United States Patent

Bucksbaum

[15] **3,670,134**

[45] **June 13, 1972**

[54] MICROWAVE OVEN NO-LOAD SENSOR

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[22] Filed: **Jan. 26, 1971**

[21] Appl. No.: **109,818**

[52] **U.S. Cl.** **219/10.55,** 333/1.1

[51] **Int. Cl.** **H05b 9/06**

[58] **Field of Search** 219/10.55; 333/24.3, 1.1

[56] **References Cited**

UNITED STATES PATENTS

3,437,777 4/1969 Nagai et al. 219/10.55

Primary Examiner—J. V. Truhe

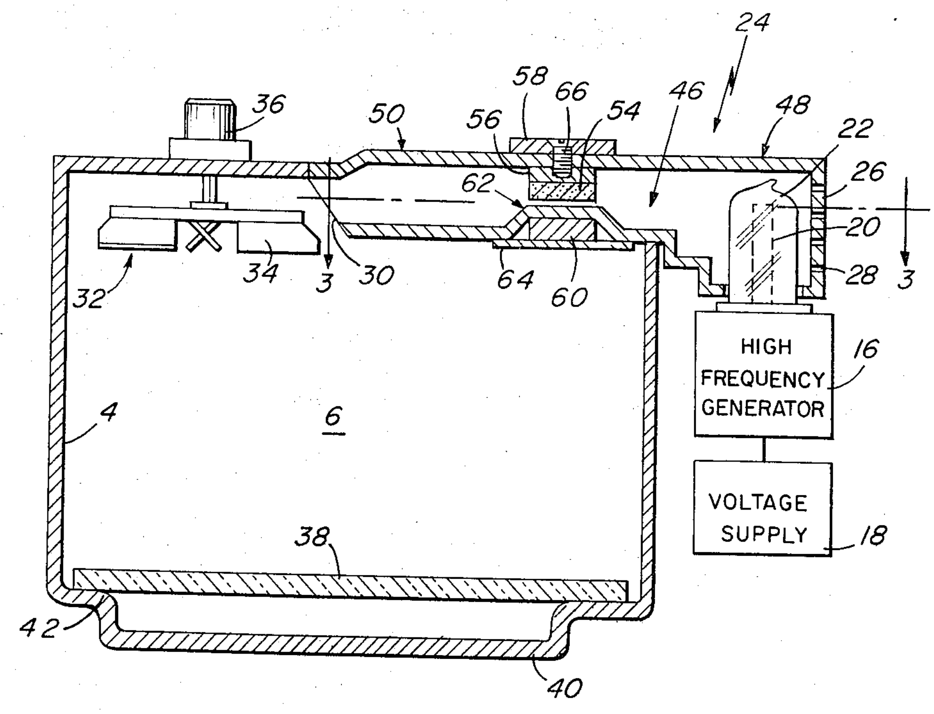
Assistant Examiner—Hugh D. Jaeger

Attorney—Harold A. Murphy

[57] **ABSTRACT**

A no-load sensor is disclosed for protection of the electromagnetic wave energy generator in an electronic heating apparatus including a magnetized body of a ferrimagnetic material disposed within the waveguide launching section. Improved magnetic field producing means include a field concentrator associated with a permanent magnet member. Embodiments are also provided within a waveguide launching section having a reduced cross-sectional area adjacent to the ferrimagnetic body to concentrate propagated electromagnetic waves with a resultant decrease in the material requirements for exciting electron spin action to direct reflected energy from a load to energy absorbing means.

12 Claims, 9 Drawing Figures



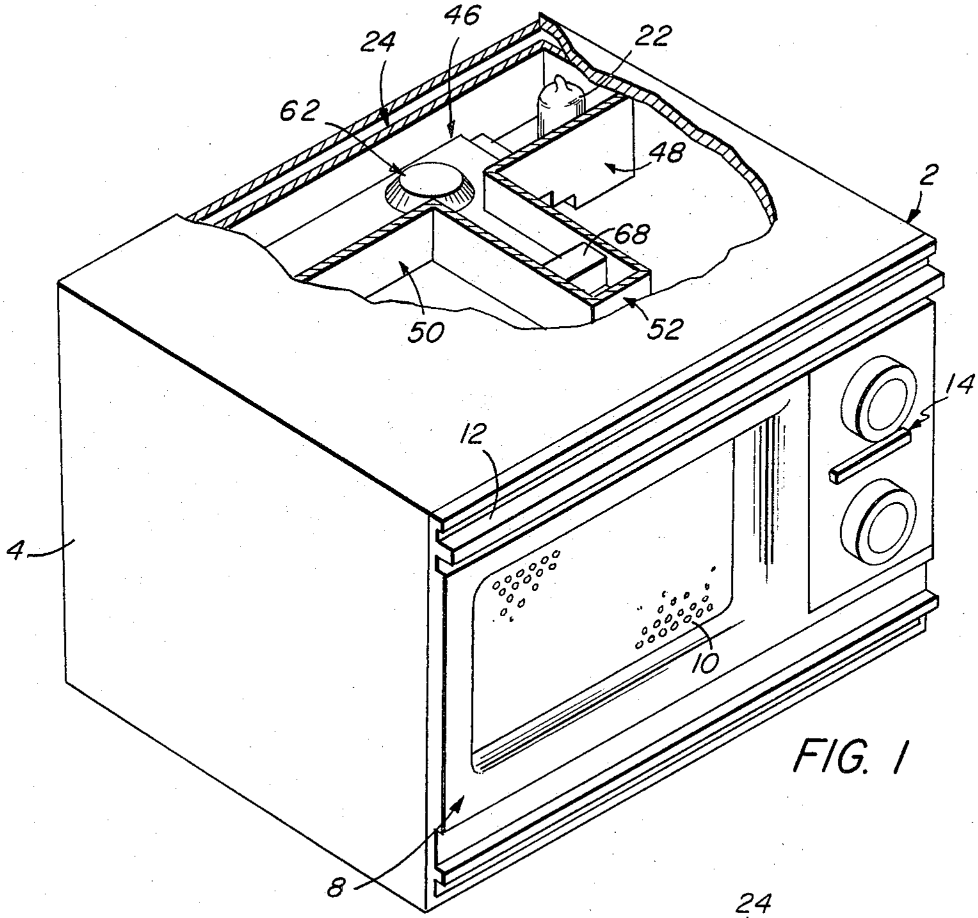

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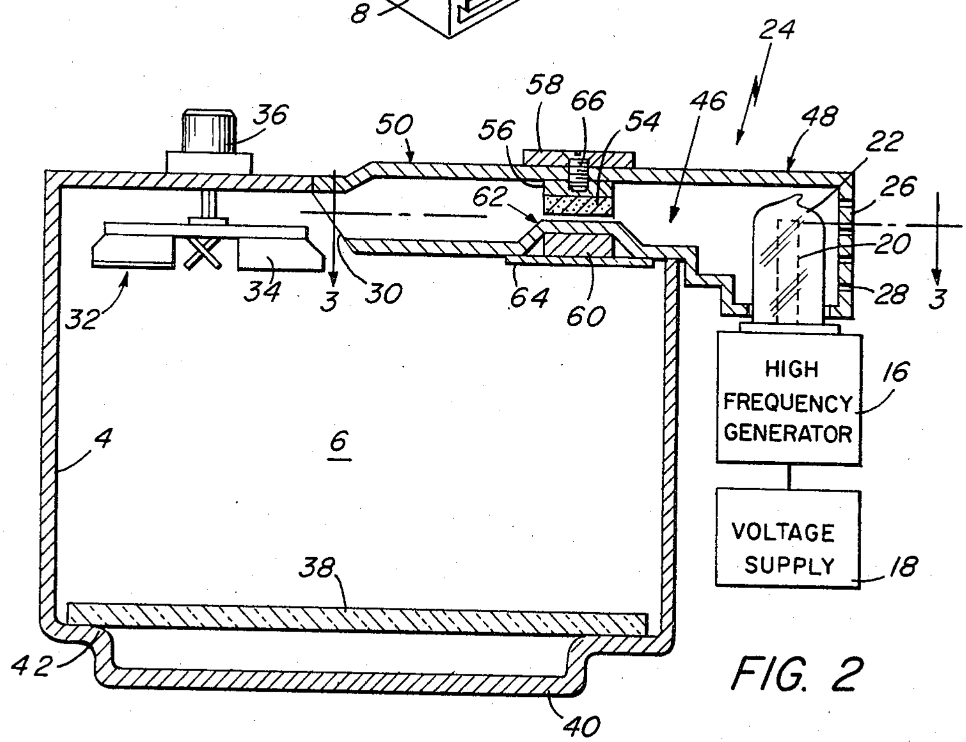
FIG. 1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HIGH FREQUENCY GENERATOR
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VOLTAGE SUPPLY
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38
42
40

FIG. 2

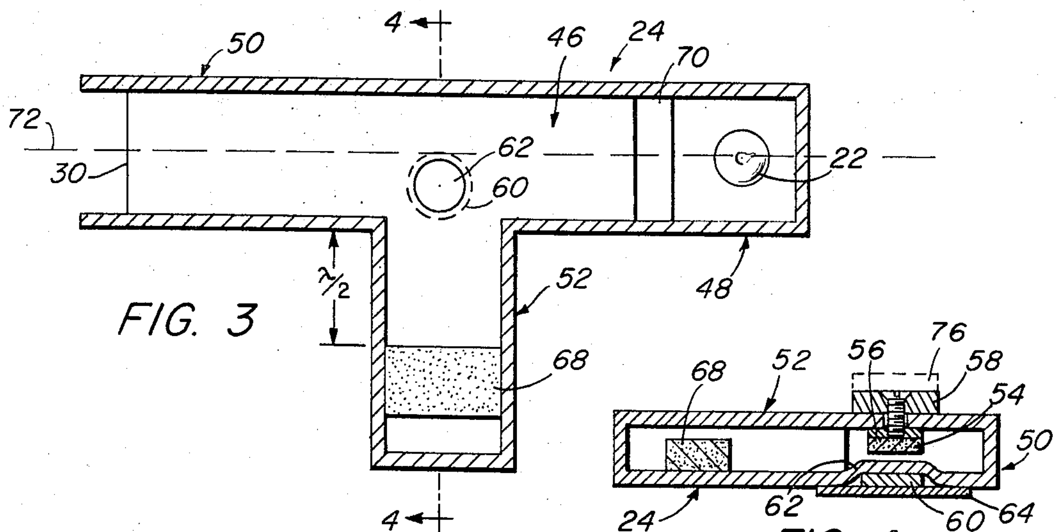

FIG. 3

FIG. 4

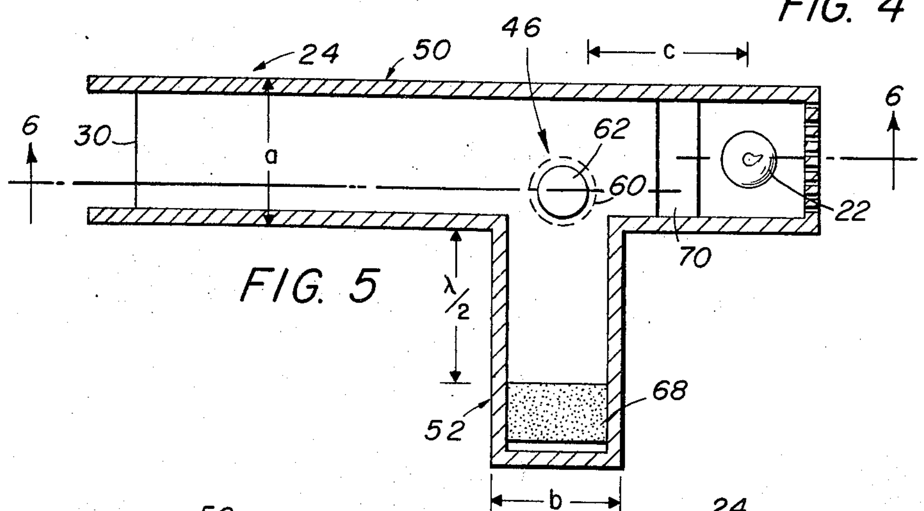

FIG. 5

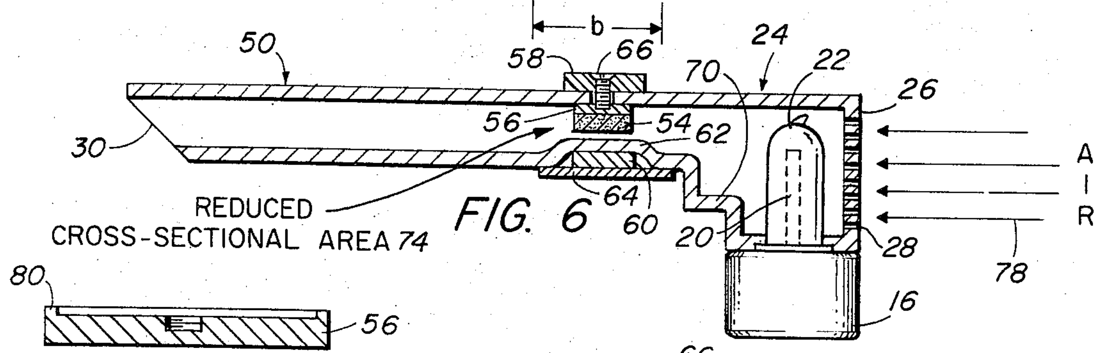

FIG. 6

FIG. 7

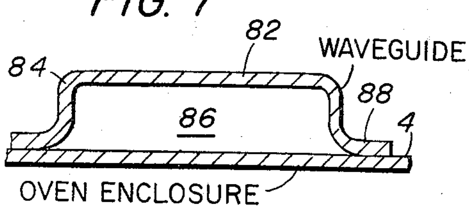

FIG. 8

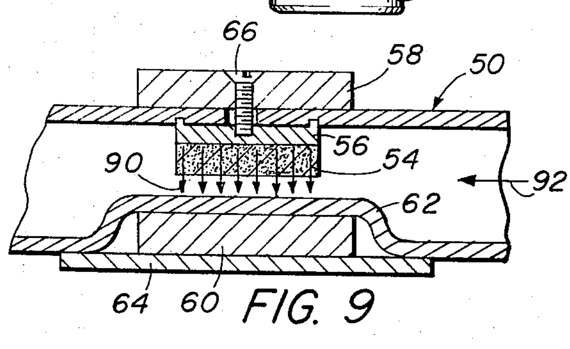

FIG. 9

MICROWAVE OVEN NO-LOAD SENSOR

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates generally to no-load sensing and protection means for high frequency heating apparatus.

2. Description of the Prior Art

Apparatus of the type disclosed utilizes electromagnetic waves directed by waveguide or other means to a conductive enclosure. The energy generator comprises the magnetron crossed field oscillator of radar system fame. The text "-Microwave Magnetrons" by G. B. Collins, Radiation Laboratory Series, Vol. 6, McGraw-Hill Book Company, Inc. 1948 provides details of the construction and operation of such devices. Such sources operate at allocated frequencies of 915 or 2,450 megahertz. Other generators include vacuum tube devices and klystrons. These sources, as well as accompanying high voltage circuits, are relatively costly.

The materials to be cooked or heated absorb high frequency electrical energy within the enclosure when the generator is matched to a load. The absence of such a load or a mismatch condition results in the reflection of energy back to the source often with catastrophic results. Means for prevention of damage by automatic sensing of no-load or severe mismatch condition, such as metallic objects, are therefore of great value.

Prior art attempts to provide the sensing and protection means are numerous. U.S. Pat. No. 2,498,719 issued to P. L. Spencer provides a circuit-controlling means for detecting and continuously monitoring the standing wave amplitudes within the launching section. The occurrence of standing wave peaks within the section in excess of a predetermined value triggers gas-filled electrical discharge devices to energize control relays opening the contacts serially connecting the generator to a voltage source.

Another suggestion is disclosed in U.S. Pat. No. 2,498,720 issued to N. R. Wild et al. wherein the cathode of the high frequency generator is automatically decoupled upon the incidence of an unduly high ratio between the standing wave maxima and minima values. Again gas discharge devices are utilized in combination with the launching section. A further prior art embodiment is noted in U.S. Pat. No. 2,679,595 issued to P. L. Spencer again monitoring voltage standing wave ratio as a function of the condition of the load. A semiconductor such as a crystal diode detects a circuit fluctuation and reduces cathode filament temperatures to terminate operation of the magnetron.

Another prior art device is shown in U.S. Pat. No. 3,412,227 issued to Carl L. Anderson wherein a directional coupler is physically associated with the waveguide line and contains energy absorbing means at one end. A neon bulb sensor and photocell transducer at the other end varies the energizing circuit current for the control relay as a result of any high power energy reflections.

In U.S. Pat. No. 3,437,777 issued to Nagai et al. a ferrite circulator is disposed in a branched rectangular waveguide circuit to direct reflected energy to an energy absorber in the event of a load mismatch condition. Since the cost of ferrite elements, heat removal means and magnetic field producing means tends to be high and the structure intricate, wide acceptance of these sensing and protection means has been adversely affected.

SUMMARY OF THE INVENTION

In accordance with the teachings of the present invention sensing and protection means are provided within a waveguide launching section coupling the energy generator to the heating enclosure. A circulator is disclosed comprising a body of a ferrimagnetic material displaying nonreciprocal transmission characteristics to the energy propagating within the waveguide section. Energy launched in the forward direction enters the heating enclosure with relatively small loss while any high power reflected energy is diverted laterally to a waveguide branch including the energy absorbing means. A magnetic circuit is provided in one embodiment within a reduced cross-sectional area of the launching section by completely disposing a magnet member within a recessed region in a waveguide wall opposite to the ferrimagnetic body. A pedestal member of a magnetizable material concentrates the flux lines perpendicular to the face of the ferrimagnetic body for more efficient saturation. The disposition of the pedestal member adjacent to the ferrimagnetic member also results in improved heat conduction for more efficient circulator action. In an alternative embodiment another magnetic field producing member may be supported adjacent the ferrimagnetic material to further enhance saturation. The reduced cross-sectional area in the region of the ferrimagnetic member results in a concentration of the fields established by the electromagnetic wave energy. Coupled with the concentration means for the disposition of the magnetic fields correspondingly lower costs will result through elimination of the need for plural ferrimagnetic members in most applications as well as the smaller volume requirement for complete saturation.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention, as well as the details for the provision of a preferred embodiment, will be readily understood after consideration of the following detailed description and reference to the accompanying drawings, wherein:

FIG. 1 is a perspective view of the embodiment of the invention with a portion of the upper wall broken away to reveal internal structure;

FIG. 2 is a vertical cross-sectional area of the illustrative embodiment of the invention;

FIG. 3 is a cross-sectional area taken along the line 3—3 of FIG. 2;

FIG. 4 is a detailed cross-sectional view taken along the line 4—4 of FIG. 3;

FIG. 5 is a cross-sectional view of an alternative embodiment of the invention;

FIG. 6 is a vertical cross-sectional view taken along the line 6—6 of FIG. 5;

FIG. 7 is a cross-sectional view of the illustrative magnetic concentrator member of the invention;

FIG. 8 is a cross-sectional view of an alternative embodiment of the waveguide launching section; and

FIG. 9 is an enlarged cross-sectional view of the overall magnetic circuit configuration of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The high frequency heating apparatus **2** is illustrated in FIG. **1**. A microwave frequency magnetron is commonly employed as the energy generator to radiate at 2,450 megahertz corresponding to a wavelength of approximately 5 inches in space. For the purposes of the present description, the term "-microwave" refers to electromagnetic energy in that portion of the spectrum having wavelengths of from 30 centimeters to 1 millimeter. Rectangular parallelepiped conductive walls **4** define heating enclosure **6** having an access opening with a door **8** incorporating a perforated panel **10**. The perforations extend over the major portion of the access opening to prevent the escape of electromagnetic energy during the operation of the apparatus. Handle **12** provides for the manual operation of the door. Panel **14** adjacent the access opening houses the electromagnetic energy generation means and associated circuitry including a high voltage source together with actuating controls.

In FIG. **2** an energy generator of the magnetron type indicated by a block **16** is coupled to a high voltage supply including all the well-known components incorporated in such apparatus. The electromagnetic wave energy is fed from the source **16** by means of an antenna probe **20** within dielectric dome member **22** extending into launching waveguide section **24** adapted to propagate the desired frequency within the heating enclosure **6**. Waveguide **24** is closed at one end by wall member 26 which may include perforations 28 to facilitate cooling of the enclosed components by circulation of air under pressure. The open inner end 30 is oriented within the heating enclosure. The electromagnetic energy is uniformly radiated by means of a stirrer 32 of the type described in U.S. Pat. No. 2,813,185 issued to Robert V. Smith. The stirrer 32 comprises a plurality of vane members 34 rotatably actuated by fractional horsepower motor means 36. The articles to be treated are positioned within the enclosure 6 on a dielectric plate member 38 spanning the bottom wall 40 and supported by shoulders 42. The plate permits the distribution of the electromagnetic wave energy on all sides of the articles to be heated by reflection from the surrounding conductive walls. Such dielectric members are also designed to absorb some of the electromagnetic wave energy in the event that an extreme mismatch condition occurs which could damage the generator.

In accordance with the invention a circulator 46 is provided within the launching section including, first, branch lines 48, 50 and 52 of, illustratively, a rectangular cross-sectional area. A ferrimagnetic element 54 having a disc configuration is supported within the junction region common to all the waveguide sections. The element is supported from the upper broad wall of the waveguide launching section 24 with an intermediately disposed concentrator member 56 of a material such as iron forming substantially a pedestal affixed to the ferrimagnetic element. Magnetic plate member 58 also of irons abuts the outer wall of the waveguide section and is joined to pedestal 56. A permanent magnet member 60 is submounted within the confines of the wall structure defined in the launching waveguide section 24 within a portion of reduced cross-sectional area provided by a recessed wall 62. Securing plate member 64 of any desired metal abuts the magnet 60. A recessed screw member 66 aids in affixing the pedestal element 56 to the upper wall of the waveguide section. Laterally disposed branch section 52 houses energy absorbing means such as a load of, for example, silicon carbide material.

Referring now to FIGS. 3 and 4 the no-load sensing and protection circulator 46 will be described utilizing the magnetic field concentration means 56 as well as the reduced cross-sectional area for the disposition of ferrimagnetic element 54. The energy launched from the generator enters waveguide section 48 having a full height dimension of, illustratively, 2.15 inches and a width of 4.3 inches for propagation of the allocated frequency. The circulator including the ferrimagnetic element is, however, provided in reduced height branch waveguide members matched to the launching section by a suitable one step one-quarter wavelength transformer 70 utilizing well-known techniques. For highly efficient circulator action one inch high guide was selected for the branch members 50 and 52 and in the region for the disposition of the circulating ferrimagnetic element a still further reduction in cross-sectional area is provided by recessed wall surface 62 housing magnet 60.

The dielectric constant characteristics of the ferrimagnetic material for element 54 as well as diameter and height are determined by magnetic field saturation requirements and the preferred orientation in accordance with circulator concepts. It is suggested that in the propagation of electromagnetic energy in the $TE_{1,0}$ mode in rectangular waveguide the bodies of the applicable material be magnetized in a direction parallel to the electric field (E) vector or parallel to the narrow walls. In addition, it is well known in the art that the proper electron spin motion for nonreciprocal propagation of electromagnetic waves is realized when the ferrimagnetic bodies are displaced from the center or longitudinal axis 72 shown in FIG. 3. This determination may possibly be explained by the so-called "-field-displacement effect" for ferrite isolators described by B. Lax and K. J. Button in the text "Microwave Ferrites and Ferrimagnetics," McGraw-Hill Book Company, Inc., 1962, pages 362–372. In unloaded rectangular waveguide the maximum electric field intensity occurs along the longitudinal axis. With asymmetrically disposed magnetized bodies the field intensity pattern for high power energy directed toward the heating enclosure will follow the approximate pattern of unloaded guide with a near center maximum. Relatively low loss or attenuation will result in the high power energy launched in the direction.

Return reflected energy, however, has an entirely different energy profile configuration with the maximum point shifted toward the narrow waveguide walls. Any such energy will contact the offset saturated magnetized ferrimagnetic body and be diverted to branch waveguide 52 where the energy absorbing load is situated. Adverse energy reflections are thereby prevented from being introduced in the path of the generator waves.

A ferrimagnetic material of superior quality is of a nickel-aluminum-ferrite combination or magnesium ferrite. The energy absorbing means 68 are disposed a discrete distance from the junction where the circulator element is placed. Conventionally, a one-half guided wavelength dimension λ/2) is preferred for reflectionless matching and low VSWR. Silicon carbide which has a high degree of thermal lag is ideally suited for the absorbing material.

Magnet member 60 is shown submounted relative to the ferrimagnetic element 54 in the reduced cross-sectional region adjacent to wall 62 in the substantially one-half height waveguide. As a result of the wave concentration the requirements for the magnet member as well as load and ferrimagnetic material are substantially reduced. Pedestal member 56 will aid in directing the magnetic field flux lines substantially perpendicular to the face of the element 54. A further feature of the invention resides in the conduction of thermal energy generated in the ferrimagnetic material by the circulator action by means of the heat sink action of the abutting pedestal member 56. This will prevent the magnetic material from rapidly reaching the Curie temperature point where magnetization is destroyed. The combination of the ferrimagnetic element, submounted magnet member, and pedestal concentrator in the reduced cross-section area waveguide and junction region also virtually eliminates the need for reactive circuit matching structure such as irises at the input and output ends of circulator 46. In view of the concentration of wave energy as well as magnetic field a single magnet 60 will suffice in most applications. Where desired, however, as an aid to further saturation of the ferrimagnetic material a second magnet member 76 indicated by dotted lines may be positioned adjacent to plate member 58.

In FIGS. 5 and 6 another variation of the invention is shown. In instances where the space available for the placement of the launching waveguide section may be limited, it is within the purview of the invention to suitably adjust the placement of the waveguide branch sections to thereby provide for the space limitation. In FIG. 5 the waveguide branch 50 has a width of, illustratively, 4.3 inches, dimension a, as shown in FIGS. 3 and 4. By narrowing the waveguide branch line 52 housing the energy absorbing load to a dimension of approximately 3.5 inches, dimension *b*, in the same 1 inch height waveguide, it is possible to shorten dimension *c* between the launching probe and the circulator by approximately 0.4 inches. The narrowing of waveguide branch 52 will lengthen this portion of the overall circulator by lengthening the one-half wavelength for the placement of the energy absorbing load 68. The height of the energy absorbing load 68 may also be suitably adjusted to match VSWR of the waveguide branch 52 to the remainder of the energy launching means.

In FIG. 6 a stream of coolant indicated generally by lines 78 are shown directed toward the passages 28 in end wall 26 to assist in the operation of the illustrative embodiment of the invention by providing additional cooling for the ferrimagnetic element and absorbing means.

In FIG. 7 a slightly enlarged cross section of the magnetic pedestal member 56 is shown to assist in the conduction of thermal energy as well as direction of the magnetic field flux lines. A notched edge 80 is shown disposed around the perimeter of the member 56 to assure better contact with the upper broad walls of the rectangular waveguide launching section 24.

In FIG. 8 another modification of the invention is shown incorporating a launching waveguide section 82 which is provided with rounded corners 84 to form a waveguide launching section. A three-sided substantially U-shaped member from a sheet metal may be stamped to provide the passageway 86 when suitably joined by welding or soldering as at 88 to the upper wall 4 of the oven enclosure. This structure will not only provide for a simplified and compact structure but will lower the overall cost of the oven apparatus.

In FIG. 9 the idealized magnetic circuit is disclosed utilizing the components of the invention to provide for the concentration of the launched wave energy as well as magnetic flux lines in the region of the ferrimagnetic element. The components previously described have been similarly numbered. The most efficient operation of the resultant circulator will follow with the magnetic lines 90 provided by the magnetic member being oriented perpendicular to the face of the magnetic member being oriented perpendicular to the face of the ferrimagnetic element 54. The flux lines lines, therefore, are at right angles to the magnetic vector of the launched microwave energy indicated by the arrow 92 moving along the waveguide section 50. This arrangement will provide for enhancement of the attenuation of the reflected returning energy as well as the lowest insertion loss for the energy initially launched from the microwave energy generator. The arrangement also discourages any fringing flux lines from arising which will result in inefficient operation and the requirement for larger bodies of the ferrimagnetic material to be disposed within the waveguide section.

An efficient no-load sensing and protection means has been disclosed which is simple to implement in electronic heating apparatus. Some modifications and variations in the structure have been heretofore described in detail and numerous other alternations will be readily apparent to those skilled in the art. It is intended, therefore, that the foregoing illustrative embodiments and detailed description be considered in the broadest aspects and not in a limiting sense.

What is claimed is:

1. High frequency heating apparatus comprising:
an enclosure;
an electromagnetic energy generator;
means for coupling said energy from said generator to said enclosure;
said coupling means having a passage therethrough with a section thereof of reduced cross-sectional area;
nonreciprocal transmission means including a magnetized ferrimagnetic material disposed within said reduced cross-sectional area to receive and propagate in a direction away from said generator energy reflected from said enclosure; and
means for absorbing said reflected energy.

2. High frequency heating apparatus comprising:
an enclosure;
an electromagnetic energy generator;
means for coupling said energy from said generator to said enclosure including a waveguide transmission line;
said coupling means having a passage therethrough with a section thereof of reduced cross-sectional area;
a circulator including a member of a ferrimagnetic material disposed within said reduced cross-sectional area to receive and propagate in a direction away from said generator energy reflected from said enclosure;
means for magnetizing said ferrimagnetic material with the magnetic field flux lines being directed substantially perpendicular to the face of the ferrimagnetic member; and
means for absorbing said reflected energy.

3. The apparatus according to claim 2 wherein said coupling means include a section of hollow rectangular waveguide.

4. The apparatus according to claim 2 wherein said coupling means include a three-sided hollow transmission line having rounded corners.

5. The apparatus according to claim 2 wherein said energy is first launched in a waveguide coupling means having a predetermined height consonant with the frequency of operation and the remainder of said coupling means including the section of reduced cross-sectional area has an overall height of approximately one-half the first height dimension.

6. The apparatus according to claim 2 wherein said magnetizing means include a permanent magnet member mounted opposite to the ferrimagnetic member.

7. The apparatus according to claim 2 wherein said magnetizing means include a submounted permanent magnet member disposed in said reduced cross-sectional area.

8. The apparatus according to claim 2 wherein said magnetizing means include a magnet member disposed opposite to the ferrimagnetic material member and mounted wholly within the plane defined by the outer confines of said waveguide line.

9. The apparatus according to claim 2 wherein said member of ferrimagnetic material is supported by a member of a magnetizable material to concentrate the magnetic field flux density within the said ferrimagnetic material.

10. The apparatus according to claim 2 wherein said ferrimagnetic member is mounted on a pedestal member of a magnetizable material abutting a wall of said waveguide transmission line.

11. The apparatus according to claim 10 wherein said pedestal member has an annular notch section for engaging said waveguide wall.

12. The apparatus according to claim 2 wherein said energy absorbing means are disposed within a branch section of waveguide having a narrower width than the remainder of said coupling means.

* * * * *