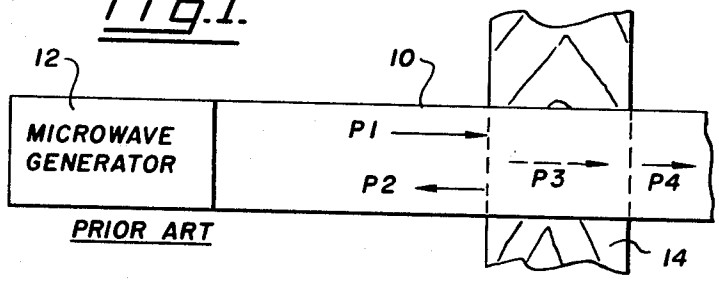
Jan. 23, 1973 L. ADMIRAAL 3,712,971

WAVEGUIDE APPARATUS FOR MICROWAVE DRYING OF MATERIALS

Filed June 3, 1971

Fig. 1.



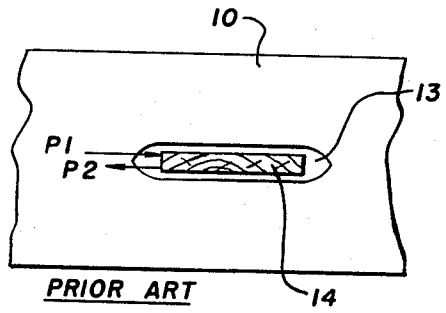


Fig. 2.

Fig. 3.

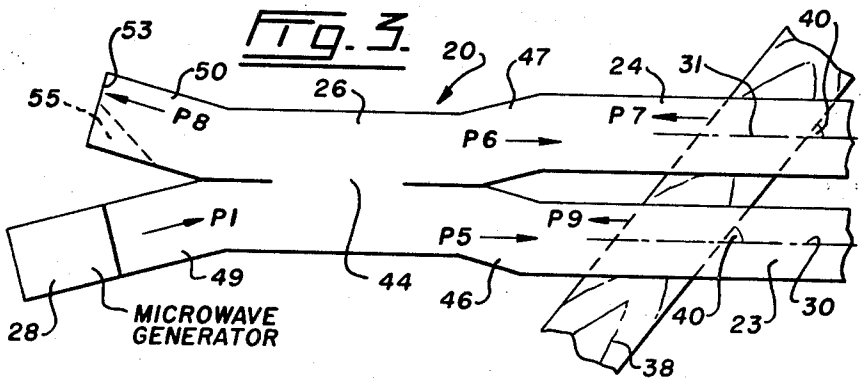
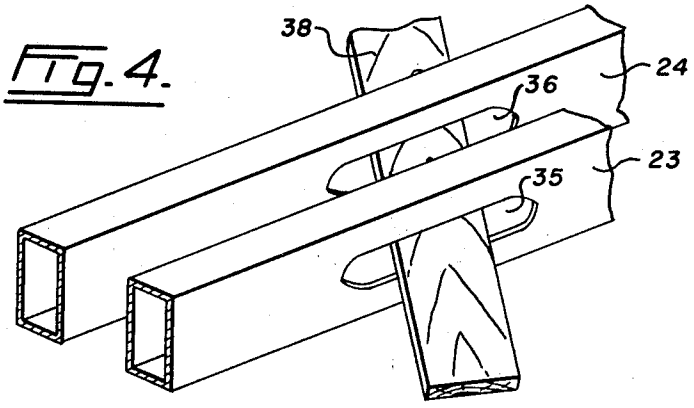


Fig. 4.



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United States Patent Office 3,712,971 Patented Jan. 23, 1973

3,712,971

WAVEGUIDE APPARATUS FOR MICROWAVE DRYING OF MATERIALS

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Filed June 3, 1971, Ser. No. 149,546
Int. Cl. H05b 9/06
U.S. Cl. 219—10.55 7 Claims

ABSTRACT OF THE DISCLOSURE

A 4-port hybrid coupling a microwave generator to a set of waveguides which have slots therein through which lumber can travel at an angle of less than 90° to the longitudinal centerlines of the waveguides.

This invention relates to waveguide apparatus for drying moisture-laden materials, such as lumber, wood-based materials, bagasse, paper and the like, by microwave energy.

Although many types of materials may be dried by the present apparatus, it is primarily designed for lumber and is so described herein for convenience.

When microwave energy is directed at a piece of lumber located in the slots of a waveguide system and extending at right angles to said waveguide, a large percentage of the power is reflected, particularly if the wood is wet. This represents a waste of power, and the reflected energy is damaging to the microwave generator. Wet lumber can reflect up to 60% of the microwave energy, while dry lumber can reflect up to 20%.

This waste of power can be very costly, but what is more important, drying under these circumstances is not practical because of the danger to the generator.

This problem is greatly reduced or eliminated by the present invention. This is accomplished by arranging the slots in the waveguide system so that the lumber extends at an angle of less than 90° to the longitudinal centerline of the waveguide system. In addition, a 4-port hybrid is used to couple the microwave generator to the waveguide system. This system preferably is in the form of a set of parallel waveguides each having a longitudinal centerline. The hybrid has the usual ports **1** and **4** at one end, and ports **2** and **3** at its opposite end. The microwave generator is coupled to port **1** of the hybrid, while the waveguides are coupled respectively to ports **2** and **3** thereof. With this arrangement it is possible (through initial adjustment of the above-mentioned angle) to direct the reflected power from the lumber faces towards port **4** of the hybride and therefore away from the microwave generator. Furthermore, it is possible to connect to port **4** a means for the absorption of the reflected microwave energy, but this angling of the lumber makes it possible to couple a microwave reflector to port **4** in order to return the reflected power to the lumber and thereby utilize most of the generated microwave power.

This angular arrangement greatly reduces the amount of energy reflected by the lumber. For example, with the lumber path arranged so that the lumber travels at an angle of about 39° to the longitudinal centerline of the waveguides, the reflected power, all of which travels to port **4**, has been reduced to approximately 7% for all conditions of wetness. With a reflector at port **4** of the hybrid, the original reflected energy is directed back to the lumber and 7% of this or about .5% of the total is reflected again by the lumber. This reaches the microwave generator, but it is so low that it cannot cause any trouble.

Waveguide apparatus according to the present invention comprises a waveguide system adapted to be coupled to a microwave generator and having a centerline along which microwave energy from the generator travels, and opening means in said waveguide system through which lumber can pass to be exposed to said microwave energy, said opening means being arranged so that the path of travel of the lumber is at an angle of less than 90° to said centerline. It is preferable to provide stop means between the generator and the waveguide system for preventing microwave energy reflected by the lumber from reaching the generator.

A preferred form of waveguide apparatus according to this invention comprises a set of parallel waveguides having longitudinal centerlines, a microwave generator coupled to the waveguides, slots in the waveguides through which lumber can pass to be exposed to microwave energy from the generator, these slots being arranged so that the path of travel of the lumber is at an angle of less than 90° to the centerlines of the waveguides, and stop means between the generator and the waveguides for preventing microwave energy reflected by the lumber from reaching the generator. The stop means is preferably a 4-port hybrid having the usual ports **1**, **2**, **3** and **4**. The generator is coupled to port **1**, and the waveguides are coupled to ports **2** and **3**. If desired, microwave energy absorption means can be coupled to the 4th port of the hybrid, but it is preferable to couple a microwave reflector to said port so as to return microwave energy which is reflected by the wood back to the waveguides.

An example of this invention is illustrated in the accompanying drawings, in which

FIG. 1 diagrammatically illustrates a waveguide with lumber travelling therethrough at right angles to the centerline thereof,

FIG. 2 is a side elevation of part of the waveguide of FIG. 1,

FIG. 3 diagrammatically illustrates waveguide apparatus in accordance with this invention, and

FIG. 4 is a fragmentary isometric view of part of the apparatus of FIG. 3.

Referring to FIGS. 1 and 2 of the drawings, **10** is a waveguide having a microwave generator **12** coupled to an end thereof. Slots **13** in the waveguide are arranged so that lumber **14** passing therethrough extends at an angle of 90° to the longitudinal center of the waveguide. microwave energy P1 is directed through the waveguide against an edge of lumber **14**. Reflected microwave energy P2 is directed back through the waveguide to the generator. P3 represents the microwave energy absorbed in the wood, and P4 is the energy that is transmitted through and beyond the wood.

The reflected power P2 travels back to the microwave generator where it causes a temperature rise and also interfers with normal operation of the generator. This represents a great waste of power, and the generator will not function very long under these conditions. As stated above, up to 60% of the power can be reflected by wet lumber, and up to 20% by dry lumber.

FIGS. 3 and 4 illustrate waveguide apparatus **20** incorporating the present invention. This apparatus includes a set of waveguides or arms **23** and **24** extending parallel to each other, and a 4-port hybrid **26** coupling these waveguides to a microwave generator **28**. The waveguide **23** has a general longitudinal centerline **30** which is parallel to longitudinal centerline **31** of waveguide **24**. Sections **23** and **24** of the waveguide system have slots **35** and **36** therein arranged, see FIG. 4, so that the path of travel of lumber **38** through these slots is at an angle of less than 90° to the centerlines **30** and **31**, as indicated at **40** in FIG. 3. Although any angle less than 90° can be used,

it has been found that the best results are obtained by using an angle of from 35 to 55°.

Hybrid **26** is formed with a central section **44**, and a first pair of arms **46** and **47** project from one end of said central section at an agle to each other and which are coupled to the waveguides **23** and **24** respectively. A second pair of arms **49** and **50** project from the opposite end of the central section of the hybrid and at an angle to each other. These arms **46**, **47**, **49** and **50** constitute the ports **2**, **3**, **1** and **4**, respectively, of the hybrid. The microwave generator **28** is coupled to arm **49** so that microwave energy therefrom is directed equally through arms **46** and **47** of the hybrid against the lumber **38** travelling along the inclined path through waveguide slots **35** and **36**. It is preferable to provide a microwave reflector or reflection plate **53** at the end of hybrid arm **50**, although a suitable water load, indicated at **55**, may be provided instead.

Microwave energy or power P1 from generator **28** is divided in hybrid **26** equally between arms **46** and **47** as P5 and P6. The energy is directed against the inclined edge of lumber **38**. The crossing of the longitudinal centerline of the hybrid from arm **49** to arm **47** gives an automatic 90° phase shift to P6. The power P7 reflected by the lumber in waveguide section **24** is divided in the hybrid, and P8, which is one half of P7, enters arm **50**. The other half of P7 crosses the centerline and moves towards arm **49**. This crossing of the centerline imparts an additional phase shift of 90° to the power directed towards arm **49** so that it now has a 180° phase shift from the original power. At the same time, reflected power P9 in waveguide section **23** is divided in the hybrid, with half directed towards arm **49**. As this is 180° out of phase with the part of power P7 directed towards said arm, propagation in arm **49** is prohibited. The only place to go for this energy is arm **50** where it will reinforce the half being directed to arm **50** since they are in phase with each other. The remainder of P9 which crosses over in the center of the hybrid enters arm **50**. The parts of P7 entering arm **50** retains its original phase shift, while the portion of P9 crossing over in the hybrid has a 90° phase shift. There are now two electromagnetic waves of equal power and of identical phase in arm **50** which reinforce each other and travel as one wave. Therefore all the reflected power will travel towards arm **50**.

If water load **55** is used, the power in arm **50** is absorbed and lost to this apparatus. However, it is preferable to use the reflector **53**, which reflects this power back through the hybrid. This second reflected power is directed against the edge of the lumber and the power reflected from the latter is subjected to the same conditions in the hybrid as the original reflected power, with the exception that the power reflected the second time by the lumber is directed towards the microwave generator, but it is so small that it is not worth considering, and the microwave generator does not need protection against it. For example, if 7% of the original power is reflected by the board, because of the angle of the board relative to this power, 7% of the original power is reflected by reflector **53** and when this comes up against the board again, only 7% of that or approximately .5% of the original power is reflected again.

If desired, an auxiliary wavelength system can be connected to arm **50** of hybrid **26** instead of water load **55** or reflector **53**, so as to use the reflected power for drying purposes.

The combination of a 4-port hybrid, parallel waveguides and angled lumber flow has the advantages that the microwave generator is protected against reflected microwave energy, and practically all of the generated power is directed to and into the lumber. In the first instance approximately 93% of the power enters the lumber, and approximately 93% of the reflected power directed back to the wood enters the latter. Another advantage of this apparatus is that an auxiliary waveguide system may be connected by hybrid arm **50** in place of reflector **53** so that the original power reflected by the wood in waveguides **23** and **24** would be utilized in this auxiliary system.

What is claimed is:

1. Waveguide apparatus for drying moisture-laden dielectric material by microwave energy, comprising a set of parallel waveguides each having longitudinal centerline, a microwave generator coupled to the waveguides, slots in said waveguides through which material to be dried can pass to be exposed to microwave energy from the generator, said slots being arranged so that the path of travel of the material is at an angle of less than 90° to said centerline, and stop means between the generator and the waveguides for preventing microwave energy reflected by the material from reaching the generator.

2. Waveguide apparatus as claimed in claim **1** in which said stop means is a 4-port hybrid which acts as coupling means between the microwave generator and said waveguides.

3. Waveguide apparatus as claimed in claim **2** including microwave energy absorption means coupled to one of the ports of said hybrid.

4. Waveguide apparatus as claimed in claim **2** including a reflector coupled to one of the ports of said hybrid for reflecting microwave energy back to said waveguides.

5. Waveguide apparatus comprising a hybrid having a common central section and a longitudinal centerline, a first pair of arms projecting from one end of the central section on opposite sides of the centerline, waveguides coupled to the first pair of arms, a second pair of arms projecting from an opposite end of the central section on opposite sides of the hybrid centerline, a microwave generator coupled to one arm of said second pair of arms so that microwave energy therefrom is directed through both of the arms of the first pair, and slots in said waveguides through which material to be dried can pass to be exposed to said microwave energy, said slots being arranged so that the path of travel of the materital is at an angle of less than 90° to said centerline.

6. Waveguide apparatus as claimed in claim **5** including microwave energy absorption means coupled to the other arm of said second pair of arms.

7. Waveguide apparatus as claimed in claim **5** including a reflector coupled to the other arm of said second pair of arms for reflecting microwave energy back through said arms of the first pair of arms.

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U.S. Cl. X.R.

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