United States Patent

[11] 3,581,038

[72] Inventor Norman H. Williams
San Francisco, Calif.

[21] Appl. No. 821,176
[22] Filed May 2, 1969
[45] Patented May 25, 1971
[73] Assignee Varian Associates
Palo Alto, Calif.

[54] MICROWAVE APPLICATOR EMPLOYING A BROADSIDE RADIATOR IN A CONDUCTIVE ENCLOSURE

8 Claims, 4 Drawing Figs.

[52] U.S. Cl. 219/10.55, 219/10.61
[51] Int. Cl. H05b 9/06, H05b 5/00
[50] Field of Search 343/771; 219/10.55

[56] References Cited

UNITED STATES PATENTS

2,704,802	3/1955	Blass et al.	219/10.55
2,981,948	4/1961	Kurtz	343/771
3,263,052	7/1966	Jeppson et al.	219/10.55
3,308,467	3/1967	Morrison, Jr.	343/771X
3,363,253	1/1968	Ratkevich et al.	343/771

OTHER REFERENCES

RADIATION LAB SERIES Vol. 12, pps. 322 & 323, McGraw-Hill 1949

Primary Examiner—J. V. Truhe
Assistant Examiner—L. H. Bender
Attorneys—Leon F. Herbert and Stanley Z. Cole

ABSTRACT: A microwave applicator for treating material with microwave energy is disclosed. The applicator includes a relatively large conductive enclosure containing a large broadside microwave radiating antenna disposed for directing the radiated microwave energy onto the load of lossy material for treating same. The applicator is particularly useful for treating relatively large amounts of lossy material.

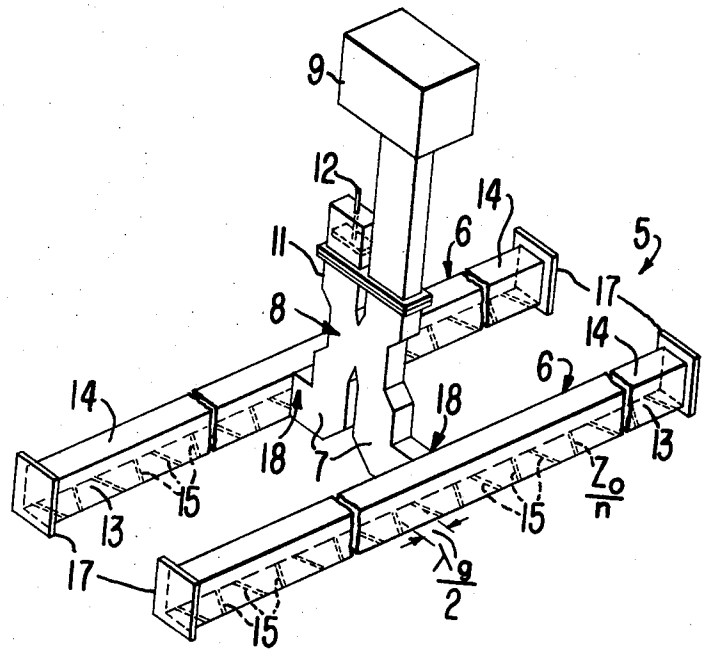


FIG. 1

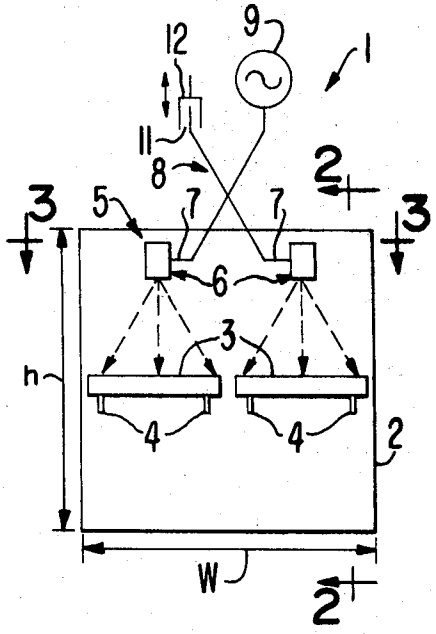
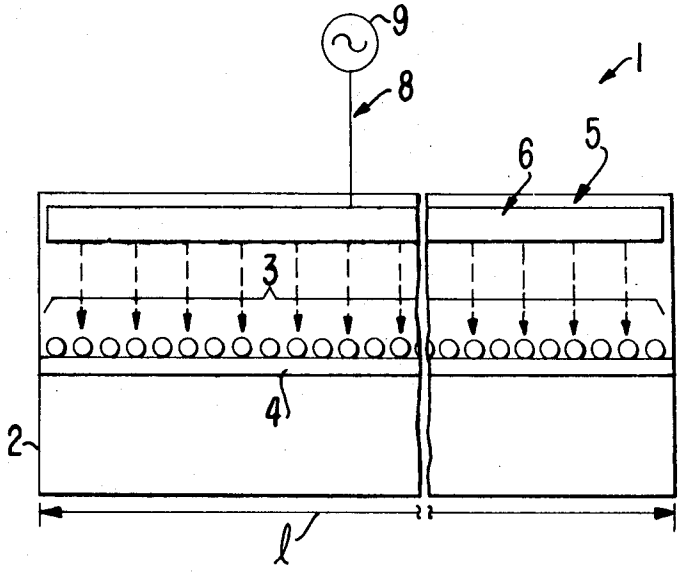


FIG. 2



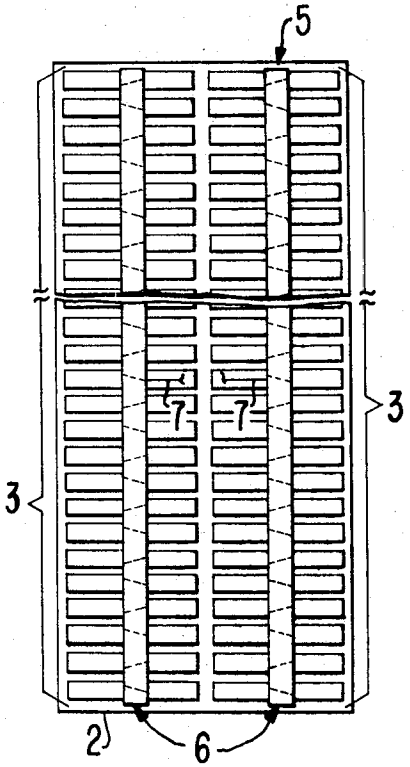
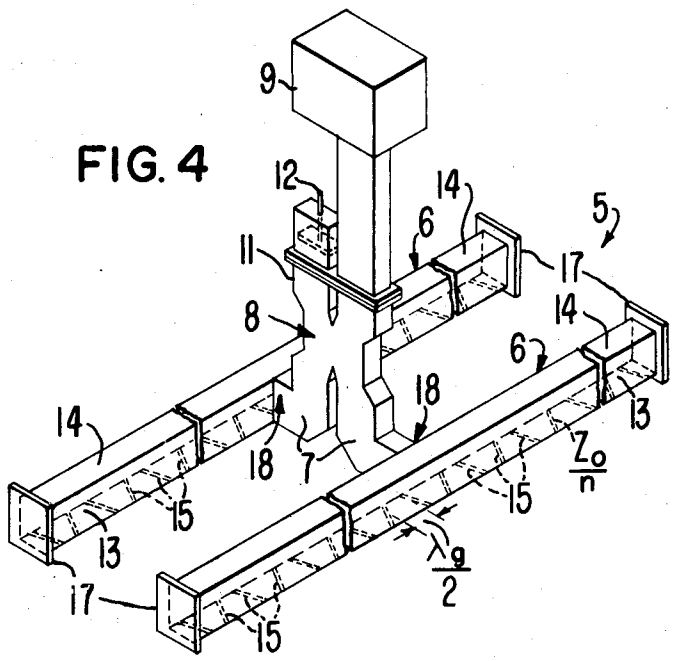


FIG. 3

FIG. 4



INVENTOR.
NORMAN H. WILLIAMS

BY

Leon F. Herbert

ATTORNEY

MICROWAVE APPLICATOR EMPLOYING A BROADSIDE RADIATOR IN A CONDUCTIVE ENCLOSURE

DESCRIPTION OF THE PRIOR ART

Heretofore, it has been proposed to employ a broadside antenna for directing microwave energy onto material to be treated as carried on a conveyor belt 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, Apr. p. 32. One of the problems with this type of microwave applicator, as pointed out in the aforementioned article, is that wave energy is reflected from the material to be treated back to the antenna. This reflection of the wave energy produces an unequal distribution of the energy in front of the large aperture of the antenna. Accordingly, the broadside antenna, which was found to be useful for heating material on the conveyor, comprised a relatively complex structure in that each of the radiative apertures of the broadside array was defined by a short section 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. In addition, there was no disclosure of means confining the radiated energy which was not absorbed by the material being treated. This stray radiation can constitute a substantial hazard and produce difficult problems of radio frequency interference if the radiative structure is not enclosed. However, if the radiator is enclosed by a conductive structure, a reflection of wave energy from the interior walls of the structure can destroy the uniformity of the energy distribution adjacent the antenna and produce a sufficient impedance mismatch to prevent efficient energy transfer to the product

Others have proposed to treat materials with microwave energy by placing the material to be treated in a relatively large conductive enclosure, such as a multimode cavity resonator, and exciting the resonator by feeding energy into the resonator at a number of spatially separated feedpoints in order to obtain a more even distribution of the energy into the material within the resonator. The problem with this arrangement is that, when relatively lossy materials are to be treated, the energy distribution within the resonator becomes very nonuniform resulting in nonuniform treatment of the material within the resonator.

SUMMARY OF THE PRESENT INVENTION

The principle 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 contained in a conductive enclosure for radiating microwave energy into a lossy material to be treated contained within the enclosure.

Another feature of the present invention is the same as the preceding feature wherein the broadside antenna includes a hollow waveguide having an array of coupling slots communicating through the wall of the waveguide to define an array of radiative elements of the antenna.

Another feature of the present invention is the same as any one or more of the preceding features wherein the conductive enclosure is elongated and the broadside antenna is elongated in the direction of the elongation of the enclosure and wherein the broadside antenna is fed with microwave energy at a point centrally disposed of the antenna.

Another feature of the present invention is the same as any one or more of the preceding features wherein the broadside antenna includes a pair of elongated parallel broadside radiators centrally fed with microwave energy from a common source via the intermediary of a power splitter connecting the pair of broadside antenna in parallel.

Other features and advantages of the present invention 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 transverse line diagram, partly in schematic form, of a microwave applicator employing features of the present invention,

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

FIG. 3 is a longitudinal sectional view of the structure of FIG. 1 taken along line 3–3 in the direction of the arrows, and

FIG. 4 is a perspective view of the microwave broadside radiator incorporating features of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to FIGS. 1—3 there is shown the microwave applicator 1 incorporating features of the present invention. Microwave applicator 1 includes a relatively large rectangular microwave energy shield in the form of a conductive enclosure 2 as of aluminum. A typical size for the enclosure 2 is a height of 8 feet, a width of 8 feet, and a length of 20 feet. Material to be treated with microwave energy such as 3.5-inch diameter and 3-foot billets of green hardwood are placed on racks 4 within the enclosure 2.

A broadside antenna array 5 is disposed over the load 3 for radiating microwave energy onto the billets 3 for treating same. The broadside radiator 5 will be described in greater detail below with regard to FIG. 4. Briefly, radiator 5 includes a pair of parallel connected elongated broadside antennas 6 extending lengthwise of the enclosure 2. The antennas 6 are centrally fed with microwave energy via a pair of waveguides 7 coupled to the two output ports of a short slot hybrid coupler 8, having its input port connected to a source 9 of microwave energy, such as a 30 kilowatt CW magnetron or klystron oscillator, operating at 2,450 megahertz. The other port 11 of the short slot hybrid coupler 8 includes an adjustable short 12 for balancing the flow of power to the two parallel broadside antennas 6.

Referring now to FIG. 4, the broadside radiator 5 is shown in greater detail. The broadside radiator 5 includes a pair of elongated parallel broadside antenna arrays 6. Each broadside antenna array 6 comprises a length of rectangular waveguide having a pair of opposed broad walls 13 and a pair of opposed narrow sidewalls 14. The narrow sidewall 14, facing the material 3 to be treated includes an array of slots 15 communicating through the narrow wall 14 at the interior face of the guide to define an array of radiative shunt slot elements 15. In order to obtain a uniform pattern of radiation from the broadside antenna 6, adjacent slots 15 of the array are excited in phase with each other. Moreover, the axial spacing of the slots 15 along guide should be less than one freespace wavelength. A convenient way to achieve the aforecited broadside conditions is to place the radiating slots 15 a half a guide wavelength apart along the axis of the guide, i.e., provide a resonant array of slots, and to oppositely incline adjacent slots 15 relative to the transverse plane of the guide such that they are excited in phase with a half wavelength spacing therebetween. More particularly, the opposite inclination of the slots 15 relative to each other introduces 180° of structural phase reversal in the excitation of the slots 15. The opposite ends of the rectangular waveguides are provided with short-circuiting plates 17, such plates 17 being spaced by one-quarter guide wavelength from the terminal slots 15.

Each of the slots 15 is dimensioned to present an impedance to the waveguide which is substantially equal to $nZ_o/2$ where Z_0 is the characteristic impedance of the rectangular waveguide and n is one-half the number of slots 15 taken along the waveguide between the end shorting plates 17.

The two short sections of rectangular waveguide **7** feed microwave energy from the short slot hybrid coupler **8** through the broad walls of the broadside antennas **6** via series T connectors **18** disposed substantially midway along the length of the rectangular waveguides. Each T sums the two impedances $Z_o/2$ seen at its arms and thus presents a match to the short section of waveguide **7**. An adjustable, i.e., movable, waveguide short **12** is affixed to port **11** of the hybrid coupler **8** for adjusting the flow of power to the two parallel broadside radiators **6**. In order for the adjustable short **12** to provide an adjustment in the splitting of the power between the two parallel radiators **6** the output ports of the hybrid coupler **8** need to look into approximately equal and small impedance mismatches. This provides a reflection of power to port **11** which can be reflected into either output port of the coupler **8** by suitable adjustment of short **12**.

In a typical example of the broadside radiators **6**, they have an overall length of approximately 30 wavelengths. Broadside slotted radiators of the general type shown in FIG. **4** are described in Vol. 12 of the Radiation Lab. Series, pp. 322 and 323, published by McGraw-Hill in 1949. The microwave applicator **1**, as disclosed herein, has been employed for drying green tan oak billets of 3.5 inches in diameter and 3 feet long utilizing the method disclosed and claimed in copending U.S. application Ser. No. 758,097 filed Sept. 6, 1968, and assigned to the same assignee as the present invention. When the broadside array is driven with 30 kilowatts CW at 2,450 megahertz, it successfully dried 80 of such tan oak billets by removing between 20 and 25 percent of their weight in 4 hours of operation.

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.

I claim:

1. In an electromagnetic energy applicator apparatus, means forming an electromagnetic energy shield for confining the energy and for containing lossy material to be treated with such energy, an electromagnetic radiative structure disposed for radiating electromagnetic energy directly onto the material to be treated within said shield, said structure comprising a pair of transversely spaced generally parallel elongated hollow waveguides, each of which is provided along its length with a generally resonant array of spaced radiative elements arranged to be excited by electromagnetic energy substantially in phase with each other at the operating frequency of the applicator to radiate a uniform pattern of radiation from each of said waveguides for uniform treatment of the lossy material, a source of electromagnetic energy, and means for feeding approximately equal amounts of electromagnetic energy from said source to each of said waveguides.

2. The apparatus of claim **1** wherein said radiative elements for each of said waveguides comprise an array of slots communicating through a wall of said waveguide.

3. The apparatus of claim **2** wherein said slots are spaced apart along the length of said waveguide by approximately an integral number of half guide wavelengths within said waveguide at the operating frequency of the applicator.

4. The apparatus of claim **3** wherein each of said waveguides is of rectangular cross section having a pair of broad and a pair of narrow walls, and adjacent slots are oppositely inclined relative to the transverse plane of said waveguide to obtain in-phase excitation of adjacent slots.

5. The apparatus of claim **2** including means for short circuiting both ends of each of said hollow waveguide and said means for feeding electromagnetic energy into said hollow waveguides does so at a point generally midway along the length of each.

6. The apparatus of claim **5** wherein said centrally disposed microwave feed includes a short slot hybrid coupler having one input port to be connected to said source of electromagnetic energy and having a pair of output ports, a pair of waveguides transversely directed of said slotted parallel waveguides for interconnecting each of said output ports of said hybrid coupler and the central feed point of each of said slotted waveguides for feeding approximately equal amounts energy to each of said parallel slotted waveguides from said common source of electromagnetic energy.

7. The apparatus of claim **6** including a movable wave reflective element coupled to a fourth port of said hybrid coupler for balancing the power flow to said parallel slotted waveguide radiators.

8. The apparatus of claim **6** wherein said pair of transversely directed waveguides are coupled through the broad walls of said slotted waveguides to form series T connections to each of said parallel waveguides, and wherein the impedance of each of said slot radiative elements is approximately $nZ_o/4$, wherein n is the number of radiative slots in each parallel slotted waveguide and Z_o is the characteristic impedance of each of said parallel waveguides.