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SLOTTED WAVEGUIDE APPLICATOR

Filed April 28, 1967

2 Sheets-Sheet 1

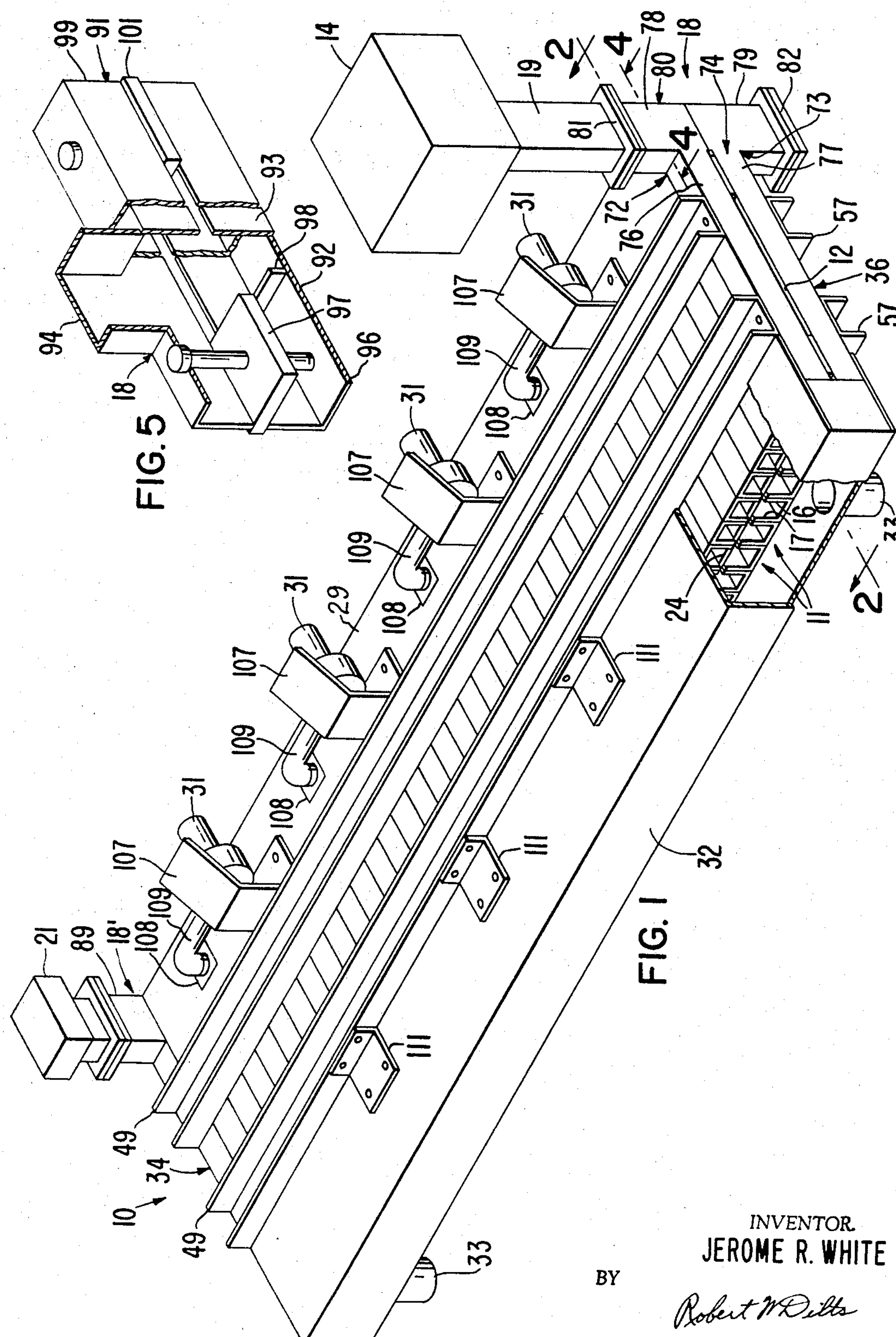

FIG. 5

FIG. 1

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SLOTTED WAVEGUIDE APPLICATOR

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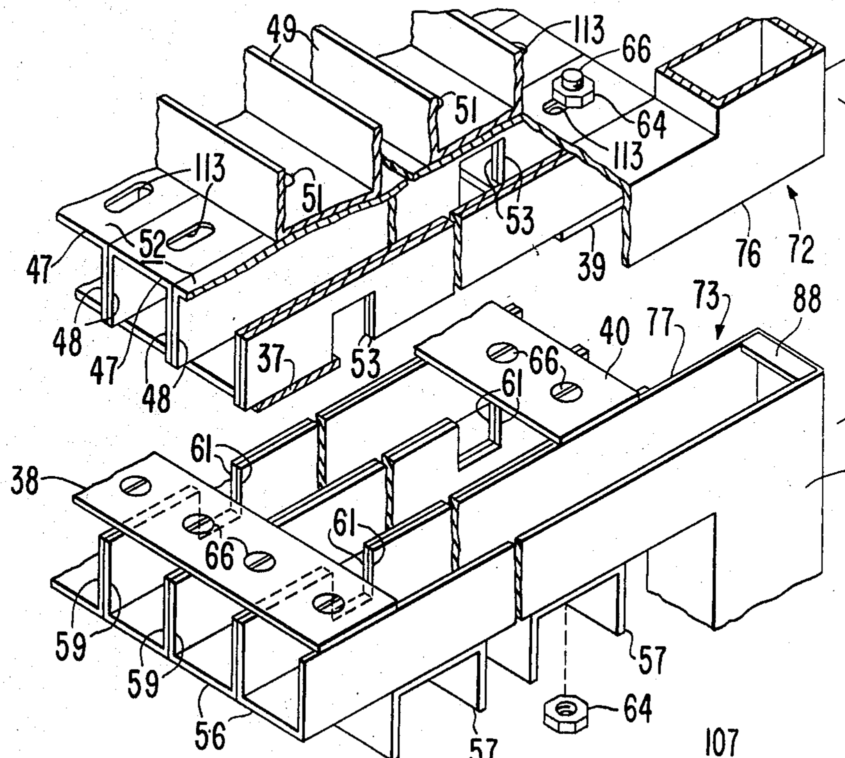

FIG. 3

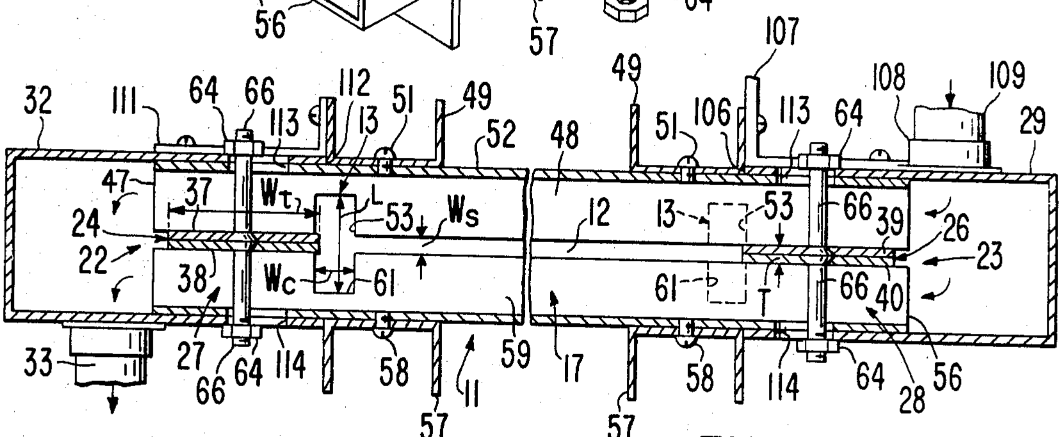

FIG. 2

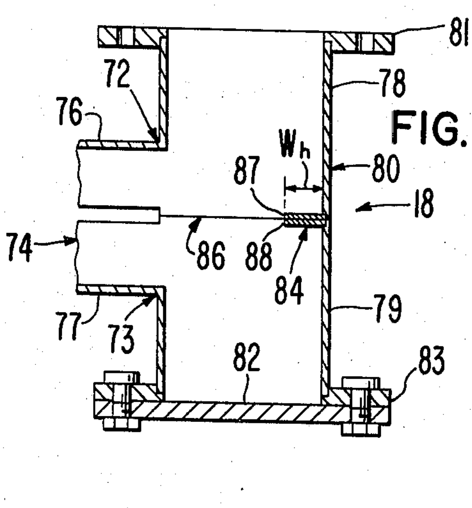

FIG. 4

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3,471,672
SLOTTED WAVEGUIDE APPLICATOR

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U.S. Cl. 219—10.55 21 Claims

ABSTRACT OF THE DISCLOSURE

The slotted waveguide applicator includes two sets of open-ended U-shaped half waveguides with the half waveguides of each set parallelly aligned. The sets of half waveguides are mounted spaced apart to define contiguous slotted wide walls. Notches are provided in the contiguous arms of each half waveguide to define coupling holes inwardly displaced from opposite ends of the waveguides. A thin conductive strip is fastened at each end of the waveguides to extend through slots defined by the spaced apart half waveguide sets between each of the ends of the waveguides and the notches in their arm. An inlet air plenum is provided at one side of the applicator to direct air through the open ends of the applicator while an exhaust duct is provided at the opposite side to convey away the circulated air. Means for coupling the applicator to a source of electromagnetic energy and to a water load comprising an H-plane T-junction are also disclosed.

BACKGROUND OF INVENTION

The present invention relates generally to slotted waveguide microwave heating devices, and more particularly, to a serpentine type microwave heating device.

Slotted waveguide type microwave heating devices or applicators commonly are employed to heat a workpiece under continuous-flow feed conditions. In most applications, a plurality of slotted waveguide sections are joined to define a serpentine path for electromagnetic wave energy for heating the workpiece as it is passed through each waveguide section. In such applicators, the workpiece to be heated is passed through the waveguide section with its surfaces parallel to the electric field component of the electromagnetic field established therein. Contrary to most other types of applicators, slotted waveguide type applicators can be excited to present a uniform electromagnetic field distribution to workpieces substantially larger than the wavelength of the applied energy.

Unfortunately, however, the prior art serpentine applicators have limitations which have made them unsuitable for many industrial applications. For example, electromagnetic wave energy coupled to the workpiece being heated is maximized by minimizing undesirable wave reflections within the waveguide structure. To minimize the formation of such reflections within the waveguide structure, it has been the practice to form the serpentine microwave path with U-shaped waveguide bends connecting the ends of straight waveguide sections. However, such structures require considerably more space than the actual working space in which the workpiece is exposed to the electromagnetic waves. Moreover, even in such structures, effective suppression of undesirable wave reflections often is complicated by differences in the dielctric constants of different workpieces and by changes which take place in th dielectric constant of the workpiece as it is being heated. Generally, such variations in the dielectric constant have been compensated for by employing common adjustable impedance matching devices at selected locations along the serpentine path.

Another limitation common to prior art serpentine applicators is the difficulty of providing access to its interior during operation in order to circulate air therethrough or to view the interior. The difficulty of providing the desired access is due to the necessity of constructing the applicators to prevent the escape of hazardous microwave energy to its surroundings. Hence, in prior art applicators, only limited viewing through screen meshes and the like has been possible. Furthermore, air circulation has been obtained only through the use of either complex non-microwave propogating air circulating systems or powerful air pumps for overcoming the high air flow impedance presented by the microwave shielding of less elaborate air circulating systems.

Many uses of serpentine applicators require that they be cleaned often. Since the interior of such applicators are closed to the surroundings, it is necessary to disassemble them in order to clean the interior or undertake most other preventative maintenance. Furthermore, the structure of many applicators results in the disassembly and assembly tasks being time-consuming and costly.

SUMMARY OF INVENTION

The present invention is a serpentine type slotted waveguide microwave applicator which includes features which overcome the limitations and resultant disadvantages of the prior art serpentine applicators. More particularly, the microwave applicator of the present invention includes a plurality of adjacently disposed waveguide sections having apertures in their walls for passing a workpiece through the waveguide sections. The waveguide sections are intercoupled through coupling holes in adjacent walls at locations inwardly displaced from the ends of the waveguide sections to define a serpentine path for microwave energy. A conductive member is located between each coupling hole and the proximate end of the waveguide sections to define a short circuit path for the electric field component of the electromagnetic field propagated through the waveguide sections. The conductive member is disposed relative to the associated coupling hole so as to minimize wave reflections at the intercouplings between the waveguide sections. Such a structure provides a simple way of minimizing wave reflections along the entire serpentine path thereby maximizing the electromagnetic wave energy available for heating.

The structure of the applicator of the present invention readily lends itself to being adapted to allow easy access to its interior, e.g., for cleaning or inspecting purposes. Such access can be provided by opening the ends of the waveguide sections. Hazardous microwave energy will be prevented from escaping to the surroundings by constructing the waveguide sections and selecting the microwave frequency so that the conductive members form with the associated waveguide sections waveguide end portions beyond cut off. By providing essentially an unobstructed path through each waveguide section, the interior of each waveguide section can be observed during operation, simple systems can be employed to circulate air or other gaseous medium through the applicator, and some preventative maintenance can be performed without disassembling the applicator.

Furthermore, the unique technique of intercoupling the waveguide sections of the applicator of the present invention facilitates constructing a compact applicator which easily can be manufactured and repeatedly assembled and disassembled. These features are realized by forming the waveguide sections from first and second sets of identical half sections of waveguides arranged in a parallel array with adjacent walls contiguous and with the half sections of each set fixed together and demountable from those of the other set as a unit.

Accordingly, it is an object of this invention to provide a serpentine type microwave applicator formed from a plurality of waveguide sections intercoupled with a minimum of wave reflection.

More particularly, it is an object of this invention to provide a serpentine type microwave applicator formed from a plurality of intercoupled waveguide sections wherein the coupling between the waveguide sections can be adjusted to control the electromagnetic energy transmission therebetween.

Another object of this invention is to provide a compact serpentine type microwave applicator.

It is a further object of this invention to provide a serpentine type microwave applicator which can be easily assembly and disassembled.

Still another object of this invention is to provide a serpentine type microwave applicator of a configuration permitting easy access to its interior during operation without radiating radio frequency interfering and hazardous electromagnetic energy to its surroundings.

Yet a further object of this invention is to provide a serpentine type microwave applicator through which air or other gaseous medium easily can be circulated.

Yet another object of this invention is to provide a serpentine type microwave applicator of modular construction permitting the construction of an applicator of any selected length.

BRIEF DESCRIPTION OF DRAWINGS

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

FIGURE 1 is a perspective view of a microwave applicator according to the present invention.

FIGURE 2 is a cross sectional view of the applicator taken along lines 2—2 of FIGURE 1.

FIGURE 3 is an exploded perspective view of a portion of the applicator of FIGURE 1.

FIGURE 4 is a cross sectional view of the T-junction taken along lines 4—4 of FIGURE 1.

FIGURE 5 is a partially broken perspective view portraying an alternate way of mounting the T-junction of FIGURE 4 to a waveguide.

With reference to FIGURES 1–2, the slotted waveguide applicator **10** includes a plurality of waveguides **11** having apertures such as slots **12** for passing a workpiece through the waveguide. The waveguides **11** are intercoupled in series through coupling holes **13** to define a serpentine path for electromagnetic energy provided by source **14**. To minimize power losses through radiation, the width W_S of the slot apertures **12** should be no greater than is necessary to allow easy transport of the workpiece, and preferably, no greater than one-third the distance between the slot apertures of one waveguide **11**.

A uniform electric field intensity is desired in the vicinity of the workpiece so that it may be uniformly heated. Such a field can be realized by, for example, employing rectangular waveguides **11** with slots **12** provided in opposite wide walls **16** and **17** which is excited to propagate TE_{10} waves having an electric field component normal to the wide walls. In accordance with standard practice, slots **12** are located in the center of the wide walls **16** and **17** to minimize leakage and to maximize the energy coupled to the workpiece.

Any of the common microwave guiding structures can be employed to couple electromagnetic energy from the source **14** to excite the intercoupled waveguides **11**. Furthermore, the applicator **10** can be excited at any point of intercoupled waveguides **11**. In the applicator **10** illustrated in the drawings, a unique H-plane T-junction waveguide structure **18**, shown in detail in FIGURE 4, is employed to couple the applicator **10** to a waveguide transmission line **19** from source **14**. As will be explained in greater detail hereinbelow, the unique H-plane T-junction **18** of FIGURE 4 can provide essentially reflectionless power transfer from the waveguide **19** to the waveguide **11** of the plurality of intercoupled waveguides.

The slotted waveguide applicator **10** can be operated either as a standing-wave or as a traveling-wave applicator, the mode of operation depending upon how the applicator is terminated. In either operating mode, the required termination should be constructed to operate with the applicator **10** energized in the presence of a workpiece. By terminating the end waveguide or waveguides **11** of the intercoupled waveguides in a reflectionless dissipative load **21**, the applicator **10** is operated as a transmission line type traveling-wave applicator. The load **21** can be coupled to the applicator **10** by another H-plane T-junction waveguide structure **18'** constructed like the H-plane T-junction **18**.

Pursuant to the present invention, the coupling holes **13** are located inwardly from the ends **22** and **23** of the waveguides **11**. To control coupling between successive waveguides **11**, conductive members **24** and **26** are positioned respectively in the waveguide sections **27** and **28** of waveguides **11** defined between coupling holes **13** and each of the waveguide ends **22** and **23**. The conductive members **24** and **26** are constructed and positioned in the waveguide sections **27** and **28** to define a short-circuit path for the electric field component of the electromagnetic field propagated through the waveguide sections **11**. To minimize reflections at the coupling holes **13** intercoupling successive waveguides **11**, each of the conductive members **24** or **26** in the successive waveguides is constructed and positioned relative to its associated coupling hole **13** for minimum power reflection. The position for such a condition can be determined by standard empirical power reflection measuring techniques.

The structure of this waveguide intercoupling arrangement enables each waveguide **11** of the applicator to be open to the surroundings thereby providing easy access to any part of the interior of the applicator, even during operation. More particularly, by constructing the waveguide sections **27** and **28** and conductive members **24** and **26** and locating the conductive members **24** and **26** in the waveguide sections so that the sections are waveguides beyond cutoff at the wavelength of the applied energy, electromagnetic energy at a wavelength equal to or greater than that of the applied energy will not be freely transmitted by the waveguide sections **27** and **28**. Hence, the ends **22** and **23** of waveguides **11** can be opened to the surroundings of applicator **10** without radiating hazardous or undesirable electromagnetic energy to its surroundings unless higher order modes are present in the excited waveguides **11**. However, by proper choice of the dimensions of the waveguides **11** with respect to the frequency of the applied energy, free transmission of the dominant mode can be allowed through the waveguides **11** while that of the higher order modes is impeded. If the higher order modes also are prevented from being freely transmitted through the waveguide sections **27** and **28**, the applicator **10** will not radiate any significant electromagnetic energy to its surrounding through its open waveguide ends **22** and **23**. Effective suppression of hazardous and undesirable electromagnetic energy radiation can be realized by constructing the waveguides **11** to have a cross section dimension so that the free space cutoff wavelength of the dominant mode is greater than the free space operating wavelength and the free space cutoff wavelength of the next higher mode is less than the free space wavelength of the operating mode. With the cross sectional dimensions of the waveguides **11** adjusted in accordance with these limitations and the applicator **10** excited with electromagnetic energy at a frequency higher than the cutoff frequency of the dominant mode but lower than the cutoff frequency of the next higher mode, the waveguides **11** will not support the free transmission of higher order modes.

By constructing the applicator **10** with open-ended waveguides **11**, and thereby providing easy access to the interior, it is possible to inspect its interior during operation, perform maintenance on the applicator without disassembling it, and in general gain access to the interior for any purpose for which access is desirable. But of great importance, such a construction facilitates circulating air or other gaseous medium through the applicator 10 during operation. For example, to circulate air through the applicator 10, the open ends 23 of the waveguides 11 along one side of the applicator could be inserted into an inlet plenum 29 suitably coupled to one or more air pumps 31 as the case may require to convey away the circulated air, the open ends 22 of the waveguides 11 along the other side of the applicator 10 could be inserted into an exhaust duct 32 coupled to exhaust ports 33.

Of the various waveguide configurations, rectangular waveguides are particularly convenient to use for constructing the applicator 10 of the present invention. In one embodiment of such an applicator, the rectangular waveguides 11 are parallelly aligned to have adjacent wide walls 16 and 17 which define centrally located longitudinal slots 12 and the coupling holes 13. The parallel waveguides 11 are arranged so that slots 12 and coupling holes 13 between the adjacent waveguides 11 are registered. To obtain the most compact applicator structure, the waveguides 11 are disposed with adjacent wide walls 16 and 17 of adjacent waveguides contiguous. If desired, the compact applicator structure could be constructed so that adjacent waveguides 11 share a common interpositioned wide wall. The conductive members 24 and 26 are strips in electrical contact with and extending between the centers of the wide walls 16 and 17 in the waveguide sections 27 and 28 of each waveguide 11. The conductive member 24 and the conductive member 26 located in each waveguide 11 can be separate from those in the other waveguides or can form part of an integral longitudinal member extending through a plurality or all of the waveguides 11. In any of these configurations, the amount of electromagnetic energy escaping from the waveguide ends 22 and 23 will be minimized by constructing the conductive members 24 and 26 to have a thickness, T of at least two skin depths and a width W_t of at least $\lambda/4$. For a given waveguide construction, the width W_t of the conductive members required to reduce the escaping radiation to an insignificant level will vary in accordance with the input power, with a width W_t of $4/\lambda$ being effective at any power level presently practical for microwave heating. For example, for an input power of about 2.5 kilowatts, it has been found that in the above-described waveguide configuration, the escaping radiation can be reduced to a level considerably less than 10 milliwatts (mw) per square centimeters ($cm.^2$), the accepted standard for a non-hazardous condition, by using conductive members 24 and 26 having a $T=\lambda/25$ and a $W_t=3/4$.

Towards ease of manufacturing, ease of repeated assembling and disassembling, and ease of maintenance, it is contemplated that a preferred embodiment of the applicator 10 of the present invention will be constructed from first and second sets 34 and 36 of identical half sectins of parallel waveguides arranged with adjacent walls contiguous. The half sections of waveguides of each of the sets 34 and 36 are fixed together and demountable as a unit from those of the other set.

Referring now to FIGURES 1–3 in detail, the particular preferred embodiment of the applicator 10 includes a first set 34 of rectangular U-shaped open-ended half waveguides 47 parallelly disposed with adjacent arms 48 of adjacent half waveguides 47 contiguous. The half waveguides 47 are secured in place by fastening them to two parallelly extending U-shaped channels 49, for example, with screws 51 threadingly engaging the half waveguide web portions 52. Each of the contiguous arms 48 of the half waveguides 47 define a rectangular U-shaped notch 53 inwardly spaced from the end of the half waveguides, with the notches 53 in contiguous arms 48 registered. The notches 53 of successive contiguous arms 48 are located inwardly from opposite ends of the half waveguides 47 whereby the notches of alternate contiguous arms are registered.

The applicator 10 is completed by mounting an identical second set 36 of rectangular U-shaped open-ended half waveguides 56 spaced below the first set 34 to define the slots 12 for passing a workpiece through the applicator. The half waveguides 56 of the second set 36 are secured in place to two U-shaped channels 57 by, for example, screws 58 to coextend with the half waveguides 47 of the first set 34. The arms 59 of the half waveguides 56 define rectangular U-shaped notches 61 which are aligned over the notches 53 of the half waveguides 47 of the first set 34 when the applicator 10 is assembled.

To maintain the desired coupling between all of the waveguides 11 and prevent the escape of undesirable electromagnetic energy from the open ends 22 and 23 of the waveguides 11, each of the half waveguides 47 and 56 of the waveguides should be in good electrical connection with the conductive members 24 and 26. To insure that good electrical connection is maintained between the conductive members 24 and 26 and the half waveguides 47 and 56, each of the conductive members 24 and 26 is formed from a pair of thin conductive strips 37 and 38, and 39 and 40 respectively, longitudinally extending the length of the applicator 10. One of each pair of strips, e.g., 37 and 39, are fastened by nuts 64 and bolts 66 to each of the half waveguides 47 of the first set 34, and the other strips 38 and 40 of each pair are fastened by nuts 64 and bolts 66 to each of the half waveguides 56 of the second set 36. The conductive strips are fastened by the nuts 64 and bolts 66 to press firmly against the half waveguide arms 48 and 59 and thereby form good electrical contacts therebetween.

When the applicator 10 is assembled, the half waveguides 47 and 56 define the plurality of open-ended slotted waveguides 11 with the end waveguide sections 27 and 28 of each waveguide 11 and conductive strips 37–40 forming waveguide sections 27, 28 beyond cutoff. It should be noted that in those cases where the first and second sets 34 and 36 of half waveguides 47 and 56 are spaced so that the pairs of conductive strips forming conductive members 24 and 26 do not touch, the portion of the half waveguides 47 and 56 defining the end waveguide sections 27 and 28 and the conductive strips 37–40 will form at each end of the waveguides 11 two spaced apart waveguides beyond cutoff and the space therebetween will form an extension of the non-radiating slots 12.

The U-shaped notches 53 and 61 of the assembled half waveguides form a rectangular microwave coupling hole 13 in the contiguous walls of adjacent waveguides 11. To obtain a transfer of power between adjacent waveguides 11 with a minimum of reflected power, the length L and width W_c of each of the coupling holes 13 and the location of the pairs of proximate conductive strips 37–40 relative to the coupling holes must be selected accordingly. Each of these parameters have a different effect on the power transfer characteristics between adjacent waveguides 11 and will have a best setting for any setting of the other parameters. The length L determines frequency at which power is transferred with minimum reflection. The width W_c determines the bandwidth at which power is transferred with minimum reflection. The location of the proximate pair of conductive strips 37–40 relative to the coupling hole 13 determines the degree of coupling between adjacent waveguides 11, i.e., the amount of power reflected at the coupling holes 13. The proper selection of these parameters can be determined by common empirical techniques of adjusting the length and width dimension of the coupling holes 13 and the location of the proximate pair of conductive strips 37–40 while monitoring the waveguide for reflected power.

As noted hereinbefore, the dielectric constant of the workpiece being heated influences the proper setting of the parameters for minimizing power reflections at the coupling hole 13. Furthermore, during heating the dielectric constant of the workpiece will change, hence be different at different locations along the applicator 10. The tendency of such variations in the dielectric constant of the workpiece to cause undesirable reflections can be overcome by adjusting the location of each of the pairs of conductive strips 37–40 relative to the proximate coupling hole 13. As noted hereinbefore, this can be accomplished by dividing each of the conductive strips 37–40 into a plurality of shorter members, for example, one for each slotted waveguide 11, and adjusting each pair relative to the proximate coupling hole 13 to minimize reflections. However, it has been found that the undesirable reflections can be reduced to an insignificant level by locating the pairs of conductive strips 37–40 so that their respective edges most proximate the coupling holes 13 are inclined towards the center line of the applicator 10. By proper adjustment of the angle of inclination, the power reflected at the coupling holes and along the edges of the workpiece can be minimized.

For practical considerations, it is preferred to couple electromagnetic energy to the applicator 10 by a waveguide type microwave guiding structure 18. In order to be able to disassemble the applicator 10 without having to disconnect the electromagnetic energy source 14 therefrom, the unique H-plane T-junction structure 18, shown in detail in FIGURE 4, is employed to couple energy to the applicator 10. More specifically, in one embodiment, the H-plane T-junction structure 18 is formed of demountable L-shaped half sections 72 and 73. The side arm 74 of the T-junction 18 is defined by half waveguide extensions 76 and 77 of the half waveguides 47 and 56 of the first waveguide 11 of the serially coupled waveguides forming the applicator 10. The half waveguide extensions 76 and 77 extend from the end of the first waveguide 11 distal the rectangular coupling hole 13. The waveguide extensions 76 and 77 are integrally joined respectively to flanged waveguide sections 78 and 79 which when assembled form the main transmission line portion 80 of the H-plane T-junction 18.

In operation, the electromagnetic energy source 14 is coupled, for example, to the flanged waveguide section 78 by the waveguide transmission line 19 connected to the flange 81. The other flanged waveguide section 79 is terminated with short-circuit termination 82 joined to the flange 83. The short-circuit termination 82 cooperates with an inductive window 84 located at the junction 86 of the main transmission line 80 and side arm 74 to cause all of the energy supplied by the source 14 to be coupled into the side arm 74, hence, the applicator 10. As in the case of the conductive members 24 and 26, inductive window 84 can include two plates 87 and 88 each fastened at opposing locations of the flanged waveguide sections 78 and 79 to provide good electrical connection between the inductive window 84 and sections of the main transmission line 80.

In order to excite the waveguide 11 from one end as described immediately above, the pair of conductive strips 39 and 40 are positioned so as not to extend between the half waveguides 47 and 54 defining the waveguide 11 to which the source 14 is coupled.

To protect against the generation of damaging reflections and to dissipate unabsorbed power transmitted through the applicator 10, the open end of the last waveguide 11 of the structure distal its rectangular coupling hole 13 is joined to the H-plane T-junction microwave feed 18′ which is identical to the H-plane T-junction 18. One end of its main transmission line 89 is joined to a standard water type dissipative load 21. The other end (not shown) of the main transmission line 89 is shorted to cooperate with an inductive window (not shown) to prevent reflections in the same manner as the corresponding elements of H-plane T-junction 18. Furthermore, the pairs of conductive strips 39 and 40 are positioned so as not to extend between the half waveguides 47 and 54 defining the waveguide section 11 to which the water load 21 is coupled.

With particular reference to FIGURE 5, an alternate arrangement for coupling microwave energy to a waveguide 91 with the unique H-plane T-junction structure 18 is shown. In this embodiment, the main transmission line portion 92 of the T-junction 18 is coupled at one end 93 in line with the waveguide 91 with the side arm 94 coupled to the source (not shown). The other end 96 of the main transmission line 92 is provided with a conductive member 97 positioned in the main transmission line 92 to define a short circuit path for the electric field component of the electromagnetic field propagated into the waveguide 91. An inductive window 98 is located opposite the side arm 94 and cooperates with the short circuit forming conductive member 97 to provide essentially reflectionless power transfer from the side arm 94 to the waveguide 91. This arrangement for coupling electromagnetic energy to a waveguide with the unique H-plane T-junction 18 of FIGURE 4 would be preferred when it is desirable to circulate a gaseous medium through all parts of a waveguide applicator. To establish an air flow through one slotted waveguide without radiating undesirable electromagnetic energy to its surroundings, the end 99 of the waveguide 91 distal T-junction 18 would be opened and provided with a second short circuit forming conductive member 101.

Referring again to FIGURES 1 and 2, the inlet plenum 29 for circulating air or other gaseous medium through the waveguides 11 of applicator 10 is a rectangular enclosure having an open side 106 mounted by brackets 107 to the U-shaped channels 49. The open side 106 receives the open ends 23 defined by the assembled half waveguides 47 and 54. Brackets 107 also serve to support the air pumps 31. Air is delivered to the plenum 29 through inlet ports 108 coupled to the air pumps 31 by conduits 109. A rectangular exhaust duct 32 is secured by brackets 111 to the U-shaped channel 49 to convey away the circulated air. The exhaust duct 32 has an open side 112 to receive the open ends 22 defined by the assembled half waveguides 47 and 54 and collect the circulated air therefrom for exhausting through the exhaust ports 33.

In one embodiment constructed to heat thin wide moistened paper sheets under continuous-flow feed conditions, electromagnetic energy source 14 was operated at 2,440 megacycles to deliver about 2,500 watts of power. Each set 34 and 36 included forty-two half waveguides 18 inches long having inside dimensions of about 1¾ inches wide and 1½ inches high to define when assembled forty-two slotted waveguides 11 having a width of 3$^{11}/_{16}$ inches and a height of 1½ inches with slots 12 of a width of $^{3}/_{16}$ inch and a length of 10 inches. The rectangular coupling holes 13 measured 1 inch wide and 2$^{9}/_{16}$ inches long and were located inward 4 inches from the open ends of the waveguides 11. By empirical methods, it was found that by constructing each of the pairs of conductive strips 37–40 to be $^{3}/_{32}$ inch thick and 4 inches wide, and by locating them to extend $^{5}/_{16}$ of an inch into the rectangular coupling hole 13 at the source end of the applicator 10 and ⅜ of an inch into the rectangular coupling hole 13 at the water load end, coupling between adjacent waveguides 11 was obtained throughout the applicator 10 with reflected power reduced to an insignificant level. To enable the adjustment of the position of the conductive strips 37–40, elongated apertures 113 and 114 could be provided in the open-ended waveguides 47 and 56 through which bolts 66 are passed. The proper position of strips 37–40 can be determined by the standard techniques of measuring the amount of reflected power which is present in the waveguides 11. When the reflected power is reduced to an insignificant level, strips 37–40 are positioned correctly.

Referring to FIGURE 4, the unique H-plane T-junction structure 18 which is able to couple all the power entering the junction 86 between one end of the main transmission line 80 and the side arm 74 is illustrated in detail.

As noted hereinbefore, when such a T-junction is employed to couple power into and terminate the microwave heating device of the present invention, assembly and disassembly of the device is greatly simplified. Furthermore, such a microwave guiding structure can greatly facilitate the mass production of the microwave heating structure since both sets **34** and **36** of half waveguides will be identical from input to output. More specifically, the total power transfer between the waveguide section **78** of the main transmission line **80** and the side arm **74** is accomplished by selecting an inductive window **84** of proper width W_h and by positioning the shorting plate **82** the proper distance from the junction **86**. The width W_h determines the degree of coupling between the side arm **74** and main transmission line **80**, and the distance between the shorting plate **82** and junction **86** determines the frequency at which power is transferred with minimum reflection with a proper choice of the width of the inductive window **84** and of the distance that the shorting is located from junction **86**, the normalized impedance of the T-junction **43** will equal $1+jo$. In this condition the voltage standing wave ratio (VSWR) will be unity. Hence, for a given microwave frequency and given size H-plane T-junction **18**, the proper inductive window **84** and location of shorting plate **82** can be determined by monitoring the VSWR as the width W_h window **84** and location of shorting plate **82** is varied. When the VSWR approaches unity, the reflected power approaches zero. The width W_h and the location of the shorting plate **82** is adjusted until the VSWR indicates that power is transferred between the waveguide section **78** and side arm **74** with an insignificant amount of reflection. In the aforedescribed specific embodiment, the width W_h of the inductive window **84** was **43** will equal $1+jo$. In this condition the voltage standing 1.0 inch, and the shorting plate **82** was located 7¾ inches from the junction **86**.

Although an asymmetrical type inductive window structure is illustrated in the figures, with a proper choice of the window size and location of the shorting plate **82** relative to junction **86**, it is possible to employ symmtrical inductive windows or combinations of capacitive and inductive windows to form an H-plane T-junction **18** in accordance with the present invention.

From the foregoing description, it is seen that a simple slotted waveguide applicator **10** can include any number of identical waveguides **11** to form an exceedingly compact serpentine type applicator. Furthermore, by constructing the compact applicator **10** from half sections which are the mirror images of one another and which when assembled define connected open-ended waveguides, numerous advantages can be realized which result in a serpentine type applicator structure which is practical for industrial applications. Hence, while the present invention has been described in detail with respect to particular embodiments, it will be apparent that numerous modifications and variations are possible within the spirit and scope of the invention. Hence, the present invention is not intended to be limited except by the terms of the following claims.

What is claimed is:

1. Apparatus for heating a workpiece with electromagnetic energy including an electric field component comprising a plurality of waveguides each having at least two apertures in walls thereof for passing a workpiece therethrough, said waveguides having coupling holes in their walls proximate ends of the waveguides for intercoupling the waveguides to define a serpentine path for the electromagnetic energy coupled from a source into one of said waveguides, and conductive members located in each of said waveguides between the coupling holes and their respective proximate waveguide ends to define a short circuit path for the electric field component of the electromagnetic energy across said waveguides.

2. The apparatus according to claim **1** wherein the proximate ends of said waveguides are open to the exterior of the waveguides, and said conductive members and sections of waveguides defined between the coupling holes and proximate waveguide ends form waveguide portions beyond cutoff.

3. The apparatus according to claim **2** wherein said waveguides are constructed to allow free transmission of only the dominate mode of the electromagnetic energy coupled thereto.

4. The apparatus according to claim **2** further comprising means for circulating a gaseous medium through the open ends of said waveguides.

5. The apparatus according to claim **2** wherein said conductive members are constructed to maintain the level of electromagnetic energy transmitted through the open ends to the exterior of the waveguides below 10 milliwatts per square centimeter.

6. The apparatus according to claim **2** wherein said coupling holes are constructed to have a cross sectional dimension and the conductive members are located relative to the coupling holes for minimum power reflections at the intercouplings between waveguides.

7. The apparatus according to claim **1** wherein said waveguides are parallelly aligned with adjacent waveguides having contiguous adjacent walls, said coupling holes of contiguous adjacent walls are registered, and said apertures for passing workpieces through the waveguides are located in opposite walls of each waveguide with the apertures of all the waveguides registered.

8. The apparatus according to claim **1** wherein said waveguides are rectangular with slot apertures longitudinally extending in opposite wide walls, said interconnected waveguides are adapted to be energized in the TE_{10} mode, and said conductive members are thin conductive plate members extending between and in electrical connection with opposite wide walls of the waveguides.

9. The apparatus according to claim **8** wherein said waveguides are parallelly aligned with adjacent wide walls of adjacent waveguides contiguous, said slot apertures centrally located in said wide walls of each waveguide to be registered with those of the other waveguides and said coupling holes of contiguous adjacent walls are registered.

10. The apparatus according to claim **9** wherein said coupling holes are rectangular of a selected length and width, the length and width of the coupling holes and the location of the conductive members adjusted for minimum power reflection at the coupling holes.

11. The apparatus according to claim **9** wherein said waveguides are defined by demountable identical U-shaped half sections having notches defining the coupling holes and which are mounted spaced apart when assembled to define the slot apertures, and all of said half sections are in electrical connection with the plate members.

12. The apparatus according to claim **11** wherein a conductive plate member is mounted to each half section between the coupling hole defining notch and proximate end to define a waveguide beyond cutoff.

13. The apparatus according to claim **11** wherein the adjacent conductive plate members of each of the U-shaped half sections of waveguide are integrally joined to define longitudinal strips, and said strips are positioned wiht respect to the coupling holes proximate thereto to minimize the total reflection at all of the coupling holes.

14. The apparatus according to claim **13** wherein the U-shaped half sections defining the waveguide at the end of the serpentine path defined by the interconnected waveguides are adapted with means to couple the electromagnetic energy source thereto, and the U-shaped half sections defining the waveguide at the opposite end of the serpentine path adapted with means to terminate the interconnected waveguides.

15. The apparatus according to claim **14** wherein said means for coupling the energy source to the waveguides and said means for terminating the waveguides each is an H-plane T-junction microwave guiding structures having a main transmission line with two ends and a side arm joined together to define a junction, said junction demountable along a plane of side arm bisecting the junction into L-shaped half sections, said side arm joined to the waveguide defined by the U-shaped half sections, one of the ends of the main transmission line of one of the T-junctions adapted for joining to the energy source, one of the ends of the main transmission line of the other T-junction adapted for terminating the interconnected waveguides, a short circuit means joined to the other end of the main transmission line of each T-junction, and an asymmetrical inductive window conducting plate mounted in said main transmission line of each T-junction at the junction opposite the side arm in electrical connection with both L-shaped half sections, the effective reactance of the inductive window and the distance between the junction and the short circuit means of each T-junction adjusted for minimum reflected power from the junction.

16. The apparatus according to claim **15** wherein the inductive window of each of said H-plane T-junction is formed two conducting plates with one joined to each L-shaped half section.

17. The apparatus according to claim **8** further comprising an H-plane T-junction microwave guiding structure having a main transmission line with first and second ends and a side arm joined together to define a junction, a short circuit means joined to one of the transmission line ends, one of the side arm and remaining transmission line ends adapted to be joined to said electromagnetic energy source and the other joined to the open end of one of the waveguides, and an inductive window means disposed in the main transmission line at the junction, the effective reactance of said inductive window means and the distance between the junction and the short circuit means adjusted for minimum reflected power from the junction.

18. The apparatus according to claim **17** wherein said waveguides are defined by demountable identical U-shaped half sections having notches defining the coupling holes and which are mounted spaced apart when assembled to define the slot apertures, all of said half sections are in electrical connection with the plate members, and said H-plane T-junction structure demountable into two sections along a line defined by an extension of said slot apertures.

19. The apparatus according to claim **8** wherein the conductive members are mounted to allow adjustment of their locations between the coupling holes and proximate waveguide ends.

20. The apparatus according to claim **19** further comprising a rectangular waveguide applicator for heating workpieces with electromagnetic energy, one of said side arm and remaining end of the main transmission line joined to said waveguide applicator and the other adapted to be joined to a source of electromagnetic energy.

21. Apparatus for heating a workpiece with electromagnetic energy comprising a waveguide of finite length having cross sectional dimension adapted to enhance propagation of electromagnetic energy in the dominant mode at the operating frequency thereof, said waveguide section having a pair of opposed apertures therein intermediate the end portions hereof disposed in a plane of major extent of the electric field component of said dominant mode for passing a workpiece therethrough; first coupling means for transferring electromagnetic energy into one end portion of said waveguide section; and second coupling means for extracting electromagnetic energy from the other end portion of said waveguide section, characterized in that at least one end of said waveguide is defined by a fully reflecting termination which comprises an open ended waveguide section beyond cutoff at the operating frequency of said apparatus.

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