United States Patent [19]

Sayer, Jr.

[11] **3,764,768**

[45] **Oct. 9, 1973**

[54] **MICROWAVE APPLICATOR EMPLOYING A BROADSIDE SLOT RADIATOR**

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[22] Filed: **May 19, 1971**

[21] Appl. No.: **255,287**

Related U.S. Application Data

[60] Division of Ser. No. 172,176, Aug. 16, 1971, Pat. No. 3,705,283, which is a continuation of Ser. No. 5,442, Jan. 23, 1970, abandoned.

[52] **U.S. Cl.** **219/10.55**
[51] **Int. Cl.** **H05b 9/06**
[58] **Field of Search** 219/10.55

[56] **References Cited**

UNITED STATES PATENTS

3,472,200	10/1969	Gerling	219/10.55 UX
3,555,232	1/1971	Bleackley	219/10.55
3,632,945	1/1972	Johnson	219/10.55
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Primary Examiner—J. V. Truhe
Assistant Examiner—Hugh D. Jaeger
Attorney—Leon F. Herbert et al.

[57] **ABSTRACT**

A microwave applicator for treating material with microwave energy is disclosed. The applicator includes a broadside radiator formed by a hollow elongated waveguide having an array of resonant slots communicating through the wall of the waveguide, such slots being spaced apart on their centers along the axis of the guide by one half a guide wavelength an array of slot loading members are disposed to project into the waveguide from alternate sides of adjacent slots for coupling microwave energy from the waveguide radiator through the slots in an in-phase relation to obtain a broadside radiator. The loading members may be separately adjusted for adjusting the energy profile coupled from the antenna to the load.

9 Claims, 7 Drawing Figures

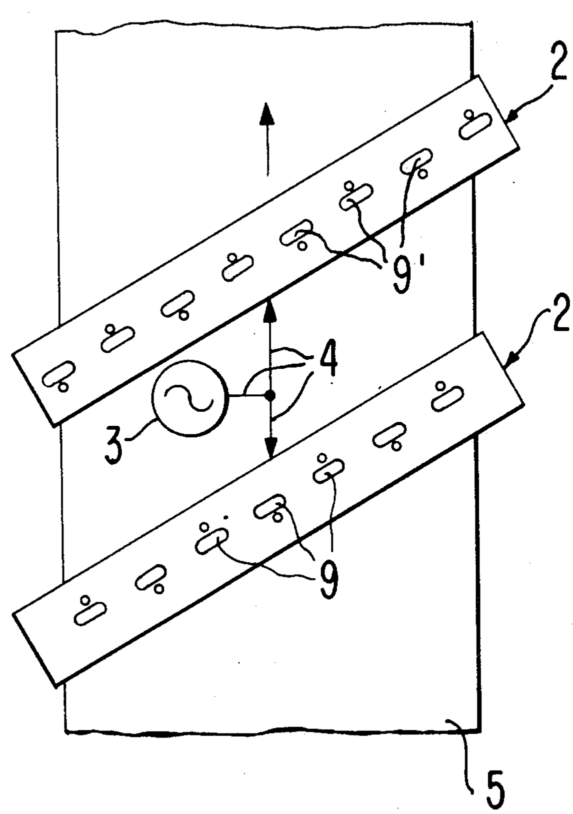


FIG. 1

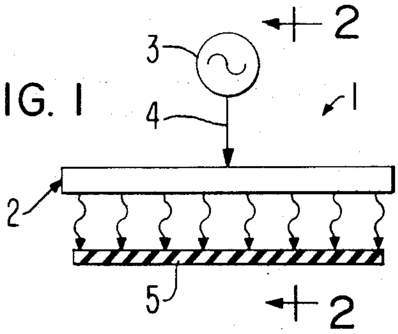


FIG. 2

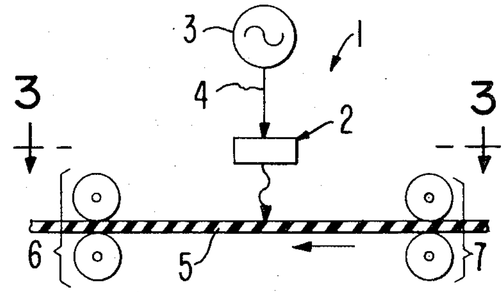
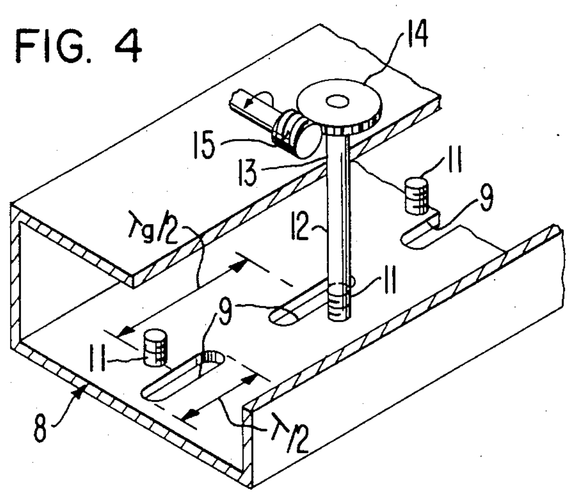


FIG. 4



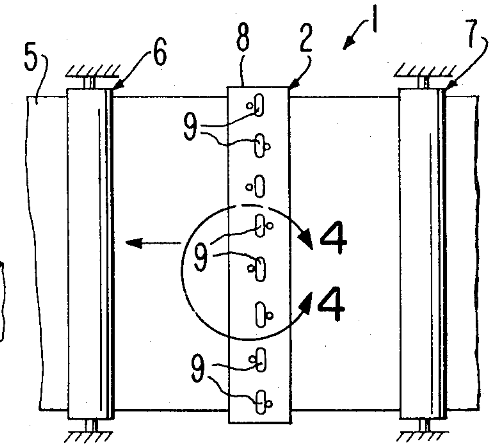


FIG. 3

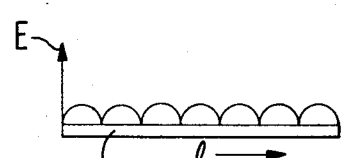


FIG. 5

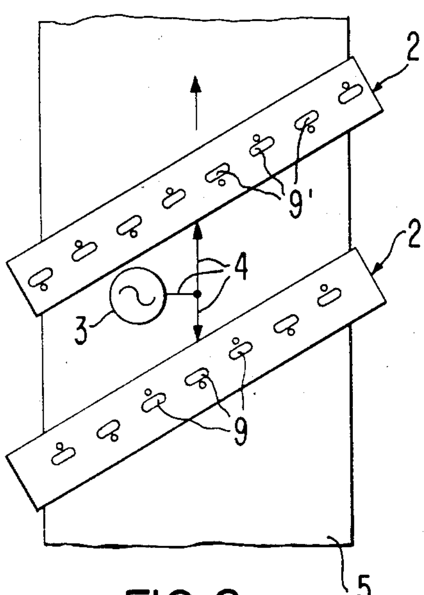


FIG. 6

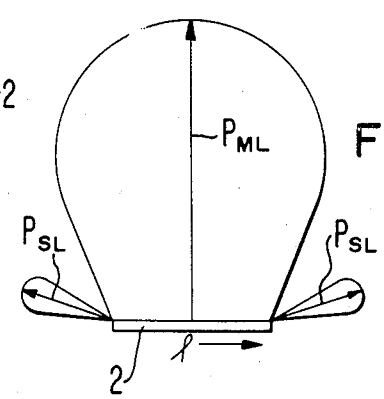


FIG. 7

MICROWAVE APPLICATOR EMPLOYING A BROADSIDE SLOT RADIATOR

RELATED APPLICATIONS

This is a division of application Ser. No. 172,176 filed Aug. 16, 1971 now U.S. Pat. No. 3,705,283 which is a continuation of parent application U.S. application Ser. No. 5,442, filed Jan. 23, 1970 now abandoned, assigned to the same assignee as the present invention.

DESCRIPTION OF THE PRIOR ART

Heretofore, it has been proposed to emply a broadside antenna for directing microwave energy into material to be treated as carried on a conveyor belt disposed immediately adjacent the array of radiating elements of the antenna. Such a microwave applicator is disclosed in the Journal of Microwave Power, Vol. 2 (1967) No. 2, of April, page 32. Use of a broadside radiator for applying microwave energy to large sheets of material is desired because such broadside radiators can be made relatively large for applying energy to wide sheets of material and the electric field vector is in-phase and uniform from one end of the antenna to the other to obtain uniform treatment of the material being treated. However, the problem associated with the prior art broadside applicator was that the radiative apertures of the broadside array were defined by short sections of rectangular waveguide directed at the material to be treated to fix the linear polarization of the wave energy emerging from each of the radiative elements. The individual rectangular waveguide radiators were excited by loop coupling from a coaxial line with the loops reversed in adjacent waveguide radiators. This resulted in a relatively complex and expensive broadside antenna. Furthermore, the use of a coaxial line limited the maximum power capability to that of the coaxial line.

SUMMARY OF THE PRESENT INVENTION

The principal object of the present invention is the provision of an improved microwave applicator for treating materials with microwave energy.

One feature of the present invention is the provision of a microwave applicator employing a broadside microwave radiator comprising a section of hollow waveguide having an array of resonant slots communicating through the wall thereof and each of said slots including a slot loading member alternating from one side of the slots to the other in adjacent slots for controlling the coupling of energy through each of the slots, whereby adjustment of the slot loading members permits control of the energy profile radiated from the antenna and into the material to be treated.

Another feature of the present invention is the same as the preceding feature including the provision of two broadside antenna portions of the aforedescribed type spaced apart in the direction of movement of the material to be treated for sequentially treating the material with the broadside energy lobes emanating from each of the antenna portions and wherein the radiative slots in one antenna are offset with respect to the other such that the center of the slots in one portion of the array are aligned in the direction of material movement with the region between the ends of adjacent slots in the other waveguide portion to obtain uniform treatment of material as conveyed through the two broadside lobes.

Another feature of the present invention is the same as any one or more of the preceding features wherein the slot loading members include means for adjusting their positions to adjust the energy profile radiated from the antenna into the material to be treated.

Other features and advantages of the present invention will become apparent upon a perusal of the following specification taken in connection with the accompanying drawings wherein:

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic transverse view of a microwave applicator employing features of the present invention,

FIG. **2** is a sectional view of the structure of FIG. **1** taken along line **2—2** in the direction of the arrows,

FIG. **3** is a view of the structure of FIG. **2** taken along line **3—3** in the direction of the arrows.

FIG. **4** is an enlarged perspective view, partly broken away, of a portion of the structure of FIG. **3** delineated by line **4—4**,

FIG. **5** is a plot of electric field intensity E versus length of a broadside slot radiator of the present invention depicting the energy profile immediately adjacent the radiative slots,

FIG. **6** is a schematic plan view, similar to the view of FIG. **3**, depicting an alternative embodiment of the present invention, and

FIG. **7** is a schematic line diagram depicting the lobe pattern of microwave power radiated from a slot radiator of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to FIGS. **1–3**, there is shown a microwave applicator **1** incorporating features of the present invention. The microwave applicator **1** includes a broadside slot radiative antenna **2** which is excited with microwave energy derived from a microwave generator **3**, such as a klystron or magnetron, via a suitable waveguide or other transmission line **4**, which is coupled into the radiative antenna **2** via a suitable T connection or other conventional coupling means. The radiative antenna **2** may be center fed or fed from either end. A sheet of material **5** to be treated is passed through the main radiative lobe of the antenna **2** for treating the material **5** with microwave energy. In a typical example, a sheet of material, such as plywood, paper pulp or dielectric sheet material, to be treated is pulled via a suitable conveying means, such as two sets of rollers **6** and **7**, through the radiative lobe of the antenna **2.** The sheet material **5** may be disposed immediately adjacent the radiative side of the antenna **2** or it may be disposed up to several wavelengths from the antenna **2.**

Radiative antenna **2** includes a hollow section of waveguide **8** which is preferably a rectangular waveguide but in certain instances may be a cylindrical waveguide. An array of resonant slots **9** are axially aligned along the axis of the waveguide **8** and each slot **9** is dimensioned to be approximately one half of a free space wavelength long at the operating frequency (see FIG. **4**). The slots **9** are spaced on their centers by one half a guide wavelength along the axial direction of the waveguide **8.** Slot loading members **11,** such as conductive screws, posts or the like are disposed on alternate sides of adjacent slots **9** for coupling microwave energy from the waveguide through the slots **9** in an in-phase relation to obtain a broadside antenna radiator **2.** Such antenna radiators of this type are disclosed in a text titled, "Microwave Antenna Theory and Design" edited by Samuel Silver and published by McGraw Hill in 1949, see pages 299–301.

In this type of radiator, the slot loading members **11** serve to introduce asymmetry into the conductive currents in the waveguide **8** such that the wave energy is coupled out of successive slots in the desired in-phase relation to obtain a broadside radiative structure. The degree of coupling through each of the respective slots **9** is a function of the amount of perturbation introduced into the waveguide structure by the loading member **11.** In the case of the loading member being a screw projecting into the waveguide **8** and threaded through a hole in the waveguide, the amount of coupling in a function of the amount of penetration of the screw **11** into the waveguide **8.**

Referring now to FIG. **5,** there is shown a plot of energy coupled through the slots **9** versus length of broadside array for a measurement taken immediately adjacent to the slots. It is seen that the energy profile of FIG. **5** has a generally squared sinusoidal shape reaching a maximum at the center of each of the radiative slots **9.** When treating sheets of material it may be desirable to obtain a more uniform application of microwave energy to the material being treated. Accordingly, the material can be moved further away from the slots **9** in which case the ripples in the energy profile diminish to substantially a uniform pattern at a few wavelengths from the antenna.

However, if the material is to be passed immediately adjacent the waveguide radiator **2,** where the energy profile of a single radiator **2** is similar to that illustrated in FIG. **5,** then a plurality of staggered radiators **2** may be employed for superimposing their sinusoidal energy profiles in a staggered relation such that the null points of one antenna profile are superimposed upon the maximum points of the other antenna profile to obtain a nearly uniform total energy profile applied to the material being treated. Such a staggered applicator system is shown in FIG. **6** wherein a pair of broadside slot applicators **2** of the type previously described, extend across the sheet of material **5** which is moving in the direction of the arrow. The center of slots **9'** of one of the broadside antennas are aligned in the direction of material flow with the web portion between the ends of adjacent slots **9** in the other broadside antenna.

The adjustable slot loading members **11** also provide a means for reducing the side lobe power radiated out the end portions of the radiators **2.** The side lobe power is generally much lower than the main lobe power as indicated by the length of the power vectors P_{ML} and P_{SL}, respectively. However, by decreasing the coupling through the slots **9** near the ends of the array **2,** the side lobe power can be reduced.

In case the material to be treated is passed immediately adjacent the slots **9,** it is desirable to adjust the slot loading member **11** from the remote side of the antenna **2.** In this case, as seen in FIG. **4,** loading member **11,** such as a threaded screw mating with a threaded hole in the lower wall of the waveguide **8,** may be threadably adjusted by means of a dielectric extension **12,** such as a low loss ceramic material, affixed to the screw **11** and extending through a hole **13** in the top wall of the guide and being affixed to a gear **14** which mates with a worm shaft **15.** The worm shaft is driven from a suitable motor, not shown, for adjusting the degree of penetration of the screw **11** into the waveguide **8** and , thus, the coupling through the corresponding slot **9.** Each slot loading member **11** would include extension **12,** gear **14** and worm **15.**

Thus, use of a broadside slot radiator **2** with adjustable slot loading members **11** has the advantage over the prior art broadside slot radiators in that it readily permits adjustment of the energy profile coupled into the material being treated and further allows better control over undesired side lobe radiation. Moreover, the energy profile may be adjusted in use for matching the radiated energy profile to an optimum energy profile required by the material to obtain uniform treating or drying of the material being treated. In other words, adjustment of the loading members with corresponding adjustment in the energy profile may be employed to advantage for eliminating wet spots in sheets of material being treated and for preventing overheating of dry spots in such material.

In the case where the material being treated is disposed a few wavelengths from the broadside antenna **2,** the material treated should present a relatively large lossy mass to the antenna **2.** Typical of such an application is the drying of moisture laden sheet materials passing through a sheet-shaped treatment zone. In such a case, the moisture laden material should preferably have a thickness in excess of one tenth free space wavelength taken in the direction of power flow from the radiating antenna into the material being treated, such that a relatively lossy load is presented to the radiator.

Since many changes could be made in the above construction and many apparently widely different embodiments of this invention could be made without departing from the scope thereof, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. Apparatus for treating material with microwave energy comprising means for transporting material to be treated along a path of travel, two microwave broadside radiation applicators positioned along said path of travel for applying microwave energy to said material, each of said applicators forming means for delivering energy to said material in zones of high and low energy alternating across said path of travel, said applicators being positioned relative to each other transversely of said path of travel so that a given point on said material first passes one of said applicators at a zone of high energy and then passes the other of said applicators at a zone of low energy.

2. The apparatus of claim **1** wherein each of said applicators comprises a waveguide, a wall of said waveguide having an array of slots thereon through which energy can be delivered to said material in alternating zones of high and low energy across said path.

3. The apparatus of claim **2** wherein said waveguide is elongated about an axis, and wherein said slots are aligned with each other parallel to said axis.

4. The apparatus of claim **2** wherein said waveguide is rectangular.

5. The apparatus of claim **3** wherein the length of each of said slots in the direction parallel to said axis is approximately one-half a free-space wavelength at the operating frequency of said waveguide, and wherein said slots are spaced-apart on their centers along the axial direction of said waveguide by approximately one-half a waveguide wavelength.

6. Apparatus for treating material with microwave energy comprising means for transporting said material along a path, two microwave applicators positioned along said path, each of said applicators comprising broadside radiator means for coupling energy to said material in alternating zones of high and low energy across said path, said applicators being positioned relative to each other transversely of said path so that a given point on said material first passes one of said applicators at a zone of high energy and then passes the other of said applicators at a zone of low energy.

7. The apparatus of claim **6** wherein each of said applicators comprises a hollow waveguide elongated about an axis, a wall of said waveguide having thereon an array of slots alligned with each other parallel to said axis to form said broadside radiator means.

8. The apparatus of claim **7** wherein said waveguide is rectangular.

9. The apparatus of claim **7** wherein the length of each of said slots in the direction parallel to said axis is approximately one-half a free-space wavelength at the operating frequency of said waveguide, and wherein said slots are spaced-apart on their centers along the axial direction of said waveguide by approximately one-half a waveguide wavelength.

* * * * *

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,764,768 Dated October 9, 1973

Inventor(s) WILLIAM H. SAYER, JR.

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

On the Abstract page, add the following:

--Assignee: Varian Associates, Palo Alto, California--.

Signed and sealed this 2nd day of July 1974.

(SEAL)
Attest:

EDWARD M. FLETCHER, JR.
Attesting Officer

C.MARSHALL DANN
Commissioner of Patents

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,764,768 Dated October 9, 1973

Inventor(s) WILLIAM H. SAYER, JR.

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