portion(s). So long as the oven is loaded these higher field intensities are usually insufficient to cause breakdown of air.

However, when the oven is unloaded (i.e., no food or other article is present) the base electric field increases to a level above that extant when the food or other article is present. In the unloaded case the local intensity of the field along the edge of a conductive portion may be sufficiently high to exceed the breakdown threshold of the air causing an electric discharge in the form of an arc to occur.

It is believed that when a field director structure is used without a susceptor present a conductive portion should be spaced by a border of a lower conductivity material (e.g., a dielectric) at least a predetermined close distance from the planar support member. Preferably the border surrounds the conductive portion. The presence of the border reduces

the local electric field intensity at the edges. The magnitude of this reduction is approximated by the following formula:

$$E_l' = E_l / (\epsilon_r'^2 + \epsilon_r''^2)^{1/2}$$

5 where E_l is the local electric field prior to addition of borders;

E_l' is the local electric field with the border;

ϵ_r' is the relative dielectric constant of the border material; and

ϵ_r'' is the relative dielectric loss of the border material.

10 In essence, due to the presence of the surrounding border the local fields are attenuated so that the breakdown threshold of air is not exceeded, thus preventing arcing.

15 When the field director is used with a susceptor the lossy layer of the susceptor also plays a part in preventing arcing. The lossy layer absorbs part of the microwave energy in the oven and converts it to heat. This absorption reduces the electric field intensity in the oven. The heat flows into a food product or other article present.

20 However when the oven is unloaded there is no food product or other article present in the oven to dissipate the heat generated by the lossy layer. This results in rapid overheating that damages the lossy layer and causes its electrical conductivity to drop significantly. This reduces the ability of the lossy layer to absorb the microwave energy.

25 Without this absorption by the lossy layer the electric field intensity in the oven increases and the high field intensity condition along the edge of a conductive portion may then exceed the breakdown threshold of the air, causing an electric discharge in the form of an arc to occur.

It is believed that when the conductive portion(s) of the field director structure is spaced from the lossy layer by a border of a dielectric material, the border reduces the local electric field intensity at the edges.

5 Prevention of Overheating When a field director structure having two conductive portions is present in an energized microwave oven a concentrated field is created in the space between these conductive portions. When a material having a moderate dielectric loss factor, such as a paperboard planar support member or a susceptor, is placed in or
10 near the region between the conductive portions the concentrated field causes this material to rapidly heat. The concentration of the field is a function of the spacing apart of the conductive portions. If the conductive portions are close enough together this concentrated field may cause the material to overheat sufficiently to burst into flames, as is the case for
15 paperboard. Increasing the spacing between the conductive portions reduces this field concentration and thus prevents overheating.

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Those skilled in the art, having the benefit of the teachings of the
20 present invention may impart modifications thereto. Such modifications are to be construed as lying within the scope of the present invention, as defined by the appended claims.

CLAIMS

What is claimed is:

1. A field director assembly for use in heating an article in a microwave oven, the field director assembly comprising:
 - 5 a generally planar support member having a geometric center;
 - a field director structure comprising a plurality of vanes each mechanically connected to the support member, at least a portion of each vane being electrically conductive, the electrically conductive portion of the vane being disposed at least a predetermined close distance from the support member,
 - 10 the electrically conductive portion of each vane having a first end and a second end, the first end of the conductive portion on each of the vanes being disposed at a distance at least a predetermined separation distance from the geometric center of the planar support member,
 - 15 so that the occurrence of overheating of the field director assembly is prevented when the same is used in an unloaded microwave oven.
2. The field director assembly of claim 1 wherein the microwave oven is operative to generate a standing electromagnetic wave having a predetermined wavelength, and wherein the predetermined separation distance is at least 0.16 times the wavelength.
- 20 3. The field director assembly of claim 1 wherein the microwave oven is operative to generate a standing electromagnetic wave having a predetermined wavelength, and wherein the predetermined close distance is at least 0.025 times the wavelength.
- 25 4. The field director assembly of claim 3 wherein the predetermined separation distance is at least 0.16 times the wavelength.
5. The field director assembly of claim 1 wherein the microwave oven is operative to generate a standing electromagnetic wave having a predetermined wavelength, and wherein the predetermined close distance is no greater than 0.1 times the wavelength.
- 30 6. The field director assembly of claim 5 wherein the predetermined separation distance is at least 0.16 times the wavelength.

7. The field director assembly of claim 1 wherein the microwave oven is operative to generate a standing electromagnetic wave having a predetermined wavelength, and wherein the predetermined close distance lies in the range from 0.025 times the wavelength to 0.1 times the wavelength.

8. The field director assembly of claim 7 wherein the predetermined separation distance is at least 0.16 times the wavelength.

9. The field director assembly of claim 1 wherein the electrically conductive portion of each vane is surrounded by a border of a lower conductivity material.

10. The field director assembly of claim 9 wherein the electrically conductive portion of the vane has a predetermined width dimension and a corner thereon, the corner of the electrically conductive portion being rounded at a radius up to and including one half of the width dimension.

11. The field director assembly of claim 9 wherein the microwave oven is operative to generate a standing electromagnetic wave having a predetermined wavelength, wherein the border has a predetermined width dimension, and

wherein the width of the border is at least 0.025 times the wavelength.

12. The field director assembly of claim 9 wherein the microwave oven is operative to generate a standing electromagnetic wave having a predetermined wavelength, wherein the border has a predetermined width dimension, and

wherein the border has a predetermined width dimension, wherein the width of the border of lower conductivity material is no greater than 0.1 times the wavelength.

13. The field director assembly of claim 9 wherein the microwave oven is operative to generate a standing electromagnetic wave having a predetermined wavelength, wherein the border has a predetermined width dimension, and

wherein the border has a predetermined width dimension, wherein the width of the border of lower conductivity material lies in the range from 0.025 times the wavelength to 0.1 times the wavelength.

14. The field director assembly of claim 1 wherein the electrically
5 conductive portion of each vane is covered with an electrically non-conducting material.

15. The field director assembly of claim 14 wherein the electrically non-conducting covering is selected from the group consisting of a polyimide tape, a polyacrylic spray coating and a polytetrafluoroethylene
10 spray coating.

16. The field director assembly of claim 1 wherein the electrically conductive portion of each vane comprises a metallic foil less than 0.1 millimeter in thickness and wherein the foil is folded over to at least a double thickness along its perimeter.

17. The field director assembly of claim 1 wherein the microwave oven is operative to generate a standing electromagnetic wave having a predetermined wavelength, and

wherein the conductive portion of each vane has a width dimension that is about 0.1 to about 0.5 times the wavelength.

18. The field director assembly of claim 1 wherein the microwave oven is operative to generate a standing electromagnetic wave having a predetermined wavelength, and wherein the conductive portion of each vane has a length dimension from about 0.25 to about 2 times the
20 wavelength.

19. The field director assembly of claim 1 wherein the electrically conductive portion of the vane has a predetermined width dimension and a corner thereon, the corner of the electrically conductive portion being rounded at a radius up to and including one half of the width dimension.

20. A field director assembly for use in a microwave oven, wherein
30 the microwave oven is operative to generate a standing electromagnetic wave having a predetermined wavelength, the field director assembly comprising:

a generally planar support member having a geometric center;

a field director structure comprising at least six vanes each mechanically connected to the support member, each vane being substantially orthogonal with respect to the planar support member, at least a portion of each vane being electrically conductive, the

5 electrically conductive portion of each vane having a first end and a second end,

the first end of the conductive portion on each of the vanes being disposed at a distance at least a predetermined separation distance from the geometric center of the planar support member, the separation

10 distance being at least 0.16 times the wavelength,

the electrically conductive portion of the vane being disposed at least a predetermined close distance from the planar support member, wherein the predetermined close distance is at least 0.025 times the wavelength,

15 so that the occurrence of overheating of the field director assembly is prevented when the same is used in an unloaded microwave oven.

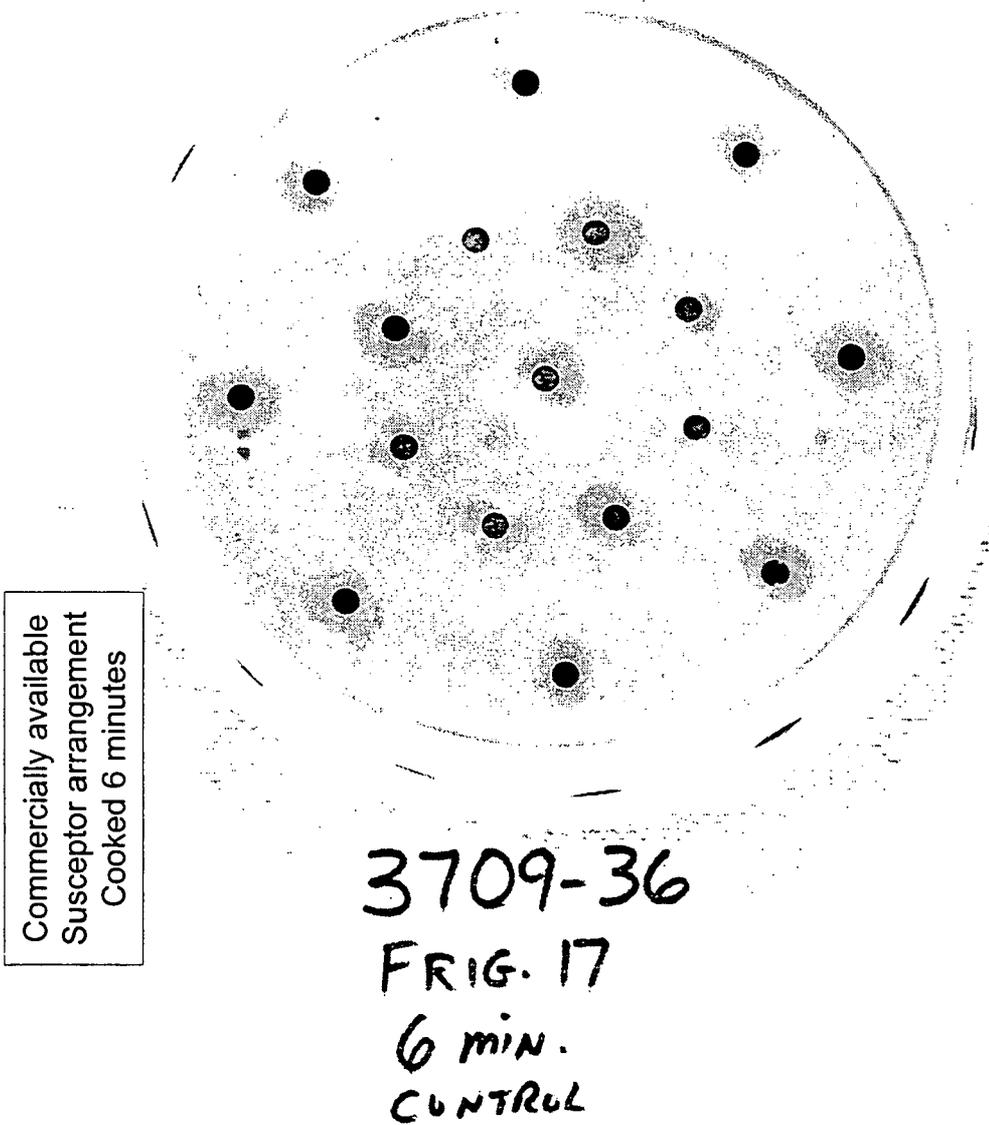
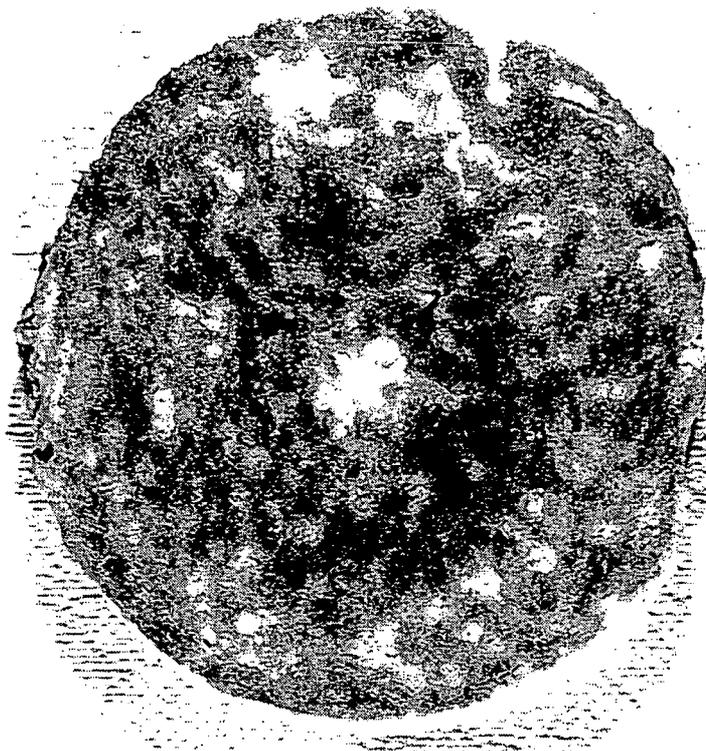


Figure 27A



Commercially available
Susceptor arrangement
Cooked 6 minutes

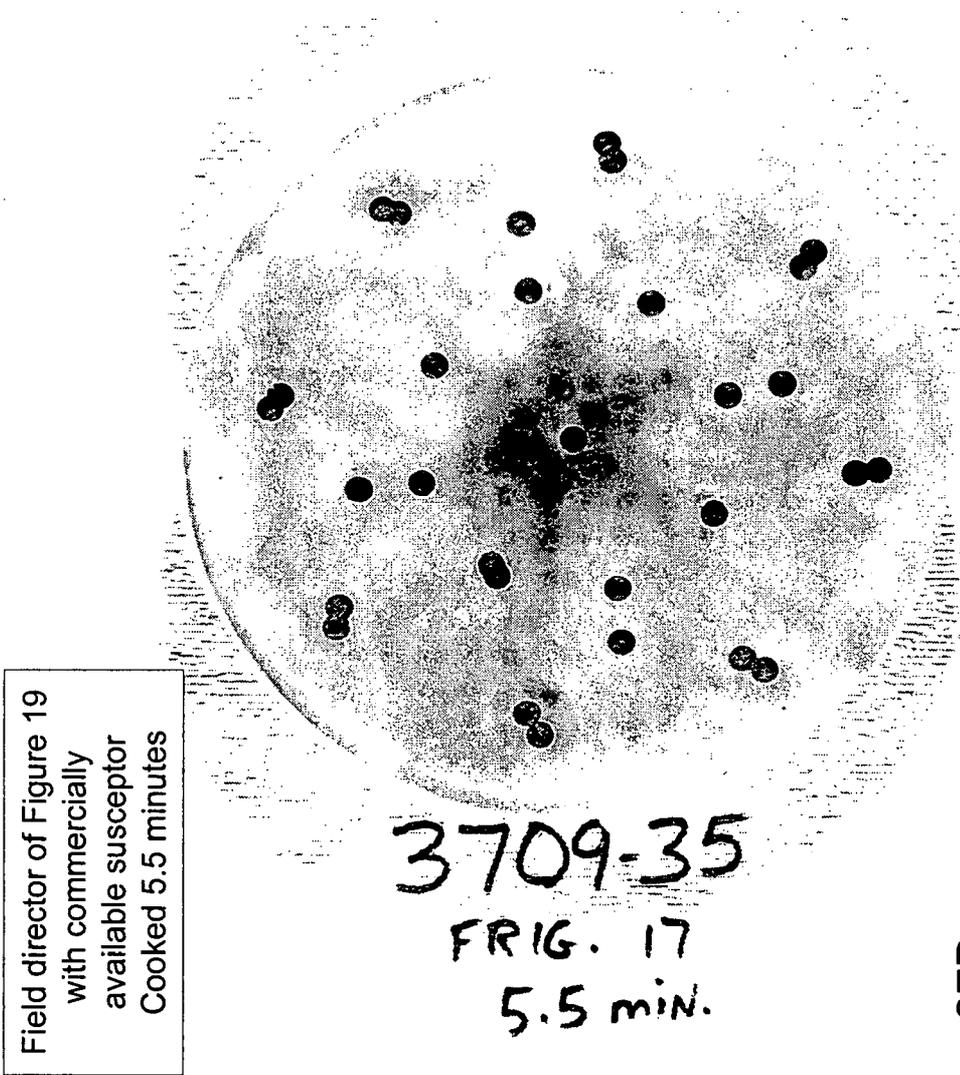
3709-36

FRIG. 17

6 min.

CONTROL

Figure 27A

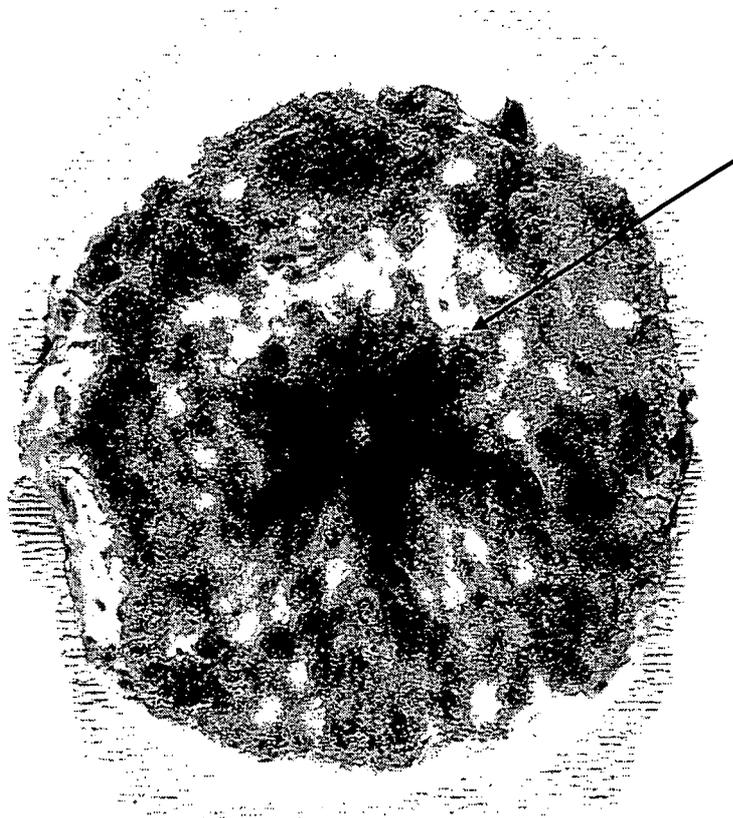


Field director of Figure 19
with commercially
available susceptor
Cooked 5.5 minutes

3709-35
FRIG. 17
5.5 min.

Figure 27B

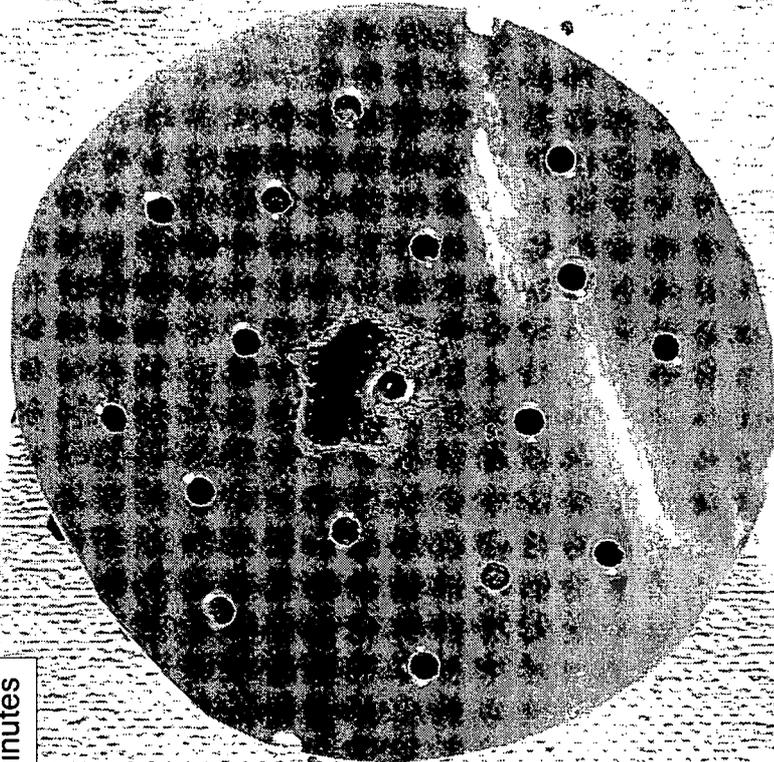
Field director of Figure 19
with commercially
available susceptor
Cooked 5.5 minutes



3709-35
FRIG. 17
5.5 min.

Film sticking/melted
To pizza bottom

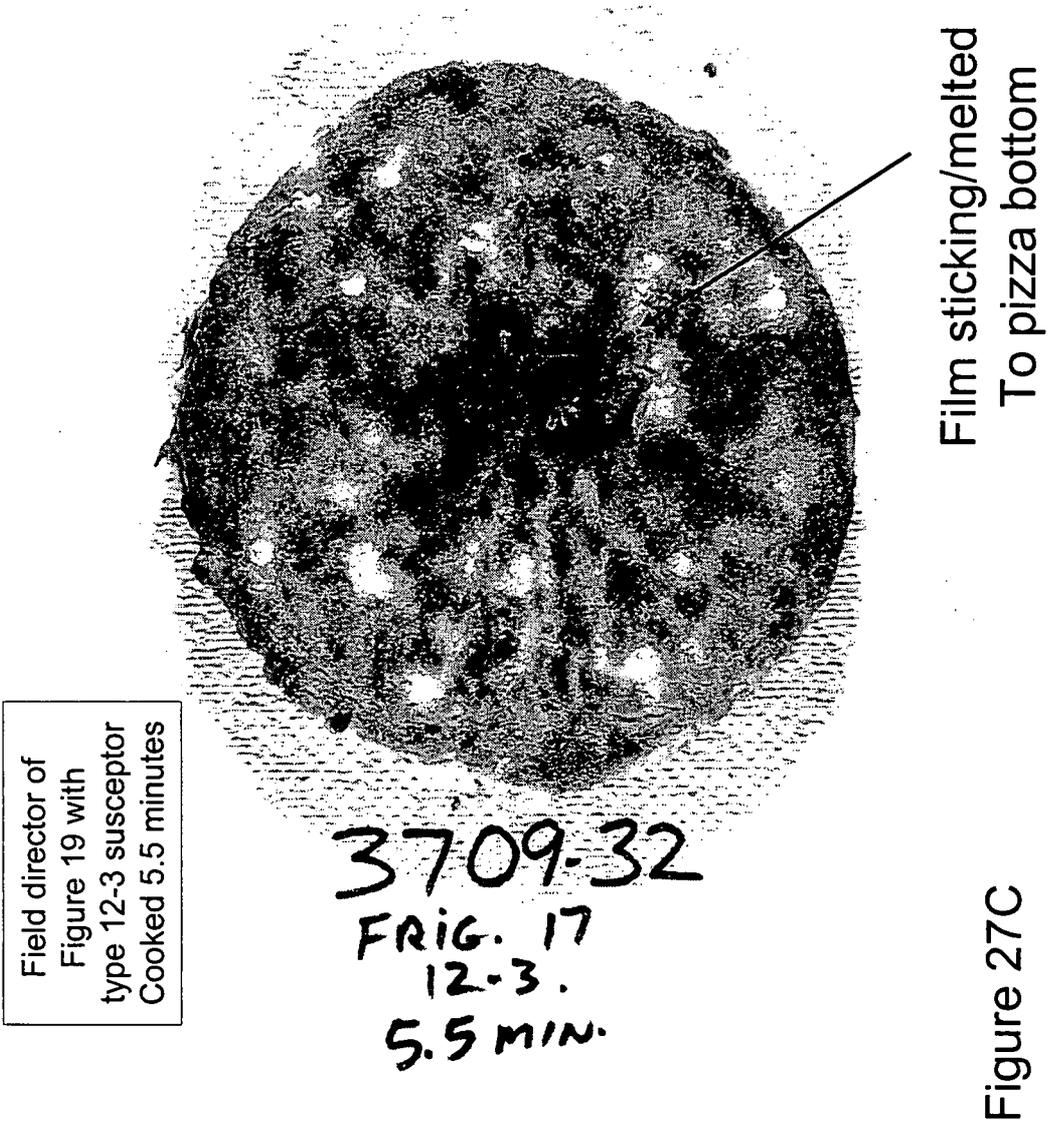
Figure 27B



Field director of
Figure 19 with
type 12-3 susceptor
Cooked 5.5 minutes

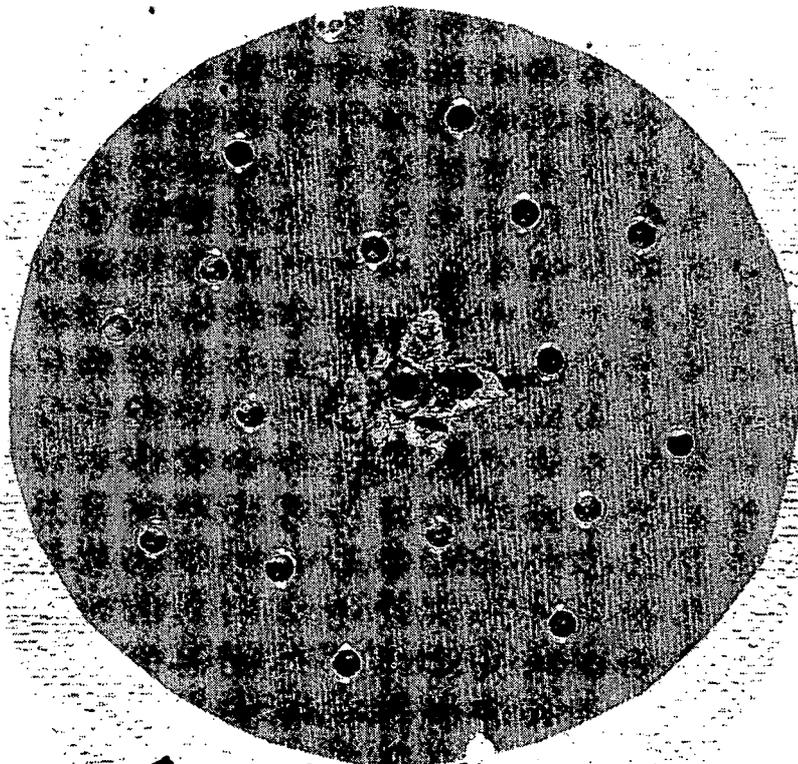
3709-32
FRIG. 17
12-3.
5.5 MIN.

Figure 27C



Field director of
Figure 19 with
type 12-3 susceptor
Cooked 5.5 minutes

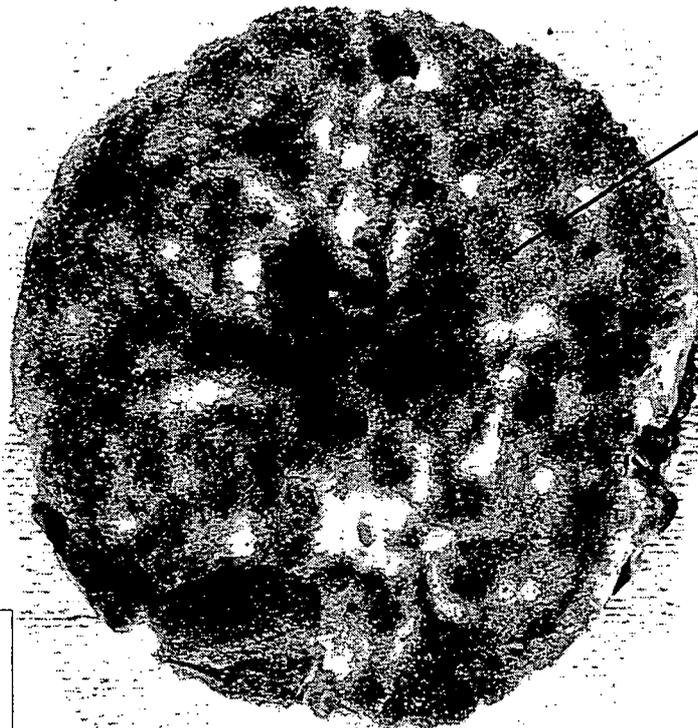
Figure 27C



Field director of
Figure 19 with
type 13-4 susceptor
Cooked 5.5 minutes

3709-34
13-4 DuPont steel #1
5:30 min. Frig. #17

Figure 27D



Film sticking/melted
To pizza bottom

Field director of
Figure 19 with
type 13-4 susceptor
Cooked 5.5 minutes

3709-34
13-4 DuPont st#1
5:30 min. Frig. #17

Figure 27D

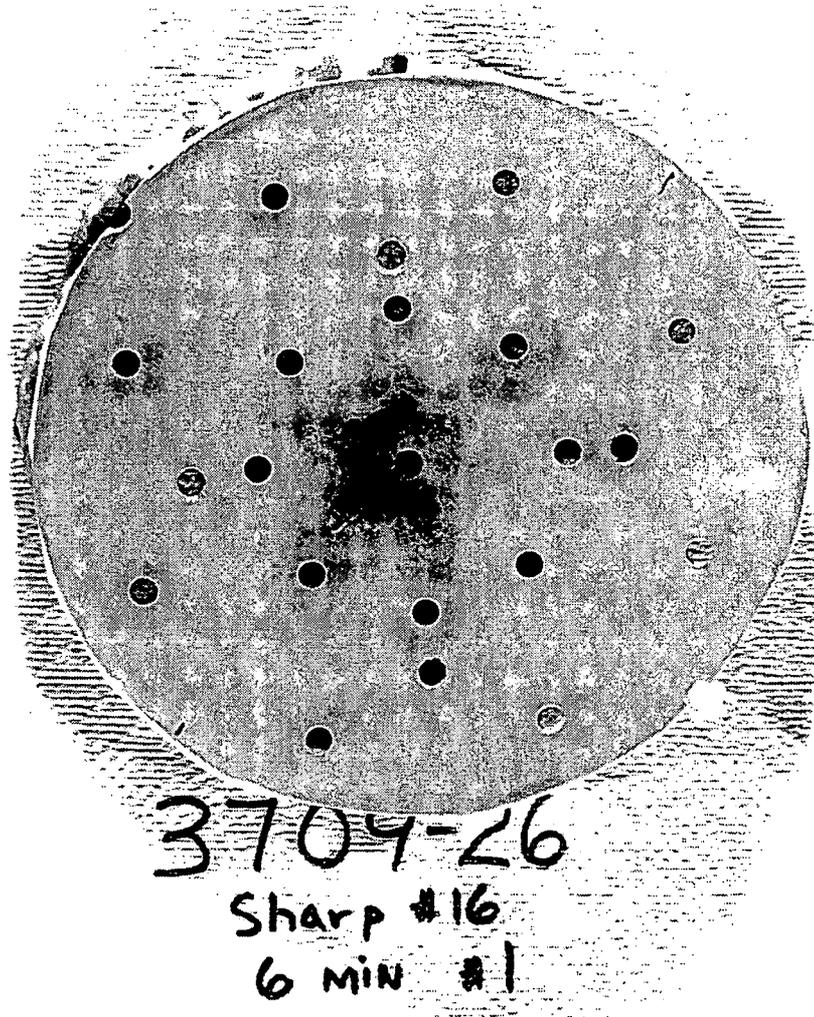
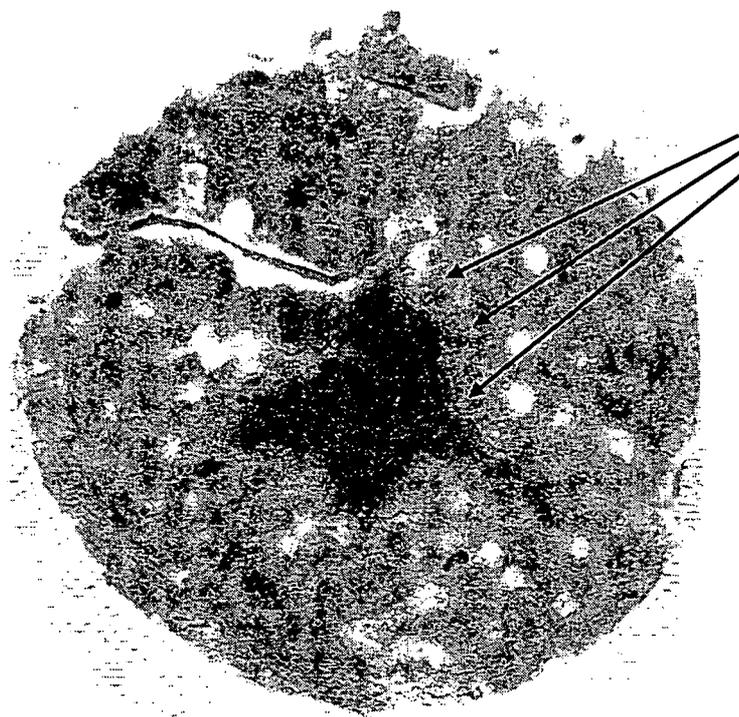


Figure 28A

Close-up view



Figure 28A



Film sticking/melted
To pizza bottom

3709-26

Sharp #16

6 min

Figure 28B

Close-up view



Figure 28B

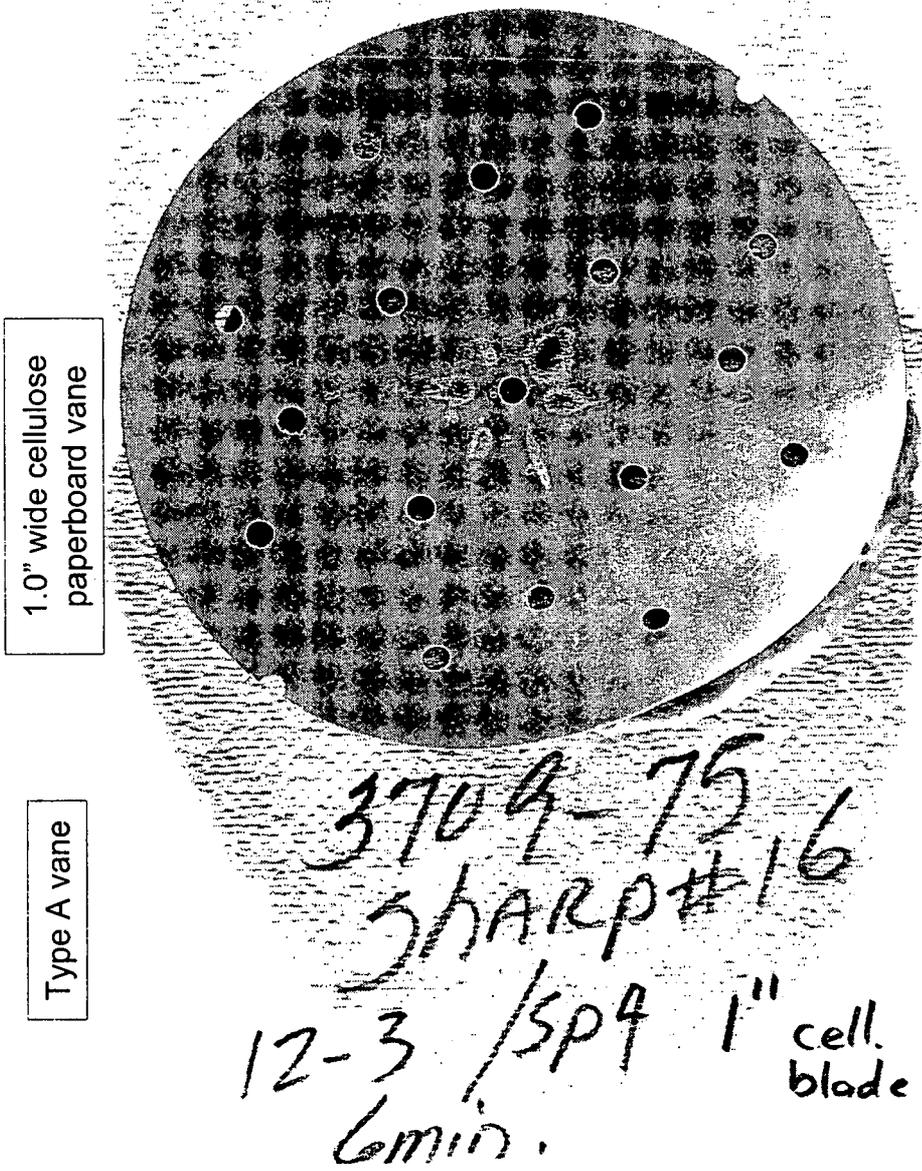
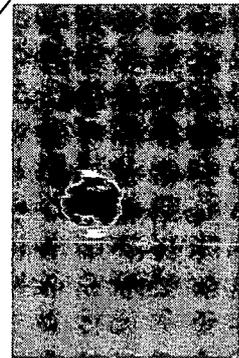
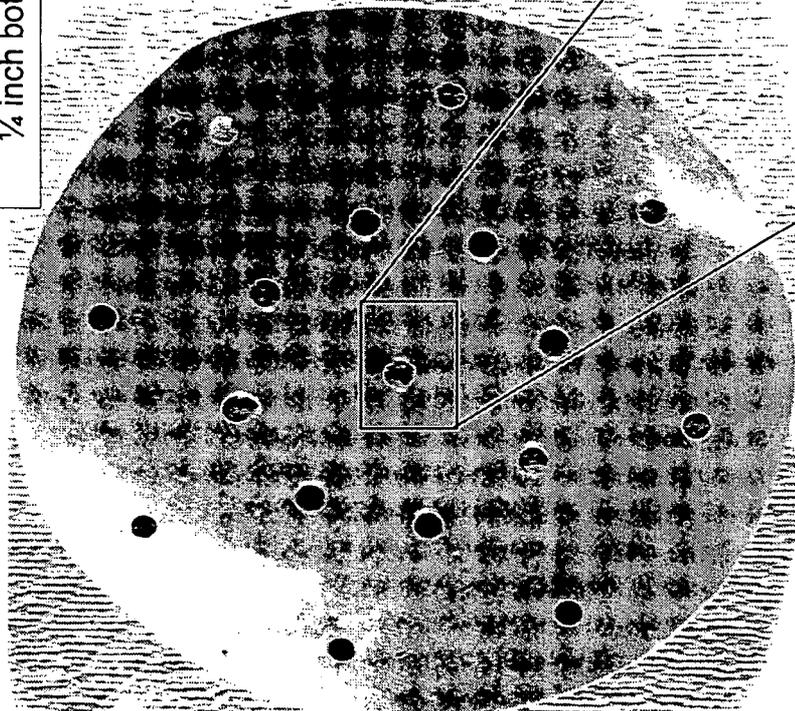


Figure 29A

1.0" wide cellulose
paperboard vane
1/4 inch bottom margin



Type B vane

3709-84
SHARP #16
12-3 / SP4 1/4" gap bott

Figure 29B

1.0" wide cellulose
paperboard vane
1/4 inch top margin

Type C vane

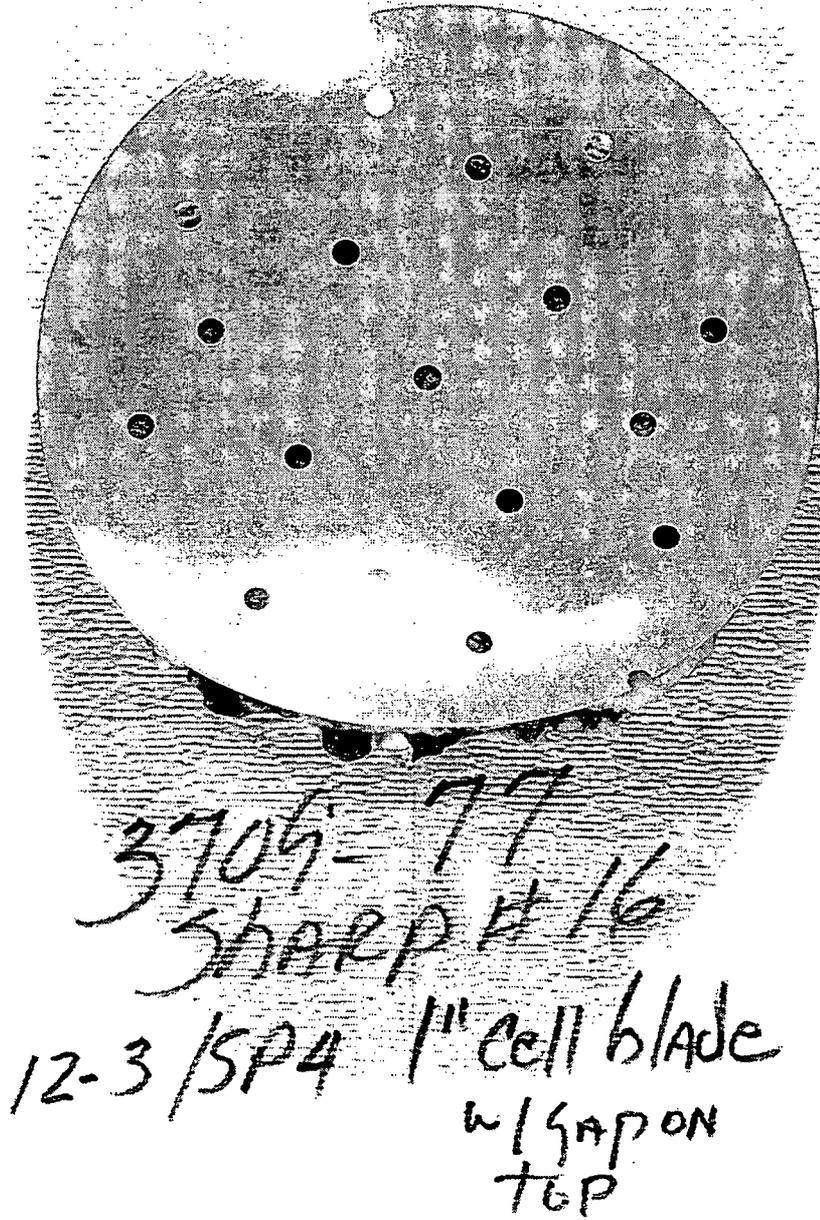
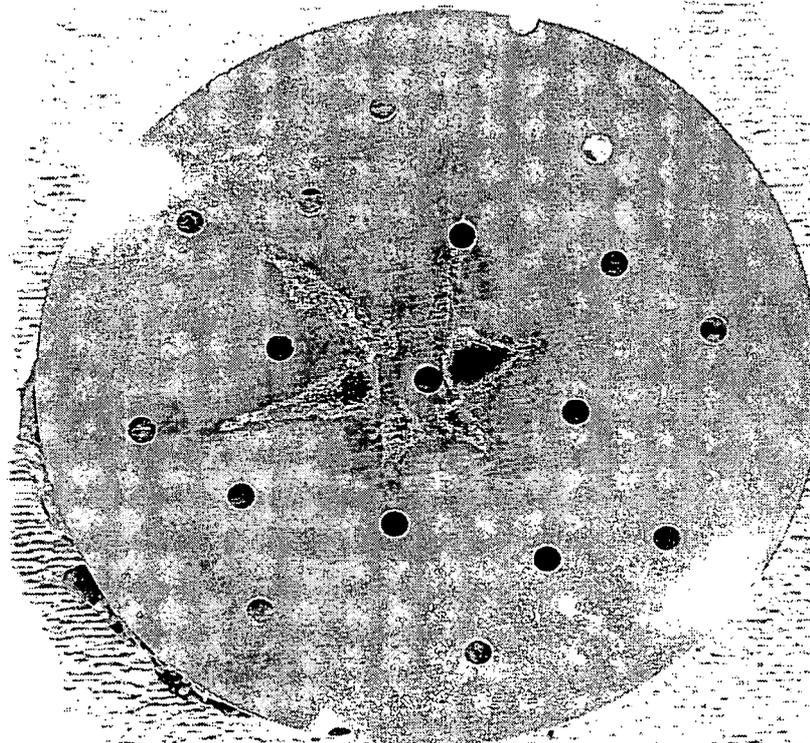


Figure 29C

1.25" wide cellulose
paperboard vane

Type D vane

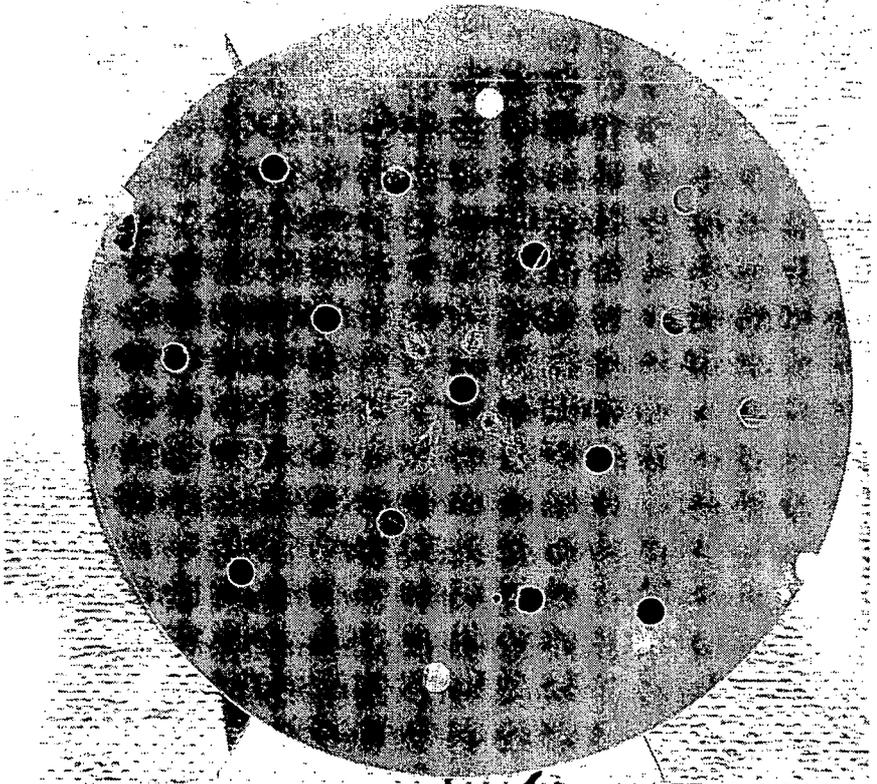


3709-78
SHARP #16
2-3 / SPA 1/4" Cell Grad.
6. min.

Figure 29D

1.25" wide cellulose
paperboard vane

Type E vane

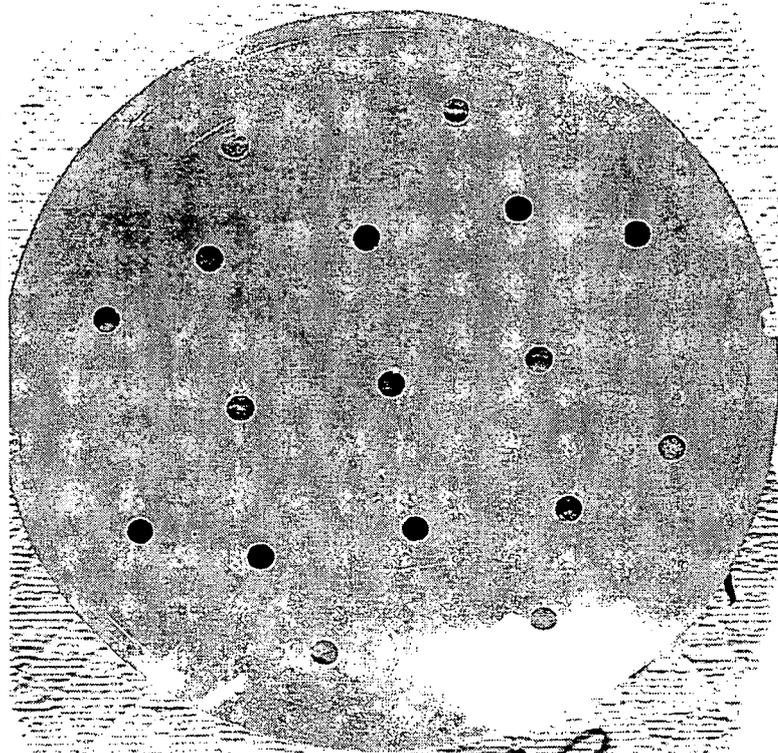


3709-80
SHARP #16
12-3 / 1/4" GAP Cell
SP#4 / Bott

Figure 29E

1.25" wide cellulose
paperboard vane

Type F vane



3709-79
SHARP #16
cell
12-3 / 1" 1/4" GAP ON TOP

Figure 29F

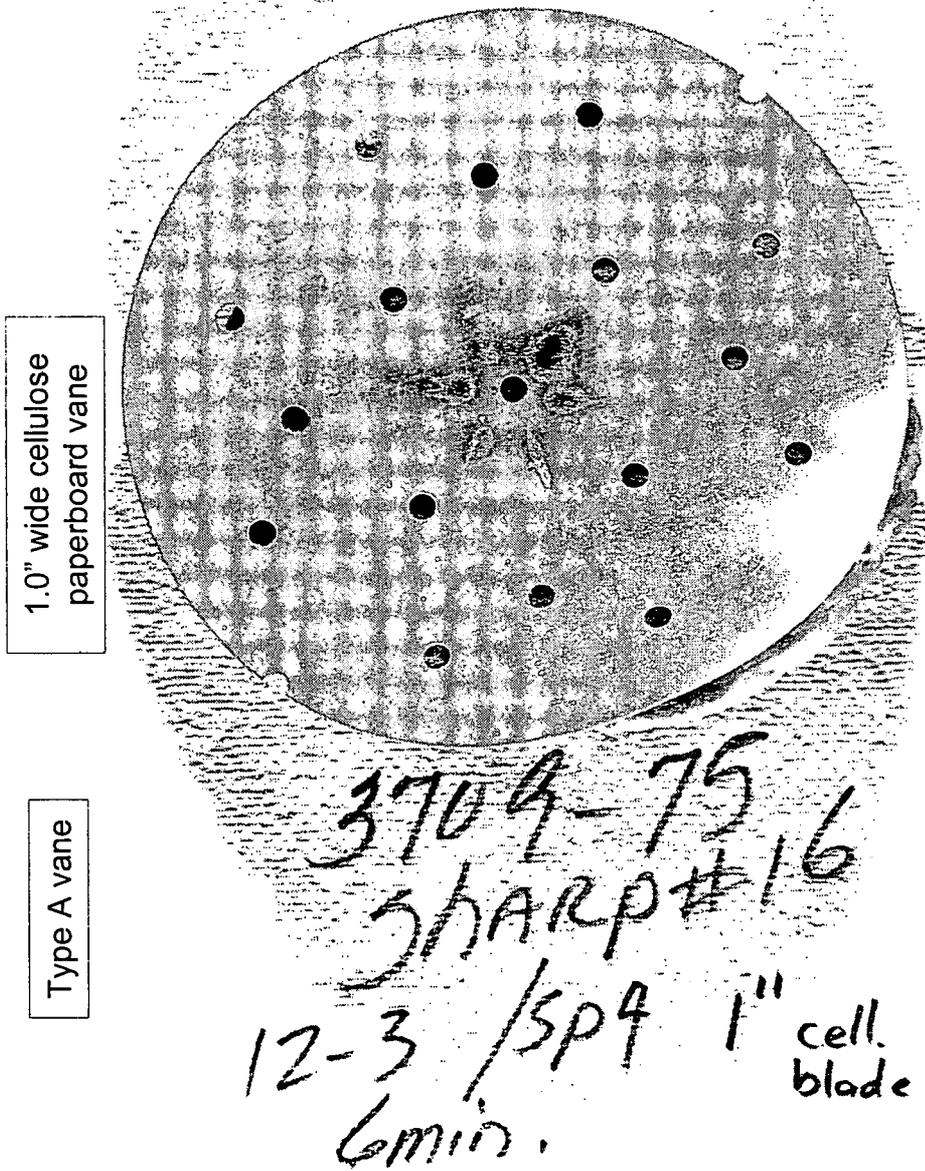
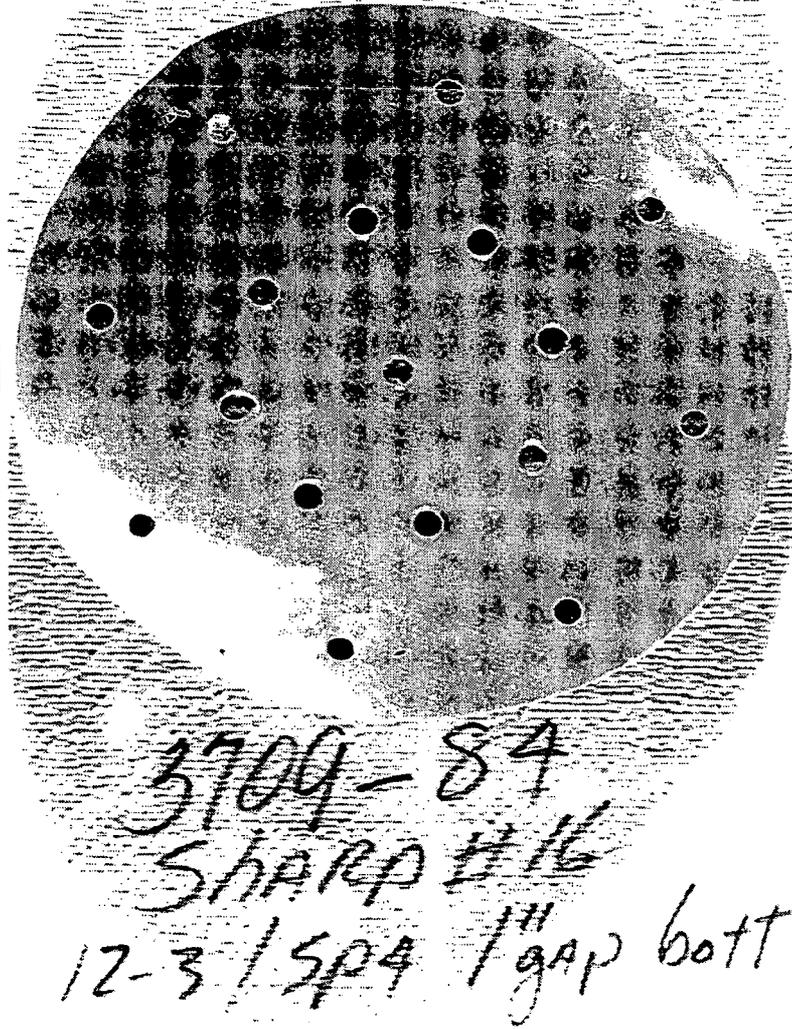


Figure 30A

1.0" wide cellulose
paperboard vane

Type B vane
1/4" top - type C



3709-84
SHARP H/K
12-3/SP4 1" gap bott

Figure 30B

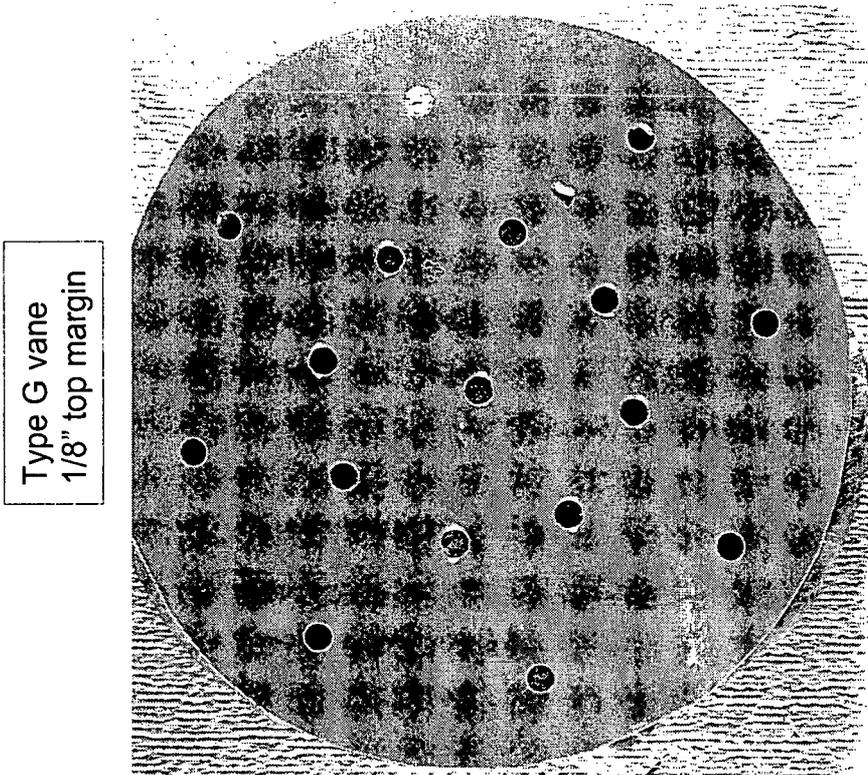
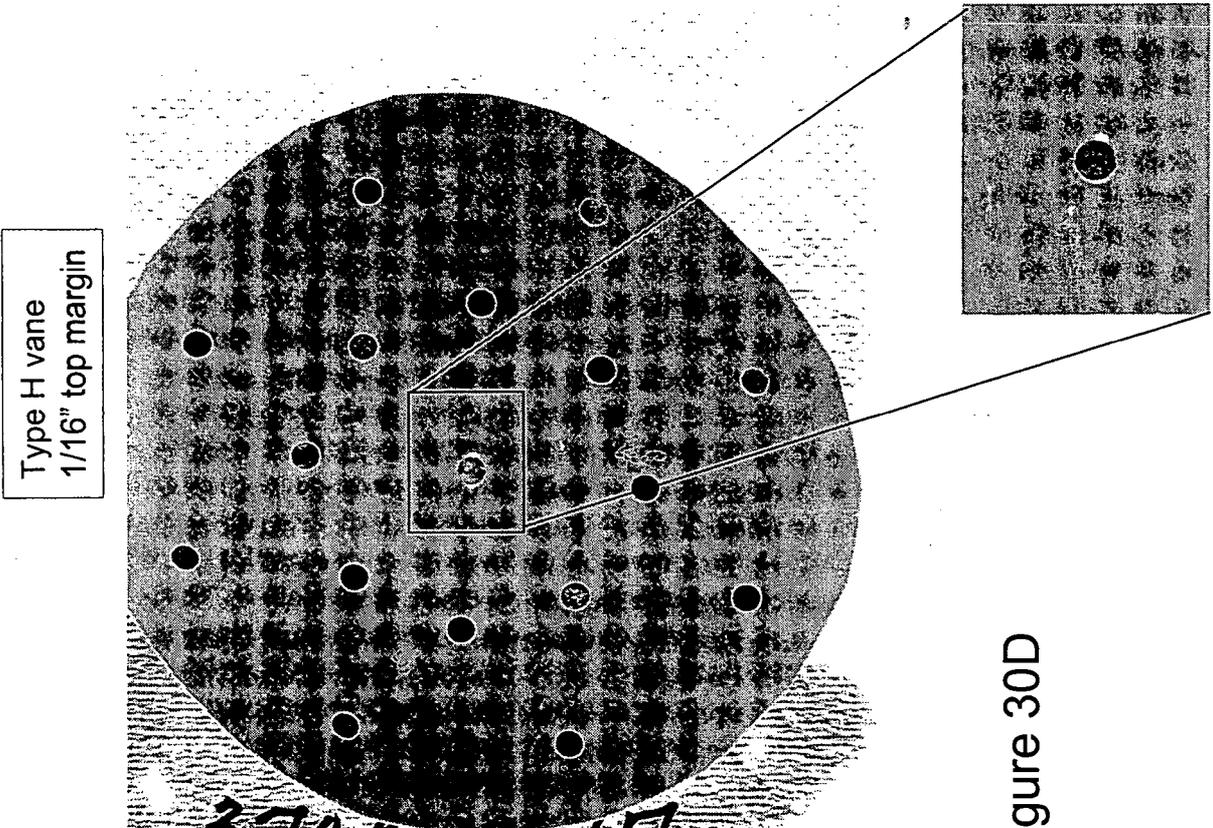


Figure 30C

3709-118
SHARP #16
12-3/SP4 | 1" blade
1/16" GAP 6min.



Type H vane
1/16" top margin

Figure 30D

3705-117
SHARP #16
12-3/SP4 1" blade
1/8" GAP 6min.