United States Patent [19]

Johnson

[11] **3,725,628**

[45] **Apr. 3, 1973**

[54] **MICROWAVE APPLICATOR WITH THROUGHPUT SUPPRESSION GUIDES AT INPUT AND OUTPUT PORTS**

[75] Inventor: **Ray M. Johnson,** Danville, Calif.

[73] Assignee: **Microdry Corporation,** San Ramon, Calif.

[22] Filed: **Oct. 29, 1971**

[21] Appl. No.: **193,908**

[52] **U.S. Cl.** .....**219/10.55,** 333/95 R

[51] **Int. Cl.** **H05b 9/06,** H01p 3/12

[58] **Field of Search** .....219/10.55; 333/98 M, 95 R, 333/81 R, 81 B; 34/1

[56] **References Cited**

UNITED STATES PATENTS

3,545,093	12/1970	Forster	219/10.55 X
3,528,179	9/1970	Smith	219/10.55 X
3,597,565	8/1971	Johnson	219/10.55

Primary Examiner—J. V. Truhe

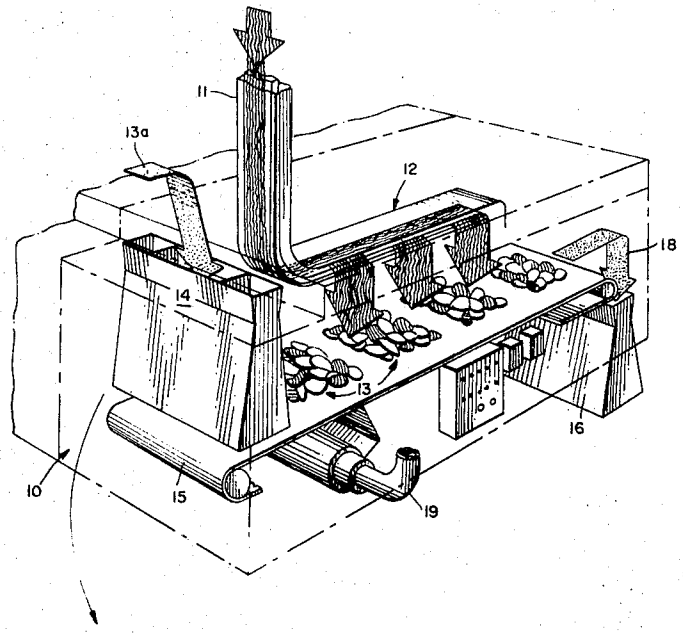
Assistant Examiner—Hugh D. Jaeger

Attorney—Carl C. Batz

[57] **ABSTRACT**

Wave guides are placed at the input and output ports of a microwave applicator for treating material whereby the material may pass through the throughput wave guides but the passage of microwaves is suppressed by the throughput wave guides without absorption of the microwave energy.

11 Claims, 7 Drawing Figures



PATENTED APR 3 1973

3,725,628

SHEET 1 OF 2

FIG. 1

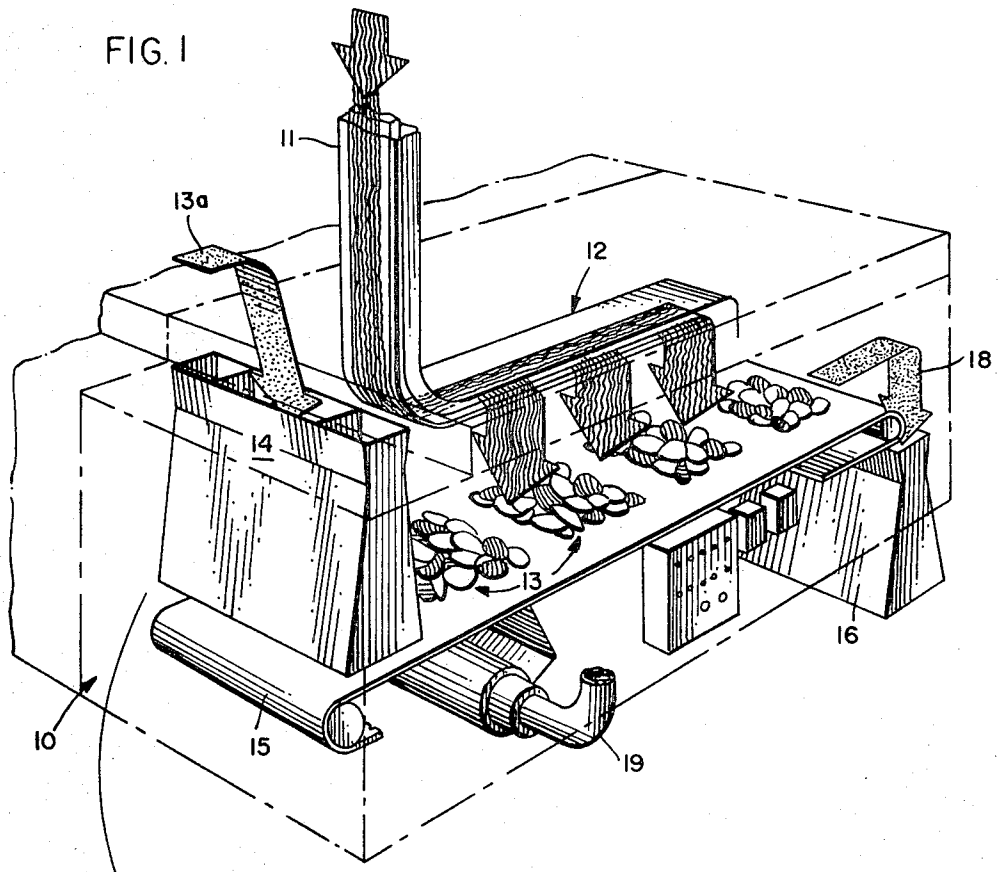
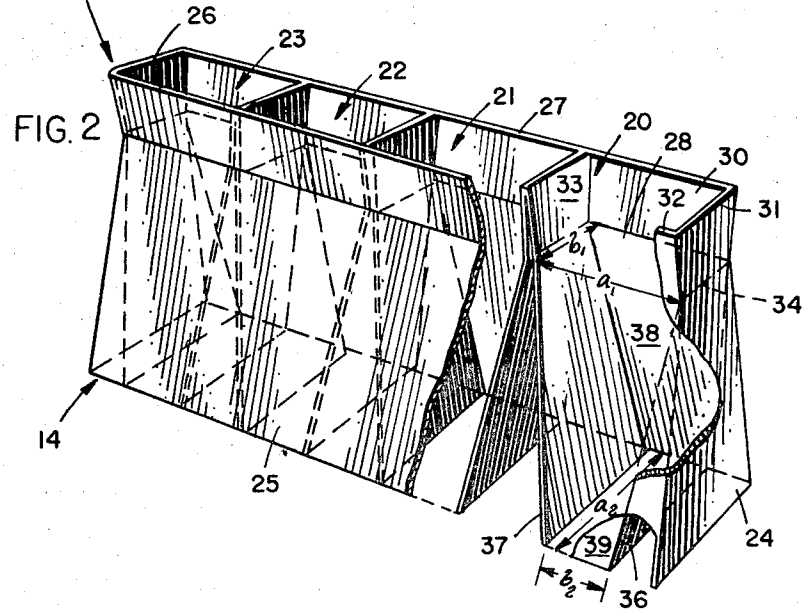
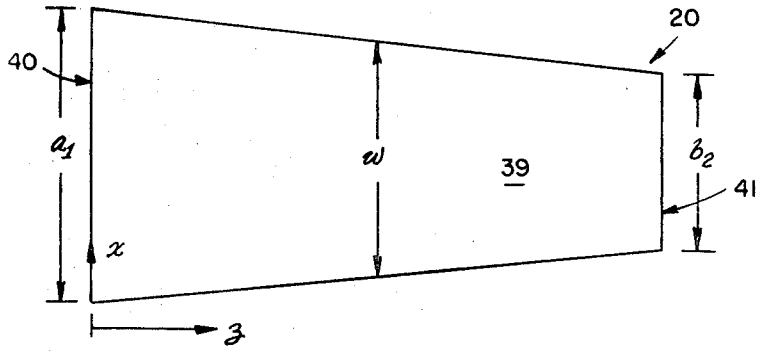


FIG. 2



INVENTOR:
RAY M. JOHNSON
BY
Carl C. Batz
ATT'Y

FIG. 3



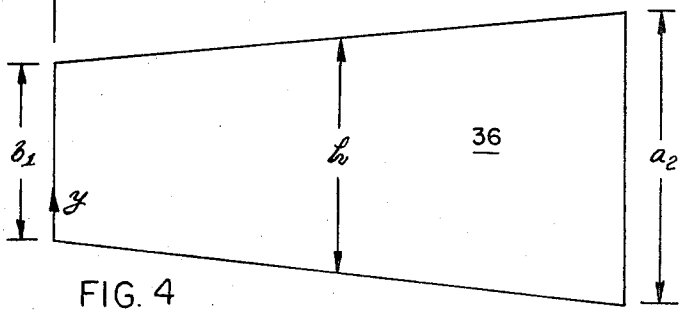


FIG. 4

FIG. 5

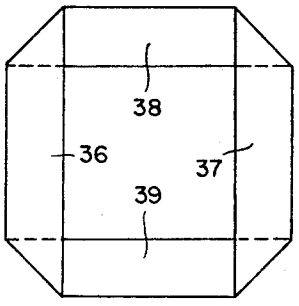


FIG. 6

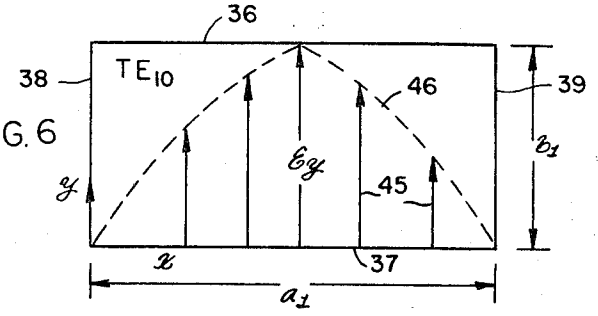
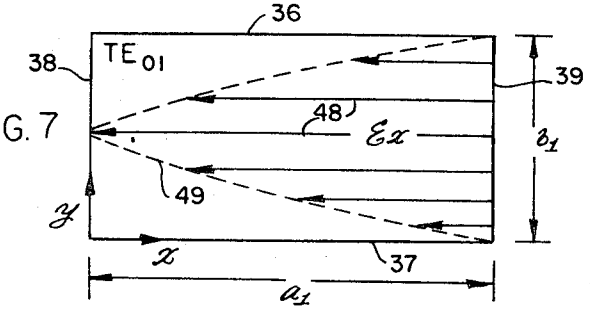


FIG. 7



INVENTOR:
RAY M. JOHNSON
BY
Carl C. Batz
ATT'Y

MICROWAVE APPLICATOR WITH THROUGHPUT SUPPRESSION GUIDES AT INPUT AND OUTPUT PORTS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to heating and cooking systems and more particularly, it relates to a microwave applicator for heating and cooking materials wherein the materials being processed are continuously passed through the applicator for treatment.

In a microwave applicator of the continuous processing type, there is required an entrance and an exit aperture in the applicator for permitting the material being processed to enter the applicator and to be passed from the applicator after processing. When these microwave systems are intended for commercial operation, it is normally desired to process large quantities of material; and this may require rather large input and exit apertures through which the material passes. These input and exit apertures may be sources for the leakage of radiation into the surrounding environment if care is not taken to protect against it.

Protection against radiation of the microwave energy while permitting material to pass through the input and exit apertures is difficult in the case of a multi-mode cavity because various modes exist within the applicator and all of these modes must be suppressed.

A multi-mode cavity of the continuous processing type is to be distinguished from a batch type of microwave oven because in the latter, the oven is not excited when the material is placed in the oven for processing, and the oven is again shut off before removing the material from the oven after processing. In this latter type of oven, protection against radiation is achieved by insuring that the cavity is completely enclosed by metal when excited.

2. Known Suppression Systems

A microwave applicator which is a wave guide, as distinguished from a multi-mode cavity may have input and output apertures which are protected against radiation by means of reject filters provided in the walls of wave guide sections leading into the input aperture and away from the output aperture. This is possible if the wave guide is excited only in predetermined modes and the reject filter is designed to protect against passage of those known modes. Such a system is disclosed in my co-pending application entitled "System and Method for Heating Material Employing Oversize Wave Guide Applicators," U.S. Pat. No. 3,632,945, issued Jan. 4, 1972.

In a multi-mode cavity, radiation of the microwave energy into the surrounding atmosphere is typically prevented by providing water loads at the input and output apertures. These water loads extend for some distance along the direction of product movement so as to absorb any fringing microwave radiation adjacent the input and output apertures. Such a system is disclosed in the co-owned Jeppsen, U.S. Pat. No. 3,427,171. Wave guide cutoff filters and reject filters may be used in multi-mode systems. However, the cross-sectional dimensions have been maintained less than one-half of the free space wavelength (λ_o) of the excitation frequency. Thus, the maximum cross-sectional area would be less than $(\lambda_o/2)^2$.

SUMMARY

In the present invention, throughput wave guides are located at the input and exit apertures in a continuous multi-mode system which permit continuous passage of the material being treated while preventing radiation of microwave energy into the surrounding environment. Each of the throughput wave guides includes a plurality of wave guides placed side by side and each defining an input aperture and an output aperture.

The individual wave guides extend in the direction of product movement, and each has conductive walls. Each of the individual wave guides forming one of the throughput suppression wave guides has a closed rectangular cross section; and at the input mouth of each guide, one transverse dimension is less than one-half the free space wavelength of the excitation frequency of the applicator and a second transverse dimension is about one free space wavelength of the excitation frequency. The conductive walls of each individual guide are tapered such that the larger dimension at the input mouth is reduced to less than one-half the free space wavelength of the excitation frequency whereas the shorter dimension at the input mouth is increased to a length equal to one full free space wavelength of the excitation frequency.

With the structure of the present invention, radiation is suppressed while passing through the throughput suppression wave guides at the input and output apertures of the applicator while, at the same time, the overall cross-sectional area through which the material being treated passes remains constant (or at least is not substantially reduced). Thus, there is no constriction of product flow at the input and exit apertures of the cavity.

Other features and advantages of the present invention will be apparent to persons skilled in the art from the following detailed description of a preferred embodiment accompanied by the attached drawing wherein identical reference numerals will be used to refer to like parts in the various views.

THE DRAWING

FIG. 1 is a perspective view of a microwave applicator incorporating the present invention;

FIG. 2 is a close-up, partially broken-away perspective view of a throughput suppression wave guide according to the present invention;

FIGS. 3 and 4 are diagrammatic side views of an individual wave guide section of a throughput wave guide constructed according to the present invention;

FIG. 5 is an end view of the section shown in FIGS. 3 and 4; and

FIGS. 6 and 7 illustrate the various field distributions capable of existing within an individual wave guide section of the throughput suppression wave guide.

DETAILED DESCRIPTION

Referring first to FIG. 1, reference numeral 10 generally refers to a microwave applicator of the continuous processing type; and more particularly, it is a multi-mode cavity or tunnel type of applicator. The applicator 10 includes a conventional source of microwave energy which excites an input wave guide 11 which, in turn, feeds a distribution system 12 for dis-

tributing the microwave energy (illustrated by the broad arrows filled with wavy lines) into the interior of the applicator **10**. It is intended that the microwave energy within the applicator be uniformly distributed so as to achieve uniform heating of the material being treated.

The product or material being treated is shown in bulk form and designated **13**. It is fed in the direction of the arrow **13***a*, through an input chute, is deposited on a moving conveyor mechanism **15** and then conveyed through the tunnel applicator and finally deposited into an exit chute through which it passes in the direction of the arrow **18**. Heated air may be forced into the tunnel applicator through a conduit **19** if desired, to purge the interior of gases produced during processing of the material.

The input chute **14** located at the input aperture of the tunnel applicator as well as the output chute **16** (which is only partially seen in FIG. **1**) are, in the present invention, wave guides which permit unconstricted passage of the bulk material through the tunnel apertures, while, at the same time, suppressing the passage of microwave energy and thereby preventing radiation of microwave energy to the surrounding environment.

Turning now to FIG. **2**, the input chute **14** is seen in greater detail; and the output chute **16** may be similar in structure so that it need not be described any further for a complete understanding of the invention. As mentioned, the input chute **14** forms an unconstricted throughput for the product; and it is formed from a plurality of input wave guides extending in the direction of product flow and generally designated by reference numerals **20, 21, 22,** and **23**. Each of the individual wave guides **20–23** forming the throughput suppression wave guide **14** themselves extend the direction of product flow. The material being treated in the illustrated embodiment passes through the individual wave guide sections **20–23** under the flow of gravity and is deposited directly onto the conveyor belt **15**, although other arrangements could equally well be employed.

Each of the individual wave guide sections **20–23** forming the throughput suppression wave guide **14** are themselves identical in structure and operation, and for brevity, only the structure of the wave guide section **20** will be described in greater detail. However, the outer sides of the throughput suppression wave guide **14** are formed of continuous sheet metal walls; and these are designated respectively **24, 25, 26** and **27**.

Turning now to the wave guide section **20**, it includes an input mouth formed of four perpendicular side sections **30, 31, 32** and **33**. The side **30–33** continue along the direction of product flow to a horizontal plane denoted **34**. The side **30** of the section **20** may be an integral portion of the side **27** of the throughput suppression wave guide **14**; and similarly the side **31** may be an integral portion of the wall **24**. The side **32** of the mouth of the section **20** may be formed integrally with the section of the sidewall **25** of the input suppression wave guide. The side **33** separates the sections **20** and **21** of the throughput suppression wave guide **14**.

Beginning at the plane **34** and moving in the direction of product flow, additional conductive walls **36** and **37** are formed respectively with the walls **31** and **33**. The walls **36** and **37** are uniformly inclined toward each other, as illustrated in FIG. **2**.

Similarly, lower sections **38** and **39** of the side walls **30** and **32** respectively are bent to incline outwardly relative to each other beneath the plane **34**.

The larger transverse dimension of the wave guide section **20**, at the plane **34** is indicated dimension a_1, and the smaller transverse dimension at this plane is denoted as b_1. Similarly, at the exit aperture of the individual wave guide section **20** the larger transverse dimension is designated a_2 whereas the smaller dimension is designated as b_2. Thus, the dimension b_1 defines the narrow width of the walls **36** and **37** whereas the dimension a_2 defines the large dimensions of those walls — namely, at their base. Further, the dimension a_1 defines the largest width of the walls **38** and **39** (which provide side walls to the individual wave guide section **20**); and the dimension b_2 defines the narrower dimension of those side walls. It will be observed that by fixing the inward taper of the walls **36** and **37** to be approximately equal to the outward taper of the walls **38** and **39**, the overall cross sectional area of the individual wave guide section **20** are preferably kept substantially constant so as to not constrict movement of the material into the tunnel applicator. Each of the sidewall portions **36–39** of the wave guide section **20** take the form of a symmetrical trapezoid with adjacent ones of the wall sections being inverted.

Turning now to FIGS. **3–5**, the tapered portion of the individual wave guide section **20** is shown somewhat diagrammatically in order to disclose the technical principles according to which the invention operates. In FIG. **3** there is shown a side view of the individual wave guide section facing the side wall **39**. It will be observed that the width of the left side of the side wall is a_1 and the width of the side wall **39** at the exit aperture is b_2. FIG. **4** is a side view of the individual wave guide section **20** taken facing the tapered side wall **36** so that the input aperture has a dimension b_1 and the exit aperture has a transverse dimension a_2. A convention is made that the direction parallel to the longest side wall (i.e. the broad wall in terms of a straight rectangular guide) is indicated by the letter *x;* the direction across the width of the narrow side wall is indicated by the letter *y;* and the position in the direction of power flow through the individual wave guide section is indicated by the letter *z* (see FIG. **3**). The overall length of the tapered part of section **20** is indicated by L. The width of the sidewall **39** is indicated by the letter *w* in any position in *z* direction; and similarly, the width of the sidewall **36** is indicated by the letter *h* in any position in the *z* direction.

For this analysis, it is assumed that the wave guide section is connected to the main body of the applicator at the position $z = o$; and a_1 is less then one free-space wavelength of the excitation frequency (λ_0) and greater than ½ λ_0. Further, b_1 is less than one-half λ_0. Thus, the input aperture **40** of the wave guide section **20**, as is illustrated in FIG. **6**, may be considered to be the input of the rectangular wave guide having broad walls **36, 37** and side walls **38, 39**. Because the height of the side walls **38, 39** (namely the dimension b_1) is less than ½ λ_0 and a_1 is greater than ½ λ_0 but less than λ_0, only the TE_{10} mode can propagate; and the intensity of the electrical field vector E_Y in the *x* direction is diagrammatically illustrated by the arrows **45**. The envelope of the intensity profile is indicated by the dash line **46**.

The TE_{01} mode is illustrated in FIG. 7 wherein the intensity of the electrical field vectors is represented by the arrows **48**, and the envelope of the intensity profile is shown as the dashed line **49**. As already mentioned, only the TE_{10} mode can propagate in the region of the input aperture **40** toward the exit aperture **41** of the wave guide section **20**; however, the TE_{01} mode is capable of propagating in the region of exit aperture **41**. The electric field vectors of the TE_{10} and TE_{01} modes are orthogonal, and they may be considered as superpositioned on one another and independent of each other. The two modes do not couple to one another to any appreciable degree. The relative excitation of the two modes at the applicator depends on the incident energy in the applicator itself. In any case, each mode can be attenuated by the proper choice of length (L) of the section, height (h) and width (w). This attenuation begins when the width of the section decreases to $\lambda_0/2$.

The attenuation constant (α) of the TE_{10} mode increases with the distance z as follows:

$$\alpha=\frac{\pi}{w}\left(1-\left(\frac{2w}{\lambda_0}\right)^2\right)^{1/2} \quad (1)$$

Equation (1) is true for a uniform guide as long as w is less than or equal to $\lambda_0/2$.

Equation (2) below defines a linear taper.

$$w=a_1-[(a_1-b_2)/L]z \quad (2)$$

The total attenuation (Atten) in this mode can be approximated by:

$$\text{Atten}=8.68\int_{z_0}^{L}\alpha dz(db) \quad (3)$$

where

$$z_0=\frac{\left[a_1-\left(\frac{\lambda_0}{2}\right)\right]L}{(a_1-b_1)}$$

Then, substituting for λ in the case of the uniform guide,

$$\text{Atten}=\frac{8.68\ L\pi}{(a_1-b_2)}\left[ln\left|\frac{\lambda_0}{2b_2}\left(1+\sqrt{1-\left(\frac{2b_2}{\lambda_0}\right)^2}\right)\right| -\left(1-\left(\frac{2b_2}{\lambda_0}\right)^2\right)^{1/2}\right] \quad (4)$$

It can thus be seen that attenuation increases with length L; and with increased taper, the greater the attenuation because it will make a_1 relatively greater than b_2.

The TE_{01} mode can be analyzed in an identical manner considering the wave guide section to be rotated approximately 90° on its axis and considering the direction of energy flow to be opposite to the direction y which is indicated in FIG. 3. If $a_1=a_2$ and $b_1=b_2$, the attenuation in each mode will be equal; and the cross sectional are of the guide throughout its length will be constant.

Another way of looking at the input chute is that many modes can be excited and exist; but only one mode can propagate any appreciable distance through each of the individual wave guide sections of the chute in the direction of product movement — this is the TE_{10} mode. However, this TE_{10} mode is attenuated when w is less than $\lambda_0/2$. TE_{mn} modes where m is greater than zero are also attenuated throughout the chute since the distance between the broadwalls is less than one-half the wave length of the excitation frequency; and modes where m is greater than one cannot propagate because the width of the broadwalls is less than or equal to the free space wave length of the excitation frequency. All the other TM modes are evanescent, and the decay rate or attenuation of these modes is much greater than for the TE_{10} mode.

All of the various modes which can exist, but not propagate, can be thought of as superimposed on one another and analyzed separately. Looking into the wave guide section from within the wave guide applicator, even the TE_{10} mode becomes evanescent, because the width of the broadwall looking in the z direction is tapered and becomes more narrow to thereby attenuate even that mode. Similarly, even though the side wall (looking in the same direction) becomes wider, to a point at which a TE_{10} mode in the orthogonal direction could propagate; nevertheless, such a mode cannot carry appreciable energy because the driving point is cut off. There should be no cross coupling between the orthogonal TE_{10} modes.

The type of throughput suppression wave guide which has been described and illustrated herein has been incorporated on the output chute of a microwave tunnel applicator used for the processing of bulk products. In particular, this applicator is used for drying potato chips and noodles. In this example, the dimension a_1 of the input aperture is 8.9 in., the dimension of the b_1 is 5.5 in., the dimension of the output aperture a_2 is 10.0 in., and the dimension of the output aperture b_2 is 5 in. The tunnel applicator was excited at a source frequency of 915 MHz. (having a λ_0 of 12.9 in.).

The throughput suppression wave guide described above suppressed the radiation of microwave energy by approximately 10 db from the emission levels present without the throughput suppression wave guide. The large chute cross section allows for the passage of bulk products such as potato chips and noodles without the bridging problems associated with conventional cutoff guides of the type mentioned earlier.

Persons skilled in the art will be able to modify certain of the structure which has been illustrated and to substitute equivalent elements to those which have been disclosed; and it is therefore intended to cover all such substitutions and modifications as are embraced within the spirit and scope of the appended claims.

I claim:

1. In combination, a microwave applicator device for applying microwave energy to a material, said applicator having a cavity containing microwave energy having a wavelength λ_0, said applicator being provided with an input port leading into said cavity and an output port leading from said cavity; and a suppression wave guide connected to at least one of said ports and through which said material may pass, said wave guide comprising a plurality of individual wave guide sections having conductive walls, each of said individual wave guide sections having a closed rectangular cross section from an input mouth to an exit aperture with a first side dimension of the input mouth of each guide section being less than about one-half λ_0 and a second side

dimension of said mouth taken perpendicular to said first side dimension being less than about λ_0 and greater than one-half λ_0, the walls of each wave guide section being tapered until said second side dimension is less than about one-half λ_0 while maintaining the cross sectional area of each section be approximately constant.

2. The combination of claim 1 wherein the exit aperture of each of said wave guide sections is rectangular having a first side dimension parallel to said second side dimension of the input mouth of said section less than about one-half λ_0 and a second transverse side dimension parallel to said first dimension of said input mouth of said section being less than about λ_0 and greater than about one-half λ_0, and wherein the overall length of the tapered portion of each section in the direction of power flow is sufficient to achieve a 10 db. attenuation for the TE_{10} mode when a product is not being processed.

3. The system of claim 1 wherein the taper of each of the walls of said individual wave guide sections is uniform and wherein the cross sectional area of each individual wave guide section remains approximately constant in the direction of power flow.

4. The system of claim 2 wherein said first dimension of the mouth of each of said wave guide sections of said throughput suppression wave guide is approximately one-half λ_0 and said second side dimension of said mouth is approximately λ_0.

5. The system of claim 4 wherein said first dimension of the output aperture of each individual wave guide section is approximately equal to λ_0 and said second dimension of the output aperture of each of said wave guide sections is approximately one-half λ_0.

6. The system of claim 1 characterized by the fact that the material being processed is bulk material which passes through said suppression wave guide along the direction of power flow under force of gravity.

7. The system of claim 1 further comprising a second suppression wave guide connected to said applicator at the other of said ports through which said material may pass, said second wave guide comprising a plurality of individual wave guide sections having conductive walls, each individual section of said second wave guide having a closed rectangular cross section of approximately constant area from an input mouth to an exit aperture, a first side dimension of the input mouth of each section of said second wave guide being less than about one-half λ_0 and a second side dimension taken perpendicular to said first dimension being less than about λ_0 and greater than about one-half λ_0, the walls of each section of said second wave guide being tapered until said second side dimension of the sections of said second wave guide at the discharge aperture is less than about one-half λ_0.

8. A wave guide section having an opening therein for passing materials therethrough while suppressing the passage therethrough of microwave energy having a wave length of λ_0 comprising conductive walls having a closed rectangular cross section and extending about said opening, said walls being tapered from a cross-sectional dimension equal to less than about one-half λ_0 at one end of said section to a value greater than one-half λ_0 but less than λ_0 at a cross section taken at the other end of said section and a second dimension taken at a cross section at said one end taken perpendicular to said first mentioned dimension being more than about one-half λ_0 but less than λ_0, said last mentioned dimension being less than one-half λ_0 when taken at the cross section at the other end of said section, said opening through said section being rectangular and of substantially constant area from one end of said section to the other.

9. A wave guide according to claim 8 comprising a plurality of said sections located side-by-side with a shorter cross-sectional dimension of one end of one of said sections being adjacent the shorter cross-sectional side of one end of the other of said sections.

10. A suppression wave guide for suppressing radiation of microwave energy while permitting the passage of material therethrough comprising a wave guide having four conductive planar walls arranged in opposing pairs to provide an input mouth nd an exit aperture, said pairs of walls tapering in opposite directions and being so dimensioned as to provide a substantially constant cross-sectional area from said input mouth to said exit aperture, said walls being dimensioned to suppress the passage of the orthogonal primary modes of microwave energy at a wave length of λ_0 at said inlet mouth and said exit aperture.

11. A wave guide as set forth in claim 8 wherein said section is arranged with its length in a substantially vertical direction whereby material may be passed through said section by force of gravity.

* * * * *