

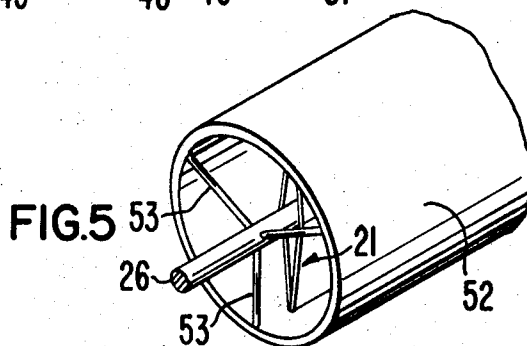
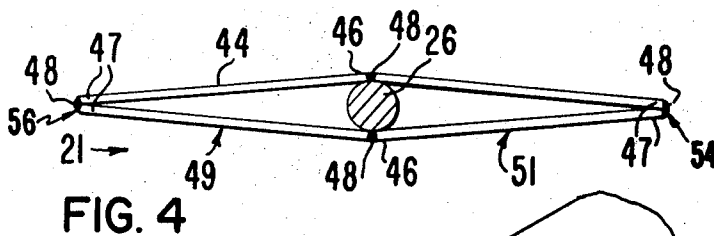
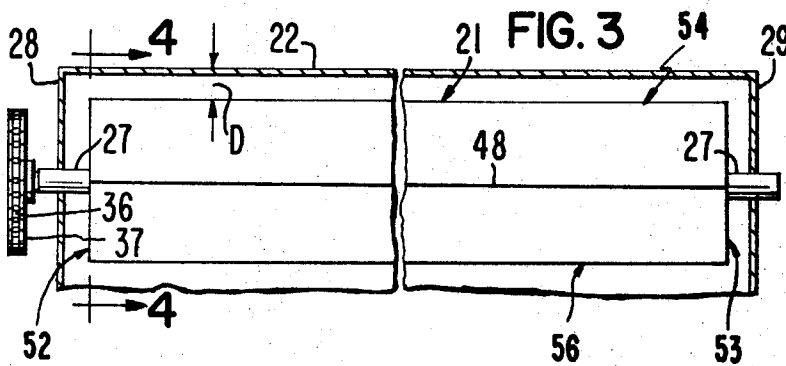
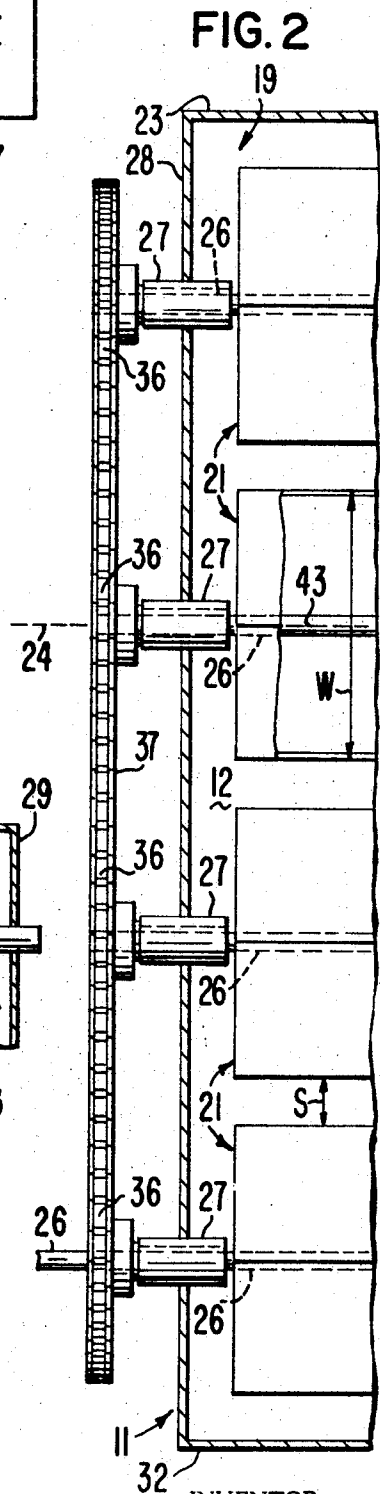
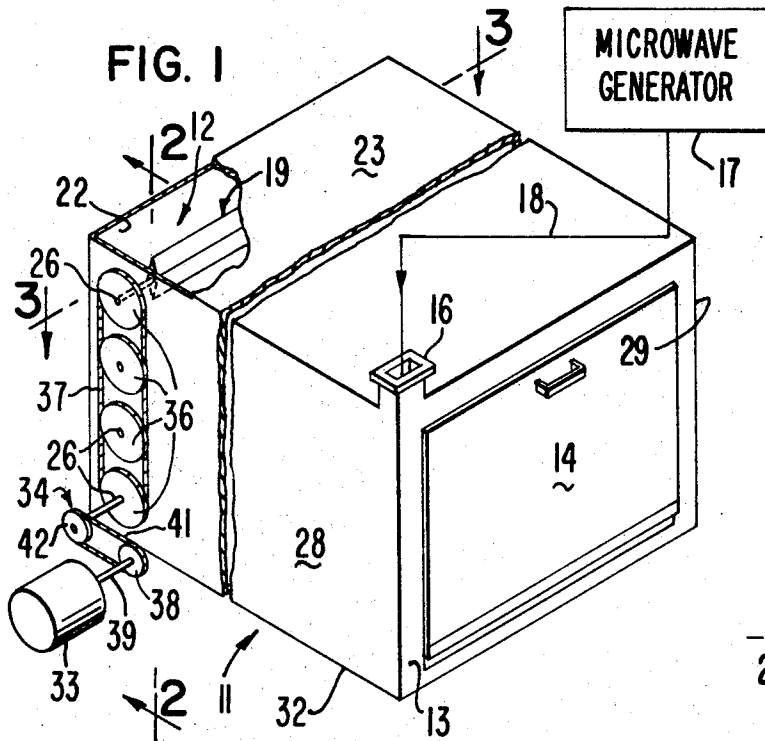
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J. R. WHITE

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MICROWAVE HEATING CAVITY WITH A VENETIAN BLIND MODE STIRRER

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INVENTOR
JEROME R. WHITE
BY
Robert M. Dilla
ATTORNEY

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Jerome R. White, San Carlos, Calif., assignor to Varian Associates, Palo Alto, Calif., a corporation of California

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ABSTRACT OF THE DISCLOSURE

A multimode rectangular cavity is excited by a microwave generator coupled by a waveguide feed to one side of the cavity. A plurality of conductive slats, each about one half wavelength wide, are rotatably mounted in front of a wall of the cavity opposite the side of the cavity at which the waveguide feed is located. The slats are mounted parallel spaced apart in a plane so that the closest possible approach between adjacent slats is less than one quarter wavelength. The slats are spaced from the wall which they front so that the closest possible approach between the wall and slats is less than one quarter wavelength. A drive motor is coupled by a transmission to synchronously rotate the slats.

BACKGROUND OF THE INVENTION

In subjecting materials to microwave energy, it is the practice to expose them to an electromagnetic field established in an excited microwave resonating device or cavity. To subject the materials to a time-averaged uniform electromagnetic field intensity, especially when in forms having a dimension on the order of the free space wavelength of the applied energy, generally, the microwave cavity is constructed so as to support a multiplicity of field intensity distributions, or mode patterns. Such a device is commonly referred to as a multimode microwave cavity. By causing the field intensity distribution to be changed, i.e., mode stirring, the time-averaged energy available to all portions of the microwave cavity is made more uniform thereby effecting a uniform application of electromagnetic energy to the material.

Heretofore, various mechanical and electronic techniques have been employed to effect the changing of field intensity distribution. Electronic mode stirring techniques involve either modulating the frequency of the microwave generator or providing multiple inputs to the microwave cavity. Such electronic techniques involve either complicated microwave generators or critical placement of the input waveguide feed relative to the microwave cavity.

With respect to mechanical mode stirrers, basically there are two types; moving antenna feeds, and those which effect a change in the geometric space of the microwave cavity as seen by electromagnetic field established therein. For practical reasons, of the two types, the moving antenna feed has proven the least suitable. This is because the waveguide plumbing feeding the moving antenna requires an exceedingly complex construction in order to prevent damaging reflected microwave energy from reaching the microwave generator. Furthermore, moving antennas are effective only in those cases where the material being subjected to the electromagnetic fields are extremely absorptive of the electromagnetic energy.

Changes in the geometric space seen by the electromagnetic field has been accomplished a number of ways. For example, microwave cavities have been constructed with deformable walls which, when moved, effect a change in the geometric space. Such devices have the advantage of causing a real change in geometric space of cavity, hence

are able to effect changes in the field intensity distribution throughout the cavity. However, such devices have the disadvantage of being structurally complex, requiring complex prime movers for the deformable wall, not being able to accomplish rapid changing of the field distribution in the microwave cavity, and causing undesirable microwave energy reflections which are detected by the power meter monitoring the output of the microwave generator and the normal power reflected from the load as variations in the net power delivered to the load. The aforementioned reflections make the evaluation of the time-averaged power delivered to the load very difficult.

Various conductive members mounted for movement within the microwave cavity also have been employed to effect a variation in the geometric seen by the electromagnetic field. These are generally classified as axially reciprocating translatable mode stirrers, and rotatably mounted reciprocating and revolving mode stirrers. All have certain advantages over the deformable wall-type mode stirrers, particularly, being of simple relative construction and being able to effect rapid changes in the field intensity distribution. However, the rotatably mounted mode stirrers are superior to the axially reciprocating translatable mode stirrers in that they can cause a more rapid change of the field distribution and they require less complex prime mover and transmission systems. Unfortunately, the prior art rotatably mounted mode stirrers generally produce only localized changes in the field intensity distribution. Hence, in large volume microwave cavities, the field intensity distributions in regions of the cavity remote from the rotatably mounted mode stirrer will not significantly be changed. To effect the desired changes in the field intensity distribution of large volume cavities, it has been the practice to locate several rotatably mounted mode stirrers at various locations in the cavity, generally, at different cavity walls. When several rotatably mounted mode stirrers are used, it is necessary either to use a separate drive motor for each mode stirrer or to employ a very complicated transmission system to link each of the mode stirrers to a single drive motor.

Therefore, a great need exists of a mode stirrer which has the advantage characterizing the deformable wall-type mode stirrer of being able to effect from a single location in a cavity changes in the field intensity distribution throughout the volume of a cavity regardless of its size while also having the advantages characterizing the rotatably mounted types of mode stirrers of a simplified construction and of being able to accomplish rapid shifting of the field intensity distribution.

SUMMARY OF THE INVENTION

The present invention relates to multimode microwave cavities for subjecting materials to microwave energy. More particularly, it relates to such a multimode microwave cavity including a rotatably mounted mode stirrer assembly which effects a change in the distribution in the field intensity throughout the volume of the cavity by simulating a change in the geometric space of the cavity as would be produced by deforming or moving a wall of the cavity.

Accordingly, it is an object of the present invention to establish a more uniform time-averaged electromagnetic field distribution throughout a microwave cavity.

More particularly, it is an object of this invention to establish a more uniform time-averaged electromagnetic field distribution throughout a microwave cavity by operating a rotatably mounted mode stirrer assembly located in a single region of the cavity.

Another object of the present invention is to establish a more uniform time-averaged electromagnetic field distribution in a microwave cavity by simulating the effects

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of deforming or moving a wall of the cavity with a rotatably mounted mode stirrer assembly.

A further object of the present invention is to establish a more uniform time-averaged electromagnetic field distribution throughout a large volume microwave cavity.

Still another object of this invention is to provide a simply constructed and easily operable rotatably mounted mode stirrer assembly which produces a more uniform time-averaged electromagnetic field distribution throughout a large volume microwave cavity.

The present invention is a multimode microwave cavity for subjecting materials to microwave energy which accomplishes the foregoing and other objects thereby overcoming many of the limitations and disadvantages of the prior art microwave cavities. More specifically, in accordance with the present invention, a microwave cavity has conductive boundary walls forming a compartment for subjecting materials to microwave energy. A microwave generator provides microwave energy at a selected frequency and is coupled to the cavity to deliver microwave energy thereto whereby an electromagnetic field is distributed throughout the compartment. To change the electromagnetic field intensity distribution in the compartment, a mode stirrer assembly is employed which comprises a plurality of structures, each having at least one slot of conductive material rotatably mounted at an axis of rotation located proximate a conductive wall of the cavity. The structures are positioned within the cavity to have the slots of adjacent structures spaced apart to extend at intervals across the front of the proximate wall. The closer the spacing between the slots of adjacent structures as well as the spacing between the slots and the proximate wall, the more nearly the operation of the mode stirrer assembly simulates the change in the geometric space of the compartment as would be produced by deforming or moving the proximate wall of the cavity. The mode stirrer assembly simulates almost exactly the effect of deforming or moving the proximate wall when the structures are positioned so that the spacing between the slots of adjacent structures when in positions of their closest possible approach is not greater than one-quarter wavelength of the microwave energy and the distance between the slots and the proximate wall of the cavity when the slots are in positions of their closest possible approach thereto is not greater than one-quarter wavelength of the microwave energy provided by the generator.

The uniformity of the time-average electromagnetic field intensity distribution throughout the compartment is enhanced, particularly through the region in which the materials are located for subjection to microwaves, by introducing the microwave energy into the cavity and locating the slots at opposite sides of the cavity. This construction places the material to be subjected to microwaves between the mode stirrer assembly and the point at which the microwave energy is introduced into the cavity.

BRIEF DESCRIPTION OF THE DRAWING

The foregoing and other objects and advantages of the microwave cavity apparatus of the present invention will become more apparent from the following detailed description and appended claims considered together with the accompanying drawing in which:

FIG. 1 is a perspective view with a broken-away portion of one embodiment of the microwave cavity of the present invention for subjecting materials to microwave energy.

FIG. 2 is an enlarged front view of a portion of this mode stirrer assembly employed in the microwave cavity taken along line 2—2 of FIG. 1 showing the relative orientation of the slots forming the mode stirrer assembly.

FIG. 3 is an enlarged top view of the mode stirrer assembly employed in the microwave cavity taken along line 3—3 of FIG. 1 showing the relative orientation of the slots and proximate cavity wall, with the slots in a different position than that shown in FIG. 2.

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FIG. 4 is an enlarged end cross sectional view of one of the slots of the mode stirrer assembly taken along line 4—4 of FIG. 3.

FIG. 5 shows a slot of the mode stirrer assembly mounted inside a tube of low loss dielectric.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIG. 1, the apparatus of the present invention comprises a multimode microwave cavity 11 having conductive boundary walls of, for example, aluminum joined together to define a compartment 12 for receiving materials to be subjected to microwave energy in order to, for example, heat the materials. In the illustrated embodiment, a rectangular cavity 11 is shown which is suited for subjecting materials to microwave energy in a batch process. To place the materials within the compartment 12, the front wall 13 is provided with a hinged access door 14. The multimode microwave cavity 11 also could be a conveyorized type having inlet and outlet passages allowing the continuous transportation of materials through the compartment 12.

To subject materials placed within the compartment 12 to microwave energy, the cavity 11 is provided with an input waveguide feed 16 and is coupled to a microwave generator 17 by a waveguide transmission line 18 joined to the waveguide feed 16. The microwave generator 17 is operated to provide microwave energy at a certain power, for example, 5 kw., and at a suitable frequency, such as 915 mHz. The cavity 11 is constructed to define a compartment 12 of a size so that a large number of different electromagnetic field distribution patterns can be established therein. Microwave energy may be introduced simultaneously into the cavity 11 at a plurality of locations in the walls of the cavity if desired.

To vary the electromagnetic field distribution in the compartment 12 and thereby, for example, effect a more uniform heating of the material located in the compartment, a mode stirrer assembly 19 is provided to change the geometric space of the compartment 12 as seen by the electromagnetic field established therein. Referring to FIGS. 1—3, the mode stirrer assembly 19 of the present invention includes a plurality of generally flat rotatably mounted slots 21 of electromagnetic reflective material, such as aluminum, located proximate and spaced from a boundary wall 22 of the cavity 11. The slots 21 are positioned at intervals across the front of the wall 22 and extend longitudinally along their axes of rotation. In this connection, as shown in FIG. 3, each of the slots has a length along its axis of rotation which is greater than its width.

Although the slots 21 can be located proximate any of the boundary walls of the cavity 11, the most beneficial mode stirring results are obtained by locating the waveguide feed 16 and slots 21 at opposite sides of the compartment 12. In the illustrated embodiment, the waveguide feed 16 is located in the top wall 23 of the cavity 11 proximate the front wall 13 and the slots 21 are positioned proximate the rear wall 22 of the cavity.

Each of the slots 21 are journally supported about an axis of rotation 24 by shafts 26 which engage bearings 27 at, for example, opposite side walls 28 and 29. By supporting the slots 21 in this manner, they extend horizontally in front of the rear wall 24. However, the slots 21 also could be oriented to extend vertically in front of the rear wall 24. Preferably, the slots 21 are supported parallel spaced apart at a uniform distance from the rear wall 24 parallel to the bottom wall 32 of the cavity 11.

To drive the rotatably mounted slots 21, one end of the shaft portions 26 of each of the slots 21 extends exteriorly of the cavity 11 and is coupled to a drive motor 33 by a suitable power transmission system 34. In the embodiment of the figures, a link chain transmission system 34 is shown which rotates the slots 21 synchronously and in the same direction. The slots 21 may be driven in other

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ways as well. For example, the slats 21 could be reciprocated, driven separately, driven out of synchronism, or driven in opposite directions. To rotate the slats 21, the link chain transmission system 34 includes a driven sprocket 36 fixed at the end of the shaft portion 26 of each of the slats 21. The sprockets 36 are driven together by a first link chain 37. The drive motor 33 is coupled to drive the link chain 37 by a driving sprocket 38 fixed to the drive shaft 39 of the motor 33 and coupled by a second link chain 41 to drive a second driven sprocket 42 fixed to an extension of one of the shaft portions 26.

Referring to FIG. 2 in detail, the width, W, in the direction perpendicular to axis of rotation 24 of each of the slats 21 is at least one-quarter and preferably about one-half of the wavelength of the applied microwave energy. The width of each of the slats 21 may be larger than one-half wavelength if desired. To closely simulate the change in the geometric space of the compartment 12 that would be produced by deforming or moving the rear wall 22 of the cavity 11, the slats 21 are located within the cavity so that the spacing, S, between adjacent slats when in the position of the closest possible approach between the adjacent slats is less than one-quarter wavelength of the applied microwave energy. In the embodiment illustrated, the one-half wavelength wide slats 21 are synchronously rotated about their longitudinal axis 43 so that at all times each of them is in the same orientation relative to the rear wall 22 of the cavity 11. Therefore, the slats 21 are mounted at locations spaced apart one-half wavelength plus the spacing S, which in the embodiment illustrated is about one-tenth wavelength. The spacing S could be larger than one-quarter wavelength of the applied microwave energy. However, as the spacing S is increased, the mode stirring effect produced by the mode stirrer assembly 19 becomes less similar to that produced by deforming or moving the rear wall 24 of the cavity 11.

With reference now to FIG. 3 in detail, the slats 21 preferably are mounted within the cavity 11 so that the distance D between the slats and the proximate rear wall 24 when the slats are in the position of the closest possible approach to the rear wall 24 is less than one-quarter wavelength of the applied microwave energy. In the illustrated embodiment, the distance D is about one-tenth wavelength. With the slats 21 located as shown in FIGS. 2 and 3, the operation of the mode stirrer assembly 19 results in a change in the geometric space of the compartment 12 as seen by the electromagnetic field which essentially is the same as that which is produced by deforming or moving a wall of cavity 11. However, as explained hereinbefore, the mode stirrer assembly 19 of the present invention can produce a more rapid change in the geometric space of the compartment 12, hence, in the distribution of the intensity of the field, more easily than can be produced by deforming or moving a wall of the cavity 12.

Referring now to FIGS. 3 and 4, an embodiment of the slats 21 of the mode stirrer assembly 19 is illustrated which is particularly rugged and facilitates rotating the mode stirrer assembly 19 under conditions of dynamic stability. Each slat 21 comprises four flat stainless steel segments 44 joined at their opposite ends 46 and 47 by welds 48 about the shaft portion 26. As illustrated in the figures, the slats 21 are shown as being rectangular. However, to prevent arcing between the ends 52 and 53 of the slats and the proximate cavity walls, the ends may be arcuate or wedge-shaped. In any case, in practice it is preferred that the opposite longitudinal edges 54 and 56 be straight and parallel. As assembled, the segments 44 of each slat 21 are joined to the shaft portion 26 at their ends 46 by welds 48. The shaft portion 26 axially extends the entire length of the slat 21 with two sections 49 and 51 defined by the joined segments 44 extending from opposite sides of the shaft portion 26. The axially extending shaft portion 26 makes the slat 21 rugged. Since the axis of rotation 24 of each of the slats 21 is coextensive with its longitudinal axis 43, the mode stirrer assembly 19 will

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be dynamically stable, thereby, greatly simplifying mounting the assembly for rotation.

The mode stirrer assembly 19 illustrated in the figures is shown as including a plurality of slats 21 having two sections 49 and 51. The slats 21 could be provided with additional sections mounted, for example, about the axis 43 to extend from the shaft portion 26.

One embodiment of the multimode microwave cavity of the present invention constructed in accordance with the FIGS. 1-4 for operation at a microwave frequency of 915 mHz. has the following specification. The compartment 12 is 54 inches wide, 42 inches high and 92 inches deep. Four slats 21 are rotatably mounted within the cavity 11 centrally between the side walls 28 and 29 with each slat 21 having a length of 48 inches and a width of 6 inches and 1/2 inch diameter shaft portion 26. Each of the slats 21 is mounted with its axis 43 located 4 inches from the rear wall 24 and spaced 7 inches from the axes 43 of adjacent slats 21. The slats 21 adjacent the top and bottom walls 23 and 32 are mounted with their axes 43 located 4 inches therefrom.

In FIG. 5, a slat 21 constructed in accordance with the embodiment of FIG. 4 is shown inserted within a tubular polypropylene shield 52. The tubular shield 52 is supported at the shaft portion 26 by spokes 53. The tubular shield 52 facilitates cleaning the mode stirrer assembly 19.

Although the multimode microwave cavity of the present invention has been described in detail with reference to a particular embodiment, from the description it is apparent that many modifications and variations are possible without departing from the scope of the invention. Therefore, the present invention is not intended to be limited except by the terms of the following claims.

What is claimed is:

1. Apparatus for subjecting material to microwave energy having a predetermined wavelength comprising conductive walls forming a multimode microwave cavity defining a compartment for receiving said material to be subjected to the microwave energy, means for introducing microwave energy into said cavity at least at one selected location, and a plurality of structures mounted for rotation within said cavity adjacent a wall thereof about axes which are generally parallel to said wall and are spaced at intervals along said wall, each of said structures including at least one slat of microwave reflective material extending longitudinally along said axis of rotation and having a length therealong greater than its dimension perpendicular to said axis of rotation, said dimension of said slat perpendicular to said axis being at least about one-quarter wavelength of the microwave energy.

2. The apparatus according to claim 1 wherein each of said slats is spaced apart from adjacent slats so that the spacing between adjacent slats when in positions of their closest possible approach is not greater than one-quarter wavelength of the microwave energy.

3. The apparatus according to claim 1 wherein said slats and location of introducing microwave energy into said cavity are at opposite sides of said cavity.

4. The apparatus according to claim 1 wherein each of said slats is spaced from the proximate conductive wall so that the distance between each of the slats and the proximate conductive wall when the slat is in its position of closest possible approach to the proximate conductive wall is not greater than one-quarter wavelength of the microwave energy.

5. The apparatus according to claim 4 wherein each of said slats is spaced apart from adjacent slats so that the spacing between adjacent slats when in positions of their closest possible approach is not greater than one-quarter wavelength of the microwave energy.

6. The apparatus according to claim 1 wherein said proximate conductive wall is planar, and said slats are rotatably mounted parallel spaced apart.

7. The apparatus according to claim 6 wherein said

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slats are rotatably mounted at a uniform distance from said proximate conductive wall.

8. The apparatus according to claim 6 wherein each of said slats is elongated and has parallel opposite longitudinal edges, each of said slats has an axis of rotation coextensive with its longitudinal axis, the spacing between adjacent slats when in positions of their closest possible approach is not greater than one-quarter wavelength of the microwave energy, and the distance between at least some of the slats and the proximate conductive wall when such slats are in their position of closest possible approach to the proximate conductive wall is not greater than one-quarter wavelength of the microwave energy.

9. The apparatus according to claim 8 wherein said slats and location of introducing microwave energy into said cavity are at opposite sides of the cavity.

10. The apparatus according to claim 8 wherein each of said slats has a lateral dimension of about one-half wavelength of the microwave energy.

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11. The apparatus according to claim 1 further comprising means coupled to rotatably drive said slats.

12. The apparatus according to claim 11 wherein said rotatably drive means is coupled to synchronously-rotate said slats.

13. The apparatus according to claim 1 further comprising a microwave generator coupled to said cavity and operated to provide microwave energy at a selected power at said predetermined wavelength.

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JOSEPH V. TRUHE, Primary Examiner

L. H. BENDER, Assistant Examiner