

(19)



(11)

**EP 2 127 482 B1**

(12)

**EUROPEAN PATENT SPECIFICATION**

(45) Date of publication and mention  
of the grant of the patent:  
**23.04.2014 Bulletin 2014/17**

(51) Int Cl.:  
**H05B 6/80 (2006.01) D06F 58/26 (2006.01)**

(21) Application number: **08710231.5**

(86) International application number:  
**PCT/IL2008/000231**

(22) Date of filing: **21.02.2008**

(87) International publication number:  
**WO 2008/102360 (28.08.2008 Gazette 2008/35)**

**(54) DRYING APPARATUS AND METHOD**

TROCKENVORRICHTUNG UND -VERFAHREN

APPAREIL ET PROCÉDÉ DE SÉCHAGE

(84) Designated Contracting States:  
**AT BE BG CH CY CZ DE DK EE ES FI FR GB GR  
HR HU IE IS IT LI LT LU LV MC MT NL NO PL PT  
RO SE SI SK TR**

(30) Priority: **21.02.2007 PCT/IL2007/000236**  
**10.07.2007 PCT/IL2007/000864**  
**30.08.2007 US 935788 P**

(43) Date of publication of application:  
**02.12.2009 Bulletin 2009/49**

(73) Proprietor: **Goji Limited**  
**Hamilton HM08 (BM)**

(72) Inventors:  
• **BEN-SHMUEL, Eran**  
**55900 Ganei Tikva (IL)**

- **ATZMONY, Daniella**  
**60850 Shoham (IL)**
- **SHAHAM, Ginadi**  
**81207 Yavne (IL)**
- **BILCHINSKY, Alexander**  
**56450 Monosson-Yahud (IL)**

(74) Representative: **Korenberg, Alexander Tal et al**  
**Kilburn & Strode LLP**  
**20 Red Lion Street**  
**London WC1R 4PJ (GB)**

(56) References cited:  
**WO-A-2005/073449 US-A- 5 321 897**

**EP 2 127 482 B1**

Note: Within nine months of the publication of the mention of the grant of the European patent in the European Patent Bulletin, any person may give notice to the European Patent Office of opposition to that patent, in accordance with the Implementing Regulations. Notice of opposition shall not be deemed to have been filed until the opposition fee has been paid. (Art. 99(1) European Patent Convention).

**Description**FIELD OF THE INVENTION

5 **[0001]** The present application is concerned generally with drying a target, optionally using RF energy. In many embodiments of the invention, the target includes clothing.

BACKGROUND OF THE INVENTION

10 **[0002]** Conventional dryers, especially clothes dryer, typically work by drawing in ambient air and heating the ambient air before passing it through a tumbler. During its passage through the tumbler, the hot air evaporates water and increases in humidity]. Conventional dryers include, but are not limited to, vented forced air dryers, spin dryers, condensation dryers, heat pump dryers, and mechanical steam compression dryers.

15 Vented forced air dryers

**[0003]** Vented forced air dryers use a fan or pump to direct heated air through a tumbling drum. The heated air heats clothing in the drum to a sufficient degree that a vapor pressure of water in/on the fabric increases and a relative humidity of air in the drum increase. A vent releases humidified air from the drum to dry the fabric.

20 **[0004]** US-A-5321897 discloses those features set out in the pre-characterising portions of the independent claims.

## SUMMARY OF THE INVENTION

25 **[0005]** According to the present invention a drier and a method of drying are characterised by those features set out on the characterising portions of the independent claims.

**[0006]** The invention relates to use of a spectral imaging module which provides a spectral image of items in the dryer. Optionally, the spectral imaging module is provided as part of a feedback loop. In an exemplary embodiment of the invention, the spectral imaging module is integrated into an RF feed. Optionally, a single RF antenna is used for both spectral imaging and heating. In an exemplary embodiment of the invention, the spectral imaging module produces a spectral image within about 100, 50, 40, 20, 10, 5 or 1 milliseconds or even 100 or 10 micro seconds (or intermediate times). Optionally, a controller adjusts RF energy in response to the spectral image. Optionally, the adjustment includes changing a heating policy. Optionally, the heating policy is defined in terms of one or more of transmitted frequencies, matching powers for matching times, reducing an amount of energy directed to problem areas (e.g. metal pieces or surface currents represented as relatively narrow peaks in the spectral image) in the spectral image.

35

BRIEF DESCRIPTION OF THE DRAWINGS

**[0007]** Exemplary non-limiting embodiments of the invention are described below with reference to the attached figures. The drawings are illustrative and generally not to an exact scale. The same or similar elements on different figures are referenced using the same reference numbers.

40

Figs. 1A, 1B and 1C are respective schematic top and side section views of a cavity 10, in accordance with an exemplary embodiment of the invention.;

Figs. 2A and 2B show two exemplary matching elements, in accordance with an embodiment of the invention;

45 Fig. 3 is a schematic isometric drawing of the interior of the cavity of Fig. 1;

Fig. 4A is a schematic drawing of an antenna useful for coupling energy into the cavity, in accordance with an embodiment of the invention;

Fig. 4B is a schematic drawing of a helical antenna useful for coupling energy into the cavity, in accordance with an embodiment of the invention;

50 Fig. 4C shows a graph of correlation of free space matched frequencies and cavity matched frequencies of a helical antenna feed;

Fig. 4D-4H are schematic drawings of various fractal antenna useful for coupling energy into the cavity, in accordance with an embodiment of the invention;

55 Figs. 5A-5C are schematic block diagrams of electromagnetic heating systems, in accordance with an embodiment of the invention;

Fig. 6 is a simplified flow chart of the operation of the system, in accordance with an embodiment of the invention;

Fig. 7 is a flow chart of a process of adjusting elements and frequency in the heating system illustrated in Fig. 5, in accordance with an embodiment of the invention;

Fig. 8 illustrates alternative RF circuitry, in accordance with an embodiment of the invention;

Fig. 9 is a graph of frequency vs. time for a typical thawing process, illustrating an automatic turn-off capability in accordance with an embodiment of the invention;

Fig. 10 shows the layout of a low frequency bias structure, in accordance with an embodiment of the invention;

Fig. 11A is a simplified flow chart of a method of determining swept power characteristics, in accordance with an embodiment of the invention;

Figs. 11B and 11C illustrate how a swept power spectrum is determined, in accordance with an embodiment of the invention;

Fig. 11D shows a pulse shape, for a pulse operative to provide the spectrum shown in Fig. 11B, in accordance with an embodiment of the invention;

Fig. 12A shows an RF heater with an auxiliary heating coil, in accordance with an embodiment of the invention;

Figs. 12B and 12C schematically illustrate a scheme for transferring waste heat from an amplifier to the heater of Fig. 12A; and

Fig. 12D shows an external view of a low weight, high efficiency RF heater, in accordance with an embodiment of the invention.

Fig. 13 is a flowchart of a method of food preparation in accordance with an exemplary embodiment of the invention;

Fig. 14 is a schematic side-cross-sectional view of a microwave cavity oven in accordance with an exemplary embodiment of the invention;

Fig. 15 is a schematic side cross-sectional view of a food package in accordance with an exemplary embodiment of the invention;

Fig. 16 is a schematic side cross-sectional view of a conveyer belt oven in accordance with an exemplary embodiment of the invention;

Fig. 17 is a graph showing a uniformity of heating in a chunk of meat, in accordance with an exemplary embodiment of the invention;

Figs. 18A and Fig. 18B are graphic representations of uniform and non-uniform heating of a chunk of meat, cut as a steak, in which Fig. 18A shows the temperature changes during heating at two locations within the steak, a fat portion and a meat portion; and Fig. 18B depicts the temperature differences between the two locations;

Figs. 19A and Fig. 19B are graphic representations of uniform heating of a chunk of meat, in which Fig. 19A shows the temperature changes during heating at three different locations within the meat and Fig. 19B depicts the temperature differences between two pairs of the above three locations;

Fig. 20 is a schematic representation of an RF clothes dryer according to an exemplary embodiment of the invention;

Fig. 21a is a picture of a modified article of clothing according to an exemplary embodiment of the invention;

Fig. 21b diagram of a clothes drying insert for an RF dryer according to an exemplary embodiment of the invention;

Figs. 22-27 are schematic representations of RF clothes dryers according to different exemplary embodiments of the invention;

Figs. 28-32 are simplified flow diagrams of methods related to drying according to different exemplary embodiments of the invention;

Figs. 33a, 33b, 33c and 33d are spectral images of an empty dryer cavity, a dryer cavity containing wet clothing, a dryer cavity containing semi-dry clothing and a dryer cavity containing dry clothing in accord with an exemplary embodiment of the invention; and

Fig. 34 is a graph showing temperature and humidity, measured at an air exit during a drying process, for both a conventional dryer and an RF dryer in accordance with an exemplary embodiment of the invention.

#### DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

**[0008]** The present application describes various methods of processing foodstuff and/or other materials. Prior to detailing such methods (e.g., in Fig. 13 and on), a description is provided of exemplary methods of control of heating in an RF cavity which is useful for some embodiments of food preparations and for other uses as well.

**[0009]** The present application describes a number of advances in the field of RF heating (e.g. microwave or UHF) heating. While, for convenience these advances are described together in the context of various apparatus and methods, each of the advances is generally independent and can be practiced with prior art apparatus or method (as applicable) or with a non-optimal version of the other advances of the present invention. Thus, for example, parts of the method of adjusting the input power can be used with the prior art apparatus of Penfold, et al., referenced above. Conversely, the inventive apparatus of the present invention (or parts thereof) can be used with the method of Penfold et al. It is expected that these combinations will not be ideal, but they are expected to give improved results over the prior art apparatus and methods.

**[0010]** Furthermore, advances described in the context of one embodiment of the invention can be utilized in other embodiments and should be considered as being incorporated as optional features in the descriptions of other embod-

iments, to the extent possible. The embodiments are presented in somewhat simplified form to emphasize certain inventive elements. Furthermore, it is noted that many features that are common to most or all embodiments of the invention are described in the Summary of the Invention and should also be considered as being part of the detailed description of the various embodiments.

**[0011]** The following are believed to novel features or variations present in some or all the embodiments described. It is understood that not all of these features may be present in any particular embodiment and that not all features are described for every embodiment for which they are applicable.

1) An apparatus and method that allow for RF heating an irregular object such that the temperature of the object is uniform within 50°C (optionally, to within 10, 6, 4 or 2 °C) when heating is completed. Exemplary embodiments provide this uniformity mainly by directly RF heating the object such that over 50% of the heating is by direct RF heating and not by conduction from other portions of the device. In some embodiments of the invention, such direct RF heating can reach 70, 80, or 90 or more percent.

2) An apparatus that includes field adjusting elements inside the cavity and method of designing and using same.

3) A heating apparatus with one or more coupling antenna for coupling energy into the cavity; a method of designing said antenna; and method of feeding energy to the heater including a method of tuning the radiated pattern of the antenna. This includes, utilizing an antenna array (with one or more feeds, having controlled phases), loop antenna, wide band antenna, fractal antenna, directional antenna, helix antenna, operating the antennas separately or coherently, designing the antenna to obtain a desired radiated pattern etc.

4) An apparatus and method to gain knowledge of a heating process before, and potentially also several times during, heating (e.g. several times a second) using a measurement of the efficiency of absorption of energy in the object being heated as function of frequency

5) An apparatus and method that is adapted to control one or more characteristics of the heating process, for example the amount of power absorbed in the heated object, based on the measurement of energy absorption efficiency (e.g. by transmitting power to compensate for the variations of energy absorption). This may be done by adjusting, for example, input power at each transmitted frequency and/or choosing frequencies to be transmitted and/or moving the field adjusting element's and/or moving the heated object and/or changing the antennas characteristics. This may be done before operation, and preferably also one or more times during operation (e.g. several times a second), based on measurements of energy absorption during heating or during a short hiatus in the heating.

6) An apparatus and method for applying a DC or low frequency electric (e.g. below 300MHz, or below some other value substantially lower than the heating frequencies used) or magnetic field to the object during RF heating. Such application is believed to change the dielectric properties of the object being heated and this provides yet another method of adjusting the power provided to the object being heated.

7) An apparatus and method in which during operation the transmitted frequencies and/or power from one or more feeds are varied in a controlled manner to get a desired heating pattern (e.g. by more than 1, 2 or 5 MHz). This variation may occur several times during operation (e.g. several times a second). In an embodiment of the invention, the desired pattern is a uniform heating pattern.

8) Apparatus and method of controlling heating based on reading of dielectric characteristics of the heated object. Reading may be obtained one or more times during heating (e.g. several times a second). For example end of thawing or boiling process, when a phase change is sensed. This can implement a cessation of heating.

9) An electromagnetic heater including multiple inputs in which the frequencies of the inputs are different by more than 5, 10 or 25 MHz.

10) An electromagnetic heater including multiple inputs in which the frequencies of at least one of the inputs changes dynamically during heating such that the frequencies at the inputs vary by 5 MHz or more.

11) An apparatus that utilizes a wideband and high efficiency (above 40%) solid state microwave amplifier to feed energy into the cavity and optionally utilize waste heat generated by the generator to heat the air in the cavity.

12) An apparatus that utilizes wasted heat generated by the RF energy generator to heat a medium, for example air in the cavity, or water, as in a water heater.

13) A method of causing a resonance structure and/or designed pattern, inside a resonator to radiate by (selectively or generally) irradiating said resonance structure and/or designed pattern thus using it as a radiation source (i.e. creating a passive source) and an apparatus comprising same.

14) Apparatus and method of using RF reflecting object, such as metals, for concentration of energy in close environment of these objects, inside a resonator, for example within the heated object or in the close environment of the heated object.

15) Apparatus and method of high-efficiency (at least 50%, at times above 70% or even 80%) RF heater. The efficiency is defined as power absorbed in the object versus power at the output of the power source. This opens the possibility of a heater that operates from a solar energy source.

16) An RF heater weighing less than 15Kg, or even less than 10Kg. In accordance with some embodiments of the

invention a the use of a high efficiency solid state amplifier rather than a microwave tube allows for using a low weight DC power source instead of the heavy duty transformer. This heat saving is additional to the replacement of a heavy magnetron with a light solid state amplifier. Furthermore, the high efficiency eliminates the need for a heat sink, e.g. by using the resonator as a heat sink. In some embodiments of the invention, the requirement for a

17) Apparatus and method of temperature information of a heated object using a TTT (a temperature sensitive, preferably passive Temperature transmitting tag the resonance of which changes due to temperature changes or which transmits the temperature information using a modulated response). This may be done if the TTT frequency is remote from the transmittal range of the device, or if the TTT's frequency is within the device's band width, and avoiding the specific TTT frequencies during heating. In some embodiments of the invention a tag having two resonant elements, one that is temperature sensitive and one that is not can be used since measurement of frequency difference is more accurate than measurement of absolute frequency.

18) An apparatus and method for RF heating including means for chamber environment control (e.g. introduction and/or removal of humidity, cooling and/or warming etc.). For example, in the case of an egg being boiled, heating would reduce the temperature gradient (and therefore stress) across the egg shell, thus reducing the chances of cracking and bursting. Optionally, the air temperature in the chamber may be varied with time, depending on the present temperature of the object and objectives such as causing condensation that closes the object being heated (such as meat).

19) An apparatus in which the power absorbed by the object being heated can be calculated based on knowledge of power input and efficiency of power transfer to the object being heated. This allows for the calculation of a current temperature and/or a turn off-time based on actual heating rather than some estimated heating time as presently used with microwave cookers.

**[0012]** Figs. 1A, 1B and 1C show respective top and side section views of a cavity 10, in accordance with an exemplary embodiment of the invention.

**[0013]** Cavity 10, as shown is a cylindrical cavity made of a conductor, for example a metal such as aluminum, and is resonant in the UHF or microwave range of frequencies, optionally between 300 MHz and 3 GHz, more preferably between 400 MHz and 1 GHz. In some embodiments of the invention, the cavity is a spherical, rectangular or elliptical cavity. However, it should be understood that the general methodology of the invention is not limited to any particular resonator cavity shape.

**[0014]** On one end 12 of the cylinder and on two sides of the cylindrical portion 14 feed antennas 16, 18 and 20 are positioned to feed energy at a frequency which is optionally chosen using the methods described below. Various types exemplary but not limiting antennae useful in carrying out the invention are shown in Figs. 4A-4C.

**[0015]** In an exemplary embodiment of the invention, one or more matching elements 22, 24 are placed inside the cavity, optionally near the feed antennas. Two types of field adjusting elements are shown, however, other shapes and materials can be used. First field adjusting element 22, shown more clearly in Fig. 2A is situated on end 12 of cavity 10. In this embodiment the element is rotatable about an axis 28 attached to the end, in a direction 30. Optionally, it is insulated from the end by an insulating sheet 32 which couples element 22 capacitively to end 12. Alternatively it is conductively attached.

**[0016]** It is believed that element 22 (as well as the other field adjusting element) has a dual effect, when properly adjusted. On the one hand it changes the modes of the cavity in a way that selectively directs the energy from the feeds into the object to be heated. A second and related effect is to simultaneously match at least one of the feeds and reduce coupling to the other feeds.

**[0017]** Field Adjusting element 24, shown more clearly in Fig. 2B is situated between feed 18 and end 12. One end of the element optionally is electrically attached to cylindrical portion 14 of the cavity. The other end of element 24 is spaced and insulated from end 12 by insulating material 36. It is free to slide along end 12 and cylindrical portion as shown by arrows 33 and 34. This sliding changes the spectral variation of the energy absorption efficiency.

**[0018]** Fig. 3 is a perspective drawing of the interior of the cavity to more clearly show the position and orientation of the feed and elements.

**[0019]** Figs. 4A-4H show three different types of antennas that are useful in carrying out the invention. These antennas are either novel *per se*, or if known have never been used for feeds in a microwave oven or heater, especially in a cavity type heater. In general, in most microwave cavity type heaters, the feeds used are not directional to any great extent and not wideband, as defined in free air. The object of the feeds to excite the modes of the cavity. Since the cavities of the prior art are excited at a single frequency or a narrow band of frequencies, the antennas were designed specifically to excite these modes. In addition, prior art microwave cavities, use waveguides or loop antennas which are not designed to lower the coupling of energy from one feed to another (they generally have only a single feed). The present inventors have discovered that the use of directional antennae and/or wideband antennae allows for better coupling to the heated object and lower coupling to other feeds.

**[0020]** In some embodiments the antennas are supplied as arrays. There are some advantages in using an antennas array. The band may be larger and there is a lower dependence of the heated object location on the results. The directivity may be controlled, even adjusted during heating. It is possible to control the phase of every single antenna of the array, controlling the RF mode. It is possible to alter the antenna structure, for example, using the helix antenna, the radius and the height of the antenna may be changed in order to tune the impedance and change the RF mode.

**[0021]** Fig. 4A shows an antenna useful for coupling energy from feeds 16, 18 and 20 into cavity 10, in accordance with an embodiment of the invention. As shown feed 16 includes a coaxial feed 37 with its center conductor 36 bent and extending into the cavity. The center conductor is bent but does not touch the walls of the cavity. Optionally, the end of the wire is formed with a conductive element 40 to increase the antenna bandwidth. The present inventors have found that antennas of the type shown are able to couple energy better to an irregular object in the cavity. It is believed that such antennas transmit directionally and if the bend is aimed toward the object being heated, then coupling to the object (as opposed to coupling to the cavity) will be improved.

**[0022]** Fig. 4B shows a helix antenna useful for coupling energy from feeds 16, 18 and 29 into cavity 10, in accordance with an embodiment of the invention. As shown feed 16 include a coaxial feed 37 with its center conductor 36' having an extension that is formed into a helix. This antenna can be designed for matching into free space over a relatively wide band of frequencies (such as that useful for the present invention) and can be made more or less directional by changing the number of turns. The free space design is then adjusted for the presence of the cavity as described below with respect to Fig. 4C. The graph of Fig. 4C shows experimental results for a helix of 7 turns, with a diameter equal to the free space wavelength and a turn pitch of less than 0.2 wavelengths. However, the present inventors have found that curves of the type shown in Fig. 4C can be found, by experimentation, for other turn characteristics as well.

**[0023]** Fractal antennas are known in the art. Reference is made to Xu Liang and Michael Yan Wan Chia, "Multiband Characteristics of Two Fractal Antennas," John Wiley, MW and Optical Tech. Letters, Vol. 23, No. 4, pp 242-245, November 20, 1999. Reference is also made to G.J. Walker and J.R. James, "Fractal Volume Antennas" Electronics Letters, Vol. 34, No. 16, pp 1536-1537, August 6, 1998. These references are incorporated herein by reference.

**[0024]** Fig. 4D shows a simple bow-tie antenna 50 as known in the art, for radiation into free space. The Bandwidth of the bow-tie (in free space) is: 604MHz @ 740MHz center frequency (-3dB points) and 1917MHz @ 2.84GHz center frequency. This antenna has a monopole directivity pattern but a broadband one (being an advantage over the narrow BW of a dipole antenna). However, monopole directivity does not irradiate in a direction parallel to the feed.

**[0025]** The band width (BW) of this antenna varies between 10MHz and maximum of 70MHz depends of the load (object) position *inside the cavity*.

**[0026]** This and the following fractal antennas can be useful in the present invention to feed energy into a cavity.

**[0027]** Fig. 4E shows a simple Sierpinski antenna 52, useful in the practice of the present invention. Generally, the cross-hatched areas 54 are metal plate and the white central area 56 is a non-conducting region. The metal plates are mounted on a preferably low dielectric constant dielectric and are connected at the corners and to center conductor 37 of coaxial feed 36, as shown. It's characteristics in the cavity are similar to those of the bow-tie antenna.

**[0028]** Fig. 4F shows a modified Sierpinski antenna 58, useful in the practice of the present invention. Generally, the cross-hatched areas 60 are metal plate and the white areas 62 are non-conducting regions. The metal plates are mounted on a preferably low dielectric constant dielectric and are connected at the corners and to center conductor 37 of coaxial feed 36 as shown.

**[0029]** For an overall extent of 103.8 mm utilizing equal size equilateral triangles, the center frequency of this antenna is about 600 MHz inside the cavity.

**[0030]** Fig. 4G shows yet another modified Sierpinski antenna 64, useful in the practice of the present invention. Generally, the cross-hatched areas 66 are metal plate and the white areas 68 are non-conducting regions. The metal plates are mounted on a preferably low dielectric constant dielectric and are connected at the corners and to center conductor 37 of coaxial feed 36.

**[0031]** Dimensions are shown on Fig. 4G for an antenna having a center frequency of 900 MHz in the cavity.

**[0032]** Fig. 4H shows a multi-layer fractal antenna 70 made up of three fractal antennas spaced a small distance (e.g. 2 mm) from each other.

**[0033]** The size of each of these antennas is staggered in order to broaden the bandwidth of the antenna. In the example shown a first antenna 72 is scaled to 0.8 of the dimensions given in Fig. 4G. A second antenna 744 has the same dimensions as the antenna of Fig. 4G and a third antenna 76 is increased in size over antenna 74 by a factor of 1.2. The volume fractal antenna (fig. 4G) has an overall bandwidth of 100MHz - this is an improvement over the 70 MHz maximum BW achieved in prior single fractal antenna (figs. 4D-4H).

**[0034]** Fractal antennas also show a center frequency change when placed in a cavity. This difference is used (as with the helical antenna to design antennas for use in cavities by scaling the frequencies.

**[0035]** In general, it is desired to utilize wideband, directional antennas to feed power into the object being heated such antennas include patch antennas, fractal antennas, helix antennas, log-periodic antennas and spiral antennas.

**[0036]** Figs. 5A to 5D are schematic block diagrams of an electromagnetic heating system, in accordance with an

embodiment of the invention.

**[0037]** Fig. 5A shows a general block diagram of each of the power feeds 90 of the system, in an exemplary embodiment of the invention. The system is controlled by a computer 92 which via a control interface (Controller) 130 controls an RF system 96 which provides power to the heated object 98.

**[0038]** Fig. 5B is a block diagram of the electronics of one of the RF feed systems 96, in accordance with an exemplary embodiment of the invention. A VCO 102 receives a signal from a control circuit 130 (Fig. 5C) which sets the frequency of the energy into the port. This energy is passed through an RF switch 104 and a voltage controlled attenuator (VCA) 106, both of which are controlled by control circuit 130. After passing through the VCA, the power and frequency of the signal have been set. A load 108 is provided for dumping the signal generated by VCO 102 when the signal from VCO 102 is not switched to the VCA.

**[0039]** The signal is then sent through the main line of an optional first dual directional coupler 110.

**[0040]** The output of the VCA is then amplified by a power amplifier 112 and after passing through an isolator 114. A signal proportional to the power reflected from amplifier 112 is also fed to the control circuit.

**[0041]** Coupler 110 feeds back a portion of the signal entering it (after detection or measurement of power) to control circuit 130. A signal proportional to the power reflected by amplifier 112 is also sent to controller 130. These signals enable supervision of VCO/VCA and the amplifier. In a production system, the directional coupler may not be necessary.

**[0042]** An RF switch 116 switches the power either to a load 118 or to the feed of resonator 98, via a second dual directional coupler 120. Dual directional coupler 120 samples the power both into and out of the resonator and sends power measurement signals to controller 130.

**[0043]** In an embodiment of the invention, RF amplifier 112 is a solid state amplifier based on the LDMOS technology.  $P_{sat} = 300W$ , Efficiency = about 22%, Effective band - 800-1000MHz Such amplifiers either have a relatively narrow bandwidth or a low efficiency (<25%) or both. This limits the optimal utility of the advances of the present invention. Recently, amplifiers have become available based on SiC (silicon carbide) or GaN (gallium nitride) semiconductor technology. Transistors utilizing such technologies are commercially available from companies, such as Eudyna, Nitronex and others. Amplifiers having a maximum power output of 300-600 W (can be built from low power (50-100 Watt) modules) and a bandwidth of 600 MHz (at 700 MHz center frequency) or a bandwidth of 400 MHz (at 2.5 GHz center frequency) are available, for example. Such amplifiers have a much higher efficiency than prior art amplifiers (efficiency of 60% is available) and much higher tolerance to reflected signals, such that isolator 114 can often be omitted for these amplifiers. A particular configuration utilizing this type of amplifier is described below in conjunction with Figs. 12A-D.

**[0044]** Turning now to Fig. 5C controller 130 comprises computer 92 which performs computations and provides a logging function of the system as well as acting as a user interface. It also controls the rest of the elements in performing the calibration and control method of the flow charts of Fig. 7.

**[0045]** Computer 132 is coupled to the rest of the system through an interface 134 which is designed to provide communication to, for example, an ALTERA FPGA 140, which interfaces with and provides control signals to the various elements of the RF system. The Altera receives inputs (as described above with respect to Figs. 5A-5C), via one or more multiplexers 136 and an A/D converter 138. In addition, it sets the frequency and power of each of the feeds (also described with respect to Figs. 5A and 5B) via D/A converters 140 and the positions of the field adjusting element optionally utilizing the method described with aid of the following flow charts. In a production system, the computer may not be necessary and the Altera or a similar controller may control and process all the necessary data. In some embodiments of the invention, the frequency is swept as described below.

**[0046]** Fig. 6 is a simplified flow chart 150 of the operation of a heating system having the structure described above. Fig. 7 is a simplified flow chart of calibration 160 of the system. As will be evident, the method operation and calibration of the system is also usable with only minor changes for operating systems with lesser or greater numbers of power feeds and/or a greater or less number of matching elements.

**[0047]** At 152 an object, for example a frozen organ or frozen or non-frozen food object, is placed in cavity 10. A calibration or adjustment routine is then optionally performed to set the variable elements in the system. These can include power output of the amplifiers 112 in each of the power feeds to the cavity at each frequency, chosen to be transmitted, the finite set of sub-bands of frequencies of each VCO 102, the method of providing energy at the various frequencies (for example sweep or other frequency variation, or the provision of a pulsed signal embodying the desired frequency and power characteristics), positioning of the matching elements (e.g., 22, 24), position of the heated object and any other variables that affect the various characteristics of the heating process, for example - the uniformity and/or efficiency of power transfer to the object. A memory contains the criteria 156 for calibrating the system. Exemplary criteria are described below. Calibration is carried 160 out to determine the new heating variables. An exemplary calibration routine is outlined in the flow chart of Fig. 7, discussed below.

**[0048]** After the new variables are determined, the new variables are set 158 and heating commences 170.

**[0049]** Periodically (for example a few times a second), the heating is interrupted for a short time (perhaps only a few milliseconds or tens of milliseconds) and it is determined 154, optionally based on a method described below, whether heating should be terminated. If it should, then heating ends 153. If the criterion or criteria for ending heating is not met,

then the calibration (or re-adjustment) routine 160 is entered. If not, the heating 170 is resumed. It is noted that during the measurement phase, the sweep is generally much broader than during the heating phase.

[0050] Calibration routine 160 for each individual channel will be described, with reference to the flow chart of Fig. 7.

[0051] In order to perform calibration, the power is optionally set at a level low enough 162 so that no substantial heating takes place, but high enough so that the signals generated can be reliably detected. Alternatively, calibration can take place at full or medium power. Calibration at near operational power levels can reduce the dynamic range of some components, such as the VCA, and reduce their cost.

[0052] Each of the inputs is then swept 164 between a minimum and a maximum frequency for the channel. Optionally, the upper and lower frequencies are 430 and 450 MHz. Other ranges, such as 860-900 MHz and 420-440 can also be used. It is believed that substantially any range between 300-1000 MHz or even up to 3 GHz is useful depending on the heating task being performed. When the broadband, high efficiency amplifiers described above are used, much larger bandwidth of several hundred MHz or more can be swept, within the range of the amplifiers. The sweep may be over several non-contiguous bands, if more than one continuous band satisfies the criteria for use in heating.

[0053] The input reflection coefficients  $S_{11}$ ,  $S_{22}$ , and  $S_{33}$  and the transfer coefficients  $S_{12}=S_{21}$ ,  $S_{13}=S_{31}$ ,  $S_{23}=S_{32}$  are measured during the sweep and a net power efficiency is determined as (for port 1 for example), as:

$$\eta_1 = 1 - (\text{Reflected power from port 1} + \text{coupled power to ports 2 and 3}) / \text{Input power.}$$

[0054] The present inventor has found that under many operating regimes it is desirable to maximize certain criteria.

[0055] In a first embodiment of the invention, the maximum net power efficiency for each port is maximized, in the sense, that the net power efficiency at a point of maximum efficiency within the sweep range is made as high as possible. The efficiency and the frequency at which the efficiency is a maximum is noted. Optionally, the width of the efficiency peak and a Q-factor are noted as well.

[0056] A second embodiment of the invention is based on a similar criterion. For this embodiment the area under each resonance peak of the net efficiency of transfer is determined. This area should be a maximum. The efficiency, the center frequency of the resonance having the maximum area and its width are noted.

[0057] In an embodiment of the invention, the criteria for determining if the variables are properly set is when the peak net efficiency (first embodiment) or the area or a width (second embodiment) is above some predetermined level or a Q-factor is below some predetermined level. For example, there may be a restriction that the area above 60% net efficiency is maximized for each of the feeds.

[0058] It is noted that energy that is neither reflected nor transmitted to the other ports is absorbed either in the walls of the cavity or in the object being heated. Since absorption in the conducting walls is much lower than that in the object by a large factor, the net efficiency is approximated by the proportion of the input power that is absorbed in the object. It is also noted that the frequency of maximum net efficiency is not necessarily the same as the frequency at which the match is best.

[0059] In an embodiment of the invention, the frequency is swept, optionally while adjusting the power. The term swept should be understood to include serial transmission of individual non-contiguous frequencies, and transmission of synthesized pulses having the desired frequency/power spectral content.

[0060] The present inventors have discovered that each frequency has maximal absorption at a specific location within an object within a cavity, which locations may vary between different frequencies. Therefore sweeping a range of frequencies may cause movement of the peak heating region within the object. Computer simulations have shown that, at least when the Q factor of a peak is low (i.e., a lot of energy is dissipated in the object being heated) the movement of the peak heating region can be quite substantial. Furthermore, the inventors have found that each mode (represented by a different peak of efficiency) acts differently when swept.

[0061] Fig. 11A is a simplified flow chart 200 of a method of determining swept power characteristics, in accordance with an embodiment of the invention. This method corresponds to acts 160 and 158 of the flow chart of Fig. 6.

[0062] After placing the object in the cavity (152) the cavity is swept to determine the input efficiency as a function of frequency (202) (e.g., obtain a spectral image). Determination of input efficiency is described in detail above. Alternatively, a pulse of energy, having a broad spectrum in the range of interest is fed into the input. The reflected energy and the energy transmitted to other inputs are determined and their spectrums are analyzed, for example using Fourier analysis. Using either method, the net power efficiency as a function of frequency can be determined.

[0063] Under some conditions, where similar objects have been heated previously, a set of tables for different types and sized of objects can be developed and used as a short-cut instead of closely spaced measurements.

[0064] Fig. 11B shows a simplified net power efficiency curve 250 at an input. It is noted that there are regions in which the efficiency is high and others in which the efficiency is low. Furthermore, some of the efficiency peaks are broader and others are narrower.



**[0065]** Next, the overall swept bandwidth (BW) is determined (204). This may include sweeping across a single peak or across several peaks.

**[0066]** In an embodiment of the invention, during the heating phase, the frequency is swept across a portion of each of the high efficiency peaks. For example, to provide even heating of objects it is believed that the power inputted to the cavity at each frequency should be the same. Thus, in an embodiment of the invention, the power at each frequency is adjusted such that  $P \cdot \eta$  is a constant for all the frequencies in the sweep. Since the power available is always limited to some value, this may set a limit on the available bandwidth for the sweep. An example of a lower limit to efficiency is shown as dashed line 252 in Fig. 11B. The sweep may be limited to frequencies having efficiency above this value.

**[0067]** Next, the positions of the field adjusting elements are set. This adjustment is optional and in some situations, even where such elements are present, they do not need to be adjusted. In general, the criterion for such adjustment is that the peaks have as high efficiency as possible with as broad a peak as possible. Specific applications may introduce additional goals, such as moving the peak to a certain band.

**[0068]** An iterative process (206, 208) is used to determine a desired position and/or orientation of the field adjusting elements. When the search process which may be any iteration process as known in the art, is completed the elements are set to the best position found. (210).

**[0069]** In an embodiment of the invention, the sweep is adjusted (212) to avoid feeding excess power into certain parts of the object. For example, if the object contains a metal rod or a metal zipper, a high peak in efficiency 254 may be generated. A metal rod can cause a concentration of energy near the ends of the rod. Avoiding irradiation at this peak can sometimes reduce the effects of such objects on even heating.

**[0070]** Next, the sweep parameters are determined (214).

**[0071]** Fig. 11C shows the power spectrum 256 of energy to be fed to the input, in accordance with an embodiment of the invention. It should be noted that no energy is transmitted at the frequency characteristic of the rod and that for other frequencies for which the efficiency is above the minimum shown at 252 in Fig. 11B. The power has a shape that is such that the product of the efficiency  $\eta$  and the power fed is substantially constant.

**[0072]** In an alternative embodiment of the invention, the energy is fed to the port in the form of a pulse rather than as swept energy. First a pulse, such as that shown in Fig. 11C is generated by a pulse synthesizer. This pulse is amplified and fed into the input. The pulse synthesizer would then replace VCO 102 (Fig. 5B). It is understood that the pulse synthesizer can also be programmed to produce a sweep for use in determining the frequency dependence of  $\eta$  (act 164 of Fig. 7).

**[0073]** A search is performed for a position of the matching elements at which the net power efficiency at all of the feeds meets the criteria. This is indicated at boxes 214 and 216, which represent a search carried out by changing the positions and/or orientations of the matching elements. Standard search techniques can be used (iteration) or a neural network or other learning system can be used, especially if the same type of object is heated repeatedly, as is common for industrial uses.

**[0074]** When the criteria are met, then the power is raised to a level suitable for heating and optionally swept. The power into the respective amplifiers is optionally normalized to provide a same *net* power into the cavity (and therefore, into the object) for each port. Optionally, the least efficient port determines the power to the object. While in prior art ovens, the user decides on the heating time, in some embodiments of the present invention the desired heating time can generally be predicted.

**[0075]** Returning again to Fig. 6, there are a number of methodologies for performing the heating 170.

**[0076]** In one embodiment of the invention, power is fed to all of the feeds at the same time. This has the advantage that heating is faster. It has the disadvantage that three separate sets of circuitry are needed.

**[0077]** In a second embodiment of the invention, the power is fed to the feeds seriatim, for short periods. Potentially, only a single set of most of the circuitry is needed, with a switch being used to transfer the power from feed to feed. However, for calibration, a method of measuring the power transmitted from port to port should be provided. This circuitry could also be used to match the feeds when power is not being fed to them. A different type of circuitry for providing both the heating and calibration functionality, in accordance with an embodiment of the invention, is shown in Fig. 8, corresponding to the circuitry of Fig. 5B.

**[0078]** The same reference numbers are used in Fig. 8 as for Fig. 5B, except as indicated below. Such a system has the advantage of being much less expensive. It is, of course, slower. However, it does allow for an additional method of equalization, in which the time duration (either alone or in conjunction with changing the input power) during which each feed is fed is adjusted so that the energy into each feed is the same (or different if that is desired).

**[0079]** Fig. 8 is similar to Fig. 5B up to the output of RF switch 116. Following RF switch 116 a second RF switch 192 transfers the power delivered by amplifier to one of the feeds. Only circuitry 200 related to feed 2 is shown.

**[0080]** Circuitry 200 operates in one of two modes. In a power transfer mode, a signal from control 130 switches power from RF switch 192 to dual directional coupler 120, via an RF switch 194. The rest of the operation of the port is as described above. In a passive mode, the input to RF switch 194 does not receive power from amplifier 112. Switch 194 connects a load 190 to the input of dual directional coupler 120. In the passive mode, load 190 absorbs power that is

fed from the cavity into the feed. For production systems additional simplification of directional coupler 120 may be possible, replacing the dual directional coupler with a single directional coupler.

[0081] It should be noted that switches 116 and 192 and optionally the local switches can be combined into a more complex switch network. Alternatively or additionally, RF switch 194 can be replaced by circulator such that power returned from the feed is always dumped in load 190.

[0082] In either the embodiment of Fig. 5B or the embodiment of Fig. 8, the frequency of the power fed to a port can be fed at the center frequency of the resonance mode that couples the highest net power, i.e., the point of maximum efficiency of energy transfer to the object being heated. Alternatively, the frequency can be swept across the width of the resonance or, more preferably along a portion of the width, for example between the -3 dB points of the power efficiency curve, or as described above with respect to Figs 11A-11C. As indicated above, optionally, the power is adjusted during this sweep so that the net input power remains constant or more nearly constant during the sweep. This can be accomplished by changing the power amplification of the power amplifier inversely to the power efficiency of the instantaneous frequency being fed.

[0083] Returning again to Fig. 6, reference is additionally made to Fig. 9, which shows a graph of frequency of a particular peak with time for a typical thawing process. This graph illustrates one method of using the changes in the properties of the object during a thawing process to determine when the process is complete.

[0084] The ordinate of Fig. 9 is the frequency chosen as an input for one of the feeds. The abscissa is time. During thawing of an object, the ice in the object turns to water. Ice and water have different absorption for microwave or UHF energy, resulting in a different return loss and coupling as a function of frequency. Not only does this change the match, but at least after rematching by adjustment of the matching elements, the frequency of the absorption efficiency peak changes. At point A, some of the ice has started to change into water and the frequency of match changes. At point B, all of the ice has changed to water and the frequency of match stops changing. By monitoring the frequency described above and especially its rate of change, the point at which all of the ice is turned into water can be determined and the heating terminated, if only thawing is desired. It is noted that the frequency change during thawing is large, as described herein, compared to allowed frequency changes in the prior art.

[0085] One of the problems of thawing a solid mass of irregular shape and irregular internal structure is that it is generally impossible to determine when all of the ice has been turned to water. Thus, in general, in the prior art, one overheats to assure that no ice is left, which, considering the uneven heating of the prior art, would enhance re-crystallization, if any were left.

[0086] Heating methods and apparatus of the present invention, which allow for both even heating and provide knowledge of the progress of the thawing, can result in much lower or even non-existent re-crystallization.

[0087] Apparatus and method according to the present invention have been used to defrost a pig's liver, Sushi or Maki and to cook an egg in the shell.

[0088] The following table shows a comparison of thawing of a cow liver by the system of the present invention and using a conventional microwave oven.

Table 1: Comparison of Inventive Method and Conventional Microwave- Cow Liver

Measurement	Inventive Method	Conventional Microwave
Initial Temperature	-50°C	-50°C
Final Temperature after thawing	8°C to 10°C	-2°C to 80°C
Power	400 Watt	800 Watt
Thawing time	2 Minutes	4 Minutes
Visible damage	None	The texture of the thawed sample was destroyed. There are frozen regions along side burned ones. No chance of survival of living cells.

[0089] The following table shows a comparison between thawing of Maki containing raw fish covered by rice and wrapped in seaweed, by the system of the present invention and using a conventional microwave oven.

Table 2: Comparison of Inventive Method and Conventional Microwave-Maki

Measurement	Inventive Method	Conventional Microwave
Initial Temperature	-80°C	-80°C
Final Temperature after thawing	2°C to 6°C	-5°C to 60°C
Power	400 Watt	800 Watt
Thawing time	40 Seconds	1 Minute
Visible damage	None	The thawing process cooked part of the salmon, therefore it was not Maki anymore.

**[0090]** An egg was cooked using the present method. Generally, eggs burst if an attempt is made to cook them in a microwave oven. However, using the system described above an egg in the shell was cooked. The white and yellow were both well cooked, and the white was not harder than the yellow. Neither part was dried out or rubbery and the taste was very good, with little if any difference from a conventional hard cooked egg. In addition, deep frozen fish have been defrosted without leaving any frozen portions and without any portions being heated above cooking temperatures.

**[0091]** In each of the above experiments, the frequency and power were adjusted automatically and the matching elements were adjusted manually, in accordance with the method given above for automatic adjustment.

**[0092]** The inventors believe that the methodology of the present invention is capable of thawing objects that are deep frozen to just above freezing with a temperature variation of less than 40 °C, optionally less than 10 °C, 5 °C and even as low a difference as 2 °C. Such results have been achieved in experiments carried out by the inventors, for a cow liver, for example.

**[0093]** Thawing objects such as meat and fish with such low differences and at high speed has the potential for prevention of development of salmonella, botulism and other food poisons. Controlled, uniform thawing has important implications in thawing organs for transplanting, without tissue destruction.

**[0094]** Fig. 10 shows apparatus for applying a DC or relatively low frequency (up to 100 kHz or 100 MHz) to an object in the cavity, in accordance with an embodiment of the invention. This figure is similar to Fig. 1, except that the cavity includes two plates 250 and 252. A power supply (not shown) electrifies the plates with a high differential voltage at DC or relatively low frequency. The objective of this low frequency field is to reduce the rotation of the water molecules. Ice is water in a solid state therefore its rotational modes are restricted. A goal is to restrict the rotational modes of the liquid water in order to make the heating rate be determined by that of the ice. The present inventors also believe that the low frequency fields may change the dielectric constant of the materials making up the object being heated, allowing for better match of the input to the object.

**[0095]** In an alternative embodiment of the invention a DC or low frequency magnetic field is applied by placing one or more coils inside or preferably outside the cavity to cause alignment of the molecules in the object. It is possible to combine low frequency or DC electric and low frequency or DC magnetic fields with possible different phases from different directions.

**[0096]** Fig. 12A shows a cavity 98 with an internal heater coil 600 placed inside the cavity. An inlet 602 and an outlet 604 allow for feeding a hot fluid through the coil to heat the air within the cavity.

**[0097]** Figs 12B and 12C show two schematic illustrations of a system for transferring heat from a high power amplifier 606 to the coil. Even at an efficiency of 60%, the amplifier can generate several hundred watts. This energy (or at least a part of it) can be transferred to heat the air and to produce infrared radiation (as a resistive coil does) in the cavity to increase the efficiency of heating.

**[0098]** Fig. 12B shows a very schematic diagram to illustrate how waste heat from an amplifier 606 can be captured. Fig. 12C shows a block diagram of the same system. Element 608 represents a cooling system for returning fluid and a fluid pumping system. It receives return fluid from outlet 604, cools the liquid (if necessary) and pumps the liquid into a gap 610 between the between amplifier 606 and an optional heat sink 612. The temperature at the input to the gap and at its output are preferably measured by sensors 614 and 616 and fed to a control system 618, which controls one and optionally more than one of the cooling and pumping rate to provide a desired heat transfer to the cavity. A fan 620 may be provided to cool the heat sink as necessary. The fluid passing between the amplifier and the heat sink also functions to transfer heat from the amplifier and the heat sink. Optionally heat conducting rigs may transfer heat between the amplifier and the heat sink with the fluid passing between the ribs to collect heat.

**[0099]** Alternatively, heat pipes or other means can be used to collect and transfer energy to the cavity. Alternatively, hot air could be passed over the amplifier and/or heat sink and passed into the cavity.

**[0100]** Use of high efficiency amplifiers with or without heat transfer to the cavity can result in highly efficient systems,

with an overall efficiency of 40-50% or more. Since amplifiers with relatively high (40V-75V) voltages are used, the need for large transformers is obviated and heat sinks can be small or even no-existent, with the amplifier transferring heat to the housing of the heater.

**[0101]** By optimizing the system, a heater as shown in Fig. 12D, including a housing 650, amplifiers and controller, as well as a user interface 652 and a door 654, as normally found on a microwave oven can weigh as little as 10 or 15 Kg or less.

**[0102]** While applicants have utilized UHF frequencies for heating in the examples described above, rather than the much higher 2.45 GHz used in the prior art, for heating applications other than thawing, a different frequency may be desirable. UHF frequencies are absorbed preferentially by ice and have a longer wavelength than the higher frequencies, so that the fields within the object are more uniform and the ice is preferentially heated as compared to the water. This provides for preferential heating of the ice and more even thawing.

**[0103]** Additional measures that may be taken to improve the uniformity are:

1) Various types and sizes of conducting materials such as tiny grains of powdered conductive material (gold) may be inserted into the sample preceding the freezing process (e.g. through the circulation of the blood or cooling fluid) and serve as reflecting sources. The insertion can be done using some template of non-conducting material (absorbing or not) holding the conducting objects. These passive energy sources can improve the uniformity of EM radiation absorption.

2) Penetration of materials that change their dielectric characteristics dependent upon temperature in a fashion that is different than that of the sample. Injecting these materials will enable changes in the dielectric characteristics of the sample in the direction desired for achieving uniform and fast warming.

3) Use of probes for measurement of various parameters of the warming process such as temperature, pressure, and so on: These probes can be inserted inside the sample preceding the freezing process or attached adjacent to the sample at any stage of the process. Measurement of these parameters provides a means for supervision (control) of the warming process such that if the warming is not optimal it will be possible to make changes in various parameters of the process. There are probes available that are suited for measurement during warming in a microwave device. These probes can also serve as an indication of when to stop a thawing or cooking process.

Such probes may be included in a bag in which the object to be heated is placed and may include a resonant element whose resonant frequency is made to vary with temperature by the inclusion of a temperature dependent element such as a temperature dependent resistor or capacitor.

Probes may be provided with resonant circuits whose frequency depends on temperature. Such probes may be scanned during the scanning used for setting sweep parameters to determine temperature. During power transfer, these frequencies should generally be avoided. In an embodiment of the invention, a temperature sensitive tag is paired with a temperature insensitive tag and the changes in the frequency of the temperature sensitive tag are determined by a difference frequency between the two. This allows for a more accurate measurement of temperature that utilizing an absolute measurement of the frequency of the temperature sensitive tag.

4) Wrapping of the sample in material that does not absorb EM radiation at the specified frequencies: This type of wrapping can serve as packaging for the sample during transportation and as part of the probe system by which it is possible to measure temperature and additional parameters at the edges of the sample. This wrapping can serve as local refrigeration for the outer surfaces of the sample (which usually have a tendency to warm faster than the rest of the sample) in order to achieve uniformity in the warming of the sample.

**[0104]** Further, the wrapping can include identification of the object to help track the object and also to provide an indication to the system of a preferred protocol for heating the object. For example the wrapping may be provided with a number of resonant elements which can be detected when the cavity is swept during calibration. The frequencies of the elements can be used to provide an indication of the identity of the object. This allows for the automatic or semi-automatic setting of the starting parameters for calibration and/or for a particular heating protocol, optimized for the particular object and conditions.

**[0105]** Alternatively or additionally, to resonant circuits, a recording/storage element of a different type is provided, for example, in the form of an RFID element or a bar-code, which includes thereon an indication of the content of a package or wrapper including the object, suggested treatment thereof and/or heating instructions. In an exemplary embodiment of the invention, the instructions are actually provided at a remote site, indexed to a key stored by the recording element. Such instructions may be, for example, stored in a table or generated according to a request, based on information associated with the identification.

**[0106]** A reader is optionally provided in the heater, for example, an RFID reader or a bar-code reader to read information off a package or a wrapper thereof.

**[0107]** In an exemplary embodiment of the invention, after the object is prepared, various types of information are optionally stored on (or in association with) the recording element, for example, size, weight, type of packing and/or

cooking/thawing/heating instructions.

**[0108]** In an exemplary embodiment of the invention, the recording element has stored therewith specific cooking instructions. Alternatively or additionally, the recording element has stored therein information regarding the platter shape and/or dielectric properties of its contents. It is noted that for industrial shaped portions, if the shape of the food is relatively regular between platters, movement of the food and/or changes in size and/or small changes in shape will not generally affect the uniformity by too much, for example, shifting a heating region/boundary by 1-2 cm. Optionally, the platter includes a depression and/or other geometrical structures which urge the food item to maintain a desired position relative to the platter borders.

**[0109]** During heating of the food, the parameters of the heating are optionally varied. The effect of the varying may cause non-uniformity in space and/or in time. In an exemplary embodiment of the invention, a script is provided which defines how and what to vary. Optionally, the script includes decisions made according to time (e.g., estimation of an effect) and/or food state (e.g., measurement). Various measuring methods are described above. Estimation is optionally based on a simulation or on empirical results from previous heating cycles. Optionally, the script is conditional (e.g., modified, generated and/or selected), for example, based on the position of a platter in the oven and/or personal preferences (which may be stored by the oven).

**[0110]** In an exemplary embodiment of the invention, a script is provided on the recording element or at a remote location. Optionally, a script is selected by a user selecting a desired heating effect.

**[0111]** In one example, a single food item may experience different power levels for different times, in order to achieve a desired texture/flavor.

**[0112]** In an exemplary embodiment of the invention, a script is used to set different energy levels and/or different times to apply such energies.

**[0113]** In one example, a script is as follows:

- (a) Heat all platter so that the food reaches a relatively uniform temperature of 5 degrees Celsius.
- (b) Uniformly heat whole platter at 80% for 5 minutes and then full power for 10 minutes.
- (c) Heat to 40 degrees Celsius.
- (d) Maintain heat for 10 minutes. It is noted that a desired heat can optionally be maintained by estimating the energy absorption while applying a known amount of cooling. Alternatively, actual heat absorption may be estimated based on a known amount of energy absorption and a measurement of air temperature leaving the cavity. Optionally, the oven includes a source of cooling air and/or has coolable walls and/or tray.
- (e) Reduce heat to 30 degrees Celsius.
- (f) Wait 10 minutes.
- (g) Report "done" but leave at 30 degrees Celsius until removed.

**[0114]** In an exemplary embodiment of the invention, the script includes other conditions, for example, detecting changes in color (e.g., browning), steaming (e.g., by phase change of water), volume (e.g., dough rising will change the behavior of the cavity in ways that can be anticipated).

**[0115]** Optionally, the script includes a request to the user to add ingredients (e.g., spices), or to mix or reposition object.

**[0116]** In an exemplary embodiment of the invention, the script takes into account the quality of uniformity control achievable by the oven. For example, if a higher level of uniformity is desired than basically provided by the oven, heating may include pauses where power is reduced, to allow heat to even out in the object. The length of the delays is optionally pre-calculated for the food substances and a calibrated lack of uniformity of the oven. Alternatively or additionally to reducing power, the food and/or the heating areas may be moved one relative to the other so as to better distribute heating.

**[0117]** In an exemplary embodiment of the invention, no script is provided. Instead, the heating times and/or parameters are based directly on the desired results, measured food properties and/or measured heating properties. Such desired results may be user provided or indicated by the recordable element.

5) Liquid injection: (similar to cooling liquid) that is suitable for a biological sample, the purpose of which is to cause uniform warming: This liquid is used in the field of hyperthermia. In this field warming of a biological area is done in order to remove a cancerous growth. From knowledge derived from this field it is possible to understand that a liquid such as this can cause a drastic change in the warming uniformity and can enable use of a warming device that is more simplified than would be required without its use.

6) Penetration of active radiation sources in the sample during the freezing process: These sources are active, which means connected to an external supply line that will be used as a source of EM radiation that will emanate from within the sample.

**[0118]** The present invention has been described partly in the context of thawing. The inventors believe that based on the results shown above, it can be expected that the methods of the present invention, can be used for baking and

cooking, areas in which conventional microwave ovens are notoriously weak or for other heating operations, especially those for which a high level of uniformity or control is needed and/or in which a phase change takes place.

[0119] Utilizing various embodiments of the invention, the UHF or microwave energy may be deposited uniformly in an object to within less than  $\pm 10\%$ ,  $\pm 20\%$  or  $\pm 30\%$  over 80% or 90% or more of the object.

#### **Exemplary food preparation processes**

[0120] Fig. 13 is a flowchart of an exemplary process 1300 of food preparation in accordance with exemplary embodiments of the invention. After a brief review of the flowchart, each act will be expanded on. It should be appreciated that the order of acts may be varied and that several of the acts shown are optional. The process shown includes food preparation, storage and consumption, generally at a remote location. In some cases, only the preparation and/or consumption portions of the process are carried out.

[0121] At 1302, the food is arranged for processing, for example, being cut to size.

[0122] At 1304, the food is optionally pre-processed, for example, a surface thereof dried (e.g., air-dried) or spices added.

[0123] At 1306, the food is optionally cooked. Optionally, food is processed during cooking, for example, spices added.

[0124] At 1308, the food is cooled, frozen, canned and/or otherwise prepared for storage.

[0125] At 1310, the food is packaged. As will be described below, the packaging is optionally selected to match the food shape and/or reheating process. In some cases, the food is packaged at an earlier stage.

[0126] At 1312, one or more properties of the food are optionally measured. Such measurements may be stored for example, on the package or at a central location.

[0127] At 1314 the food is delivered, for example, to stores and/or restaurants.

[0128] At 1316, the food is heated, for example, for thawing or cooking. Optionally, various properties of the heating/food (e.g. a spectral image, e.g., a scan of the dissipation of RF energy at different frequencies) are measured (1318) and used to adjust heating parameters (1320). Alternatively or additionally, one or more properties of the heating/food are estimated (1322) and the heating parameters are modified (1324). The modification may be, for example, spatial (e.g. moving patches and or the heated object and/or changing the frequencies), and/or heating profile (i.e. the frequencies transmitted and the matching powers) (e.g., a time/frequency/power triplet).

[0129] It is noted that the movement of the object affects the spectral image (e.g. the absorption in each frequency). The triplet defines the transmission selected. For each frequency there is a time of transmission and a power of transmission (thereby generating the triplet). The longer the heater transmits in a given frequency at a given power, the more energy is dissipated in the object. Movement may affect the decision of whether or not to transmit at a given frequency, at what power and for how long. It should be noted that in some embodiments of the invention, location/movement are not "measured" directly, but often affect the spectral image. It is noted that the total absorbed power may be estimated using methods as described herein.

[0130] At 1326, the food is optionally consumed and/or classified for consumption according to the quality of the food preparation and/or storage.

[0131] The following discussion is loosely based on two examples, one of preparation of food portions, in which multiple food items are provided on a single platter and one of industrial preparation of food, such as a fish. Other examples include, omelet, rice, meat, cake, fresh fruit or vegetables, salad, dairy products, seasonal products, short shelf life products, medicine and/or food additives.

#### **Exemplary RF heater**

[0132] Fig. 14 is a schematic cross-sectional view of an RF heater 1400, in accordance with an exemplary embodiment of the invention. This heater may be used, for example, for cooking/heating/thawing, including 1306 and 1316 of Fig. 13. Heater 1400 generally follows the description of Figs. 1-10, showing radiator antennas 16, 18 and 20 and field adjusting elements 22/24. RF system 96 and computer/controller 130/92 as described above may be used, optionally with different programming as described below. As indicated by the shape in the figure, the cavity may be rectangular or have another form. In particular, the controller may contain an ASIC and optionally include an ability to execute RF simulations. Other implementation methods, including software, firmware and hardware may be used. Optionally, the controller includes one or more tables of desirable settings to use under various input conditions to achieve desired outputs. Such tables may be generated/calibrated on an individual device basis or for a plurality of optionally similar devices. Variations of the above design may be provided as well. Some embodiments of the invention may be practiced, possibly with reduced quality, using a standard microwave oven. The following elements are described briefly and then again as part of the exemplary food preparation process.

[0133] Optionally, the oscillators for sweeping and for heating are different, for example, using a VCO for sweeping, optionally with periodic calibration and a stable oscillator for heating. An exemplary such system is described in US

Provisional Patent Application No. 60/924,555 filed 21 May 2007 for ELECTROMAGNETIC HEATING, the disclosure of which is incorporated herein by reference.

[0134] An optional imager 1402, for example an X-Ray imager, a millimeter wave imager or CCD is used to obtain an image, optionally including water concentrations and/or dielectric properties of a food item placed on a tray 1406.

[0135] Tray 1406 optionally has one or more guide elements 1408 to ensure correct placement of food (especially food provided in suitably designed packages) thereon. Optionally the oven is programmed or programmable to act differently for certain package designs. Tray 1406 is optionally mobile, for example, using an actuator (not shown).

[0136] A reader 1404 is optionally provided, for example, an RFID reader or a bar-code reader to read information off a package. Optionally, the reading is done by same sensor as used for the sweeping, possibly at a different frequency. It is noted that even if the heating antenna are optimized for a certain frequency range, they can still operate at other ranges, harmonic or not.

[0137] The information read off the package may, in some embodiments, include instructions regarding the desired taste, texture and/or other effect of the food preparation (e.g. browning, whether a steak should be raw or well done, etc.). For example, a steak package may include at least two distinct operation instructions - well done but less crispy or medium and more crispy. After acquiring the information from the package, the oven may prompt the user to select between the modes. Each mode dictates, for example, what power level(s) to use at what frequency and when, whether or not to provide power that would dissipate in a crisping element and how much and when to provide same. In addition, the oven might be sensitive to the power absorbed in the object or a portion thereof, and upon achieving a pre-determined change, the change is detected by the oven and the oven can react and change the heating mode. For example, the package can include a liquid that expands during heating. As the cooking progresses the steam created by the liquid opens the package, and the device detects the change in the spectral image (due to the phase change of water), which can be used to decide to turn on a browning mode. Alternatively, a packaging site (take away at a restaurant or industrial facility) may use different packages, each with distinct instructions for heating modes (e.g. fast and less uniform or vice versa). Thus a user may purchase packed food that would heat at the user's preferred heating rate (rather than only the desired cooking effect). Alternatively or additionally, one or more sensors 1410 read a size, weight and/or machine readable information of a package, once the package is placed on the tray. Alternatively or additionally, a user enters the information, for example, into a keypad of an RF oven or using an external bar-code reader.

[0138] In an exemplary embodiment of the invention, a radiation blocking baffle 1412 is provided which can be selectively positioned (e.g., 1414) to block radiation from food on tray 1406. While a rotary hinge activated by an actuator 1416 is shown, other designs may be used, for example, baffles which come from two or more sides of the food, and sliding baffles.

[0139] In an exemplary embodiment of the invention, one or more environmental control elements 1420 are provided, which may be used, for example, to control ambient temperature, air turbulence, humidity and/or pressure. Optionally, the one or more environmental control elements 1420 include a UV lamp. Optionally, the UV lamp is used to reduce contamination and/or bacterial growth during a keep warm operation or other long-term operations. Optionally, an environmental sensor 1422 is provided to assist in closing a feedback loop on the environment. In some cases, the RF absorption spectra indicate one or more environmental conditions, such as humidity level. In some cases, heating is modified to take into account existing environmental conditions.

[0140] In an exemplary embodiment of the invention, one or more conventional heating modules 1424 are provided, for example, an IR heater or a steam source.

#### **Dedicated devices and/or modes**

[0141] In some embodiments, the heater may be configured to maintain food at about a given temperature (e.g. about a given temperature or within a predetermined zone such as 40-45°C). In some embodiments, a dedicated heater capable of substantially only maintaining temperature is provided. In an exemplary embodiment of the invention, a heater can be set to a mode where any opening and closing of its door (if any) cause the device to automatically attempt to heat/cool an object therein (optionally only if the presence of an object is detected, e.g. by a frequency scan or weight detection) to the target temperature. Maintaining a temperature may be useful, for example, in restaurants, where a dish is maintained at a temperature suitable for serving, but desirably without damaging of the dish and/or allowing growth of pathogenic microbes. The heater may include one or more cooling elements (e.g., refrigerator coils or a cool air source) for reducing temperatures.

[0142] A "keep warm" mode may be provided in various manners, including:

(a) In an exemplary embodiment of the invention, the heater allows the food to cool or even freeze (e.g., the heater actively cools the food), and then warms the food to the desired temperature upon demand. Optionally, the cooling and heating effects apply to a same portion of the oven. Alternatively, the food may be moved between parts and/or compartments of the oven and/or a cooling coil and/or an RF heating element may so be moved (e.g., using rails

or a robotic arm). In an exemplary embodiment of the invention, the heating terminates when the object reaches the desired keep-warm temperature.

**[0143]** Alternatively, or additionally, the heater includes one or more radiation sensors which detect energy/heat emission during cooling and the controller controls the heater to input the same missing energy upon demand. Temperature measurement may be, for example, in the heater chamber, on the plate, or by sensing the food itself (e.g. IR sensor or optical fiber). In an exemplary embodiment of the invention, the reheating on demand uses a suitable power so that heating time is very short, for example, less than 1 minute, less than 30 seconds, less than 10 seconds or less than 3 seconds (e.g., if sufficient power is provided for the food size, for example, 27KW for 300gr of meat).

**[0144]** In an exemplary embodiment of the invention, an optimized starting configuration is determined during a prior heating step, so that reheating can proceed faster and with greater assurance. Alternatively or additionally, a fast scanning is carried out (e.g., 3-4msec. For example, if an object is to be thawed in 20 seconds significant changes in the spectral image could be detectable in about 2 seconds. Optionally, 10 sweeps/second are carried out, which slow down the thawing by about 1.5% of the time. Fewer sweeps can be carried out, for example 2 sweeps/sec. It should be noted however, that if the heating includes adjusting patches, each adjustment typically requires a repeated sweep before heating begins and takes time to perform. In an exemplary embodiment of the invention, a package is provided that details the starting conditions/configuration and the maximal bandwidth that may be reached by moving the patches (e.g., a best achievable result). Optionally, the package includes an average convergence time (or other statistic of the simulation). A significant deviation from the average can indicate that there might be a problem with the package and/or the heater. Optionally, in such a case, the heater uses the best result that was found even if it is not nearly as good as the expected result. Alternatively or additionally, the heater may report a problem (e.g., to user or via network).

**[0145]** Alternatively or additionally, the package information is used to reduce the number of sweeps. For example, if one heater repeats the sweep 15 times and averages the results, having "original" sweep results can allow the number of sweeps to be reduced (e.g., only to find a deviation), thus allowing a single sweep to be shorter than 1 msec, for example, 10s or 100s of microseconds.

**[0146]** Based on experimental results, the following heating times are estimated for food preparation using a 27KW heater:

- i. 400 gr beef from fresh to well-done in under 9 seconds at 27KW.
- ii. 100 gr sushi from -80deg C to thawed at 2-6deg - less than one second at 27KW.
- iii. 1.3 Kg chicken from -10 to about 2-6 deg C- about 4 seconds at 27KW

(b) In an exemplary embodiment of the invention, the food is maintained continuously at a same temperature, for example, to within 10 degrees, 5 degrees, 3 degrees or 1 degree or even 0.5 degrees (Celsius). In an exemplary embodiment of the invention, the temperature is maintained by one or more of providing heated air at the target temperature, blowing steam at a desired temperature at the food into the device or by inputting RF at low power or intermittently, such that the object would not cool below a first temperature nor heat above a second temperature. The temperature may be measured as detailed above or a predetermined heating may take place based on experimental results with like food quantities.

**[0147]** In an exemplary embodiment of the invention, the user interface of an oven according to the present invention may be reduced and/or simplified to improve the ease of operation. An oven may be for example dedicated to reach a desired final temperature (e.g. refrigeration temperature 4-8°C or room temperature (20-25°C) or any other temperature (e.g. 50-65°C, etc.). By inserting food into the oven (and optionally pressing a single button) the user activates the oven and the device terminates heating upon reaching the desired temperature, at which time it may notify the user and optionally switch to a keep-warm mode. Optionally, the oven has several final temperatures (e.g., 5-10 options each defining a temperature range of 4-10°C, covering a range between 0 and 100°C) and the user may choose the final temperature. For example, the options may be limited to partially thaw (-5-0°C), thaw (4-8°C), room temperature (20-25°C), warm (40-50°C), hot (60-70°C) and very hot (90-100°C).

**[0148]** In an exemplary embodiment of the invention, the heater has a mode that prevents unauthorized users (e.g. children) from reaching a temperature that is considered less safe (e.g. 35-40°C or more or 45-50°C or more). A similar feature may be provided to prevent damage to food or packaging or prevent fires (e.g., based on temperature or energy absorption). The temperature is optionally provided on a package or pre-stored in the heater. One setting may be pre-set to override the other. Optionally, the limiting feature is applied by requiring a special code for any step including a temperature above the limit. Alternatively or additionally, the heater door may be locked such that it would not open as long as the object temperature is higher than the safe temperature, unless a user override (e.g. code) is used. This feature may use any method of sensing the object temperature, including those of the prior art in prior art heaters. Alternatively or additionally, the rate of heating of the object may be used to calculate the cooling rate (of the object and/or a part of the packaging) and the time after heating when the door may be opened freely. ( $E = mC_p\Delta T$ , and E and



$\Delta T$  are known). Optionally, the oven supports an option of choosing a desired rate of heating which would cause the oven to either use more power or be less uniform.

**[0149]** In an exemplary embodiment of the invention, the oven is capable of automatically calculating a proper operation mode, regardless of food shape/ size/ composition/ geographic location, using for example the frequency sweep method described herein and/or using a temperature sensor, thereby supporting simplification of the interface.

#### **Arrange food (1302)**

**[0150]** In an exemplary embodiment of the invention, the food is shaped and/or arranged in a manner which matches the intended processing steps. For example, food may be arranged to have (relatively) uniform weight, thickness and/or shape. For foods in meal platters, the different foods are optionally each arranged in a predetermined compartment of a platter. Optionally, a food item is provided which affects the later processing, for example, a layer of fat or of ice may be used to later baste and/or shield a part of the food. In an exemplary embodiment of the invention, when selecting food, a note is taken of the food freshness and/or other properties thereof. Optionally the selection takes into account planned processing steps. Alternatively, the processing is modified to take the food properties into account. For example, different thawing instructions may be provided for overripe and under ripe fruit or for old fruit.

#### **Pre-Process (1304)**

**[0151]** In an exemplary embodiment of the invention, the food is pre-processed, for example, injecting water, injecting fat, adding spices or other flavoring agents and/or preservatives, adding cryogenic agents which affect the freezing process (such as alcohol), blanching, pasteurizing or enzyme deactivation (e.g., using a uniform field as described below), washing, sterilization and/or drying out of an outside layer (e.g., to reduce microwave radiation absorption at this layer and/or enhance flavor absorption), optionally using a uniform field which is limited to the layer and does not significantly extend into the food item. In some cases the food is pre-processed before arrangement and/or pre-processed both before and after arrangement, possibly applying different pre-processing types. Optionally, one or more agents are injected to improve heating process characteristics, such as by lowering Q factor, improving absorption (for example by adding salt, such as in kosher products), improve composition homogeneity and others. Other pre-processes may be selected in order to improve the spectral image (e.g. lower Q factor), as well, for example, immersion in an RF absorbing liquid. Optionally, part of the object (e.g., its surface) is differentially treated. For example, the surface is made more moist or more dry than the rest of the object such that during heating it will (or will not) dry and become more crispy or browned.

#### **Cook (1306)**

**[0152]** Some types of food are cooked or partially cooked before delivery. Any known method of cooking may be applied, including heating in a relatively uniform manner as described above. In some cases, the food is at least partially packaged before being cooked.

#### **Freeze/cool (1308)**

**[0153]** The food (cooked or otherwise) is cooled or frozen, or otherwise prepared for storage, for example, by canning (where uniform microwave heating may be applied for non-metallic packages). In an exemplary embodiment of the invention, cooling uses controlled directional cooling, for example, using a temperature gradient as described in US patent 5,873,254 and PCT publications WO 2006/016372 and WO2003/056919 to applicant IMT, the disclosures of which are incorporated herein by reference, or by uniformly heating a part of the food using microwave energy while cooling the food, and changing the heated part (relative to the food item) so that a freezing front propagates in a controlled manner. In an exemplary embodiment of the invention, the freezing is controlled to prevent damage to the texture of the food. It is noted that the feedback from microwave heating signals can be used to determine the state of freezing of a food sample, for example, by detecting dielectric property changes associated with phase and/or temperature changes.

#### **Package (1310)**

**[0154]** As noted above, the food may be packaged at an earlier stage, for example, before cooking. In an exemplary embodiment of the invention, the packaging is selected to assist in later spatially controlled microwave heating.

**[0155]** Fig. 15 illustrates an exemplary food platter 1500 for use in packaging in accordance with exemplary embodiments of the invention (e.g. in a microwave oven and/or RF heater). A body 1502, for example of molded plastic defines one, two or more compartments 1506 and 1510, in which foodstuffs, for example different foodstuffs 1504 and 1508 are

provided.

[0156] In an exemplary embodiment of the invention, platter 1500 is designed to assist in non-uniform heating of food (e.g. so that at least one food item is heated differently from at least one other food item or that a certain food is heated in layers). In an exemplary embodiment of the invention, the RF is emitted into cavity is uniformly and one or more techniques are used to vary the uniformity of energy absorbed by food. Methods that relate to utilizing packaging for controlling non-uniformity are described following.

[0157] In an exemplary embodiment of the invention, a microwave absorbing element 1512 is provided on one or more sides of a food compartment, changing the amount of energy entering into a portion of the compartment to heat food therein. Alternatively or additionally, energy absorbing and/or reflecting element 1512 is used to scorch/burn a pattern on the food when warmed (e.g., in the form of a grilling mesh on a meat dish). According to an embodiment of the present invention, the oven may select one or more times during heating wherein the frequencies that interact with element 1512 are transmitted (or are not transmitted), thereby defining when the effect of this element will, or will not, take place.

[0158] In an exemplary embodiment of the invention, a radiation absorbing and phase changing element 1514 is provided which changes its radiation absorption as it heats, thereby temporally modifying the radiation entering a nearby compartment. For example, the material may be set to melt at a certain desired temperature. Alternatively or additionally, the change in absorption is noted by a feedback system of the oven and used to detect temperature changes in the food. Optionally, heating of element 1514 is used to provide radiative or contact heating of a nearby foodstuff 1504. Multiple elements 1514, each with different phase change temperatures may be provided. Element 1514 may be a passive source (e.g. an organized structure with a predetermined frequency response, such as dipole). Optionally, passive sources (optionally completely non-emitting) are provided which are selectively activated by selectively applying or not applying frequencies to which these sources react.

[0159] One or more microwave transponders 1520 are optionally provided which generate a coded interference with the microwave in the cavity. In general, interference with the microwave cavity behavior can be detected by analyzing the resonant properties of the cavity. The coding may be used to determine the relative amplitude of the field at each point along the platter, thereby assisting in matching the modes of the microwave cavity to the placement of food therein. If only one transponder is used, it may be uncoded (since there may be no need to differentiate between transponders) and comprises, for example, a reflective element, possibly one which preferentially reflects at a certain frequency. In an exemplary embodiment of the invention, the interference element is an active element that includes a receiving element, a modulator and a transmitting element, for example a frequency doubling element may be used.

[0160] A non-RF transponder may be provided, for example, an ultrasonic transponder.

[0161] One or more temperature sensors 1516 are optionally provided. Optionally, the sensors generate a signal or interference with the field, for example, until a critical temperature is reached, at which time a part of the sensor melts or otherwise changes its electrical behavior (e.g. using a resonant structure that has a specific absorption profile. If the structure melts, its absorption pattern is no longer detected). Alternatively or additionally, an RF responding temperature sensor is provided. A more complex transponder element may include a temperature sensor that modifies the modulation according to the temperature. Another example is a simple circuit including a coil and/or a capacitor, wherein the geometry of the element (and therefore its behavior) changes as a function of temperature, for example, due to mechanical distortion thereof. In an exemplary embodiment of the invention, the oven is designed to work with a TTT (temperature sensitive/transmitting tag), as described above. As noted above, the oven is optionally designed and/or controlled to avoid transmission at the frequencies used by the TTT. In a non-RF example, there is provided a bar-code that darkens (at least in part) as a temperature is achieved or a material that changes color as a temperature is reached, for example, liquid crystals. Optionally, multiple temperature indicators are provided on the package, thereby giving an indication of uniformity of heating. Optionally an imaging sensor is provided below the tray, to image temperature on the bottom of the tray, where contact between the food and packaging is better guaranteed. Such sensors are optionally used to provide feedback on actual cooking conditions as exhibited by the food.

[0162] In an exemplary embodiment of the invention, a recording element 1518 is provided, for example, in the form of an RFID element or a bar-code, which includes thereon an indication of the content of the package, suggested treatment thereof and/or heating instructions. In an exemplary embodiment of the invention, the instructions are actually provided at a remote site, indexed to a key stored on element 1518.

### **Measure (1312)**

[0163] In an exemplary embodiment of the invention, after the food is ready (e.g., packaged for storage), various types of information are optionally stored on element 1518, for example, size, weight, type of packing and/or cooking/thawing/heating instructions. In an exemplary embodiment of the invention, measuring includes radar, ultrasound or RF imaging which indicates shape uniformity and/or amount of water. Optionally, measuring is performed before sealing the packaging. In an exemplary embodiment of the invention, the information is not directly stored on element 1518. When element 1518 is read, an index is read which is used to access remotely stored information.

**[0164]** In an exemplary embodiment of the invention, an oven is configured as a condition recorder. For example, a user may put an object in the oven (condition recorder). The oven will measure a few characteristics (e.g. RF response (dielectric function), weight, color and/or the volume or any other characteristic) and provide a record of the object (e.g. stored in the oven, sent over a network and/or printed out as a sticker or tag or programmed into a programmable tag).  
 5 Optionally, when the same object is inserted again in the oven, the oven may measure the object again and provide a comparison between the first and second sets of measurements. This comparison may indicate a condition of the sample, for example, dehydration.

**[0165]** In an exemplary embodiment of the invention, a first device is used for the first measurement and a tag is issued with that data (e.g. at a site of production) and later (e.g., at a site of consumption) a second oven reads the tag and confirms quality unchanged. If a single oven is used, a user may indicate the identity of the object to the oven (e.g., before and after storage).  
 10

**[0166]** An example of unwanted change is that if meat is stored in bad condition it may lose color (scanning can include a CCD or other image) and/or water. The changes indicate normally that the food was not stored properly. Examples of wanted change are ripening of fruit and rising of dough (e.g., if dough is left in the oven while rising, even if the oven only scans the dough). It should be noted that such scanning can be done independent of cooking, for example, purchased food can be scanned to define an initial value, and then again, before use scanning may be used to detect damage that might have occurred during storage at home, or possibly even the time that lapsed. Optionally, a table for expected spectral changes for various items is stored in the heater/scanner, for example, changes due to water loss, ripening or decomposition.  
 15

**[0167]** In an exemplary embodiment of the invention, an element like element 1518 is used for non-platter items, for example, for frozen fish, for example, in the form of a tag.  
 20

#### **Deliver (1314)**

**[0168]** Different types of food may be delivered in different ways. In one example, food is delivered to a restaurant on demand based on orders placed the night before. In an exemplary embodiment of the invention, the food is prepared according to individual preference and/or diet restrictions. In an exemplary embodiment of the invention, the preparation instructions associated with element 1518 are modified to match personal preferences. Optionally, the modification is at order time. Alternatively or additionally, the modification is when a user actually comes to collect food.  
 25

**[0169]** In an exemplary embodiment of the invention, food is made ready at a time a person orders the food.  
 30

**[0170]** In an exemplary embodiment of the invention, delivery is to a supermarket or to users at home.

**[0171]** In an exemplary embodiment of the invention, delivery is to an automated vending machine which optionally includes a controllably uniform/non-uniform heater as described herein for heating/cooking the food. In an exemplary embodiment of the invention, such a vending machine includes one or more storage compartments (e.g., refrigerator and/or freezer) and one or more heating compartments (optionally continuous with storage). When food is "ordered" the vending machine transfers the food (one or more types) to a heating portion and thaws/warms/heats the food, according to user or oven instructions (optionally based on a tag attached to the food. Optionally, a plurality of food-stuffs are heated and served together, for example, on a same platter, to the same or to different temperatures. Optionally, the food is made ready fast, for example, in a minute or less. Optionally, and unlike other vending machines, heating uses the methods described herein so there is less dependence on portion size, composition and/or position, in achieving edible results.  
 35  
 40

**[0172]** In an exemplary embodiment of the invention, the food is prepared on premises for a large feeding organization, for example, a restaurant or employee meal plan.

#### **Heat/Cook (1316)**

**[0173]** In an exemplary embodiment of the invention, the controllably uniform/non-uniform heating method described above is used to heat and/or cook the food. In an exemplary embodiment of the invention, reader 1404 of heater 1400 is used to read element 1518 and determine a desired cooking/heating setting and/or more complex configuration.  
 50

**[0174]** In an exemplary embodiment of the invention, element 1518 has stored thereon specific cooking instructions (e.g. the amount of power that is to be absorbed in the food within a given period of time, and potentially also changes in the rate of energy absorption). Alternatively or additionally, element 1518 has stored therein information regarding the platter shape and/or dielectric properties of its contents. It is noted that for industrial shaped portions, if the shape of the food is relatively regular between platters, movement of the food around the effective heating area of the oven and/or changes in size and/or small changes in shape will not generally affect the uniformity by too much, since a similar spectral image would be read and the device may automatically compensate for the minor changes. Optionally, the platter includes a depression and/or other geometrical structures which urge the food item to maintain a desired position relative to the platter borders.  
 55

**[0175]** As noted above, in some cases it is desirable to heat different parts of a platter in different ways. In particular, some of the methods of the present invention operate by providing a uniform heating area in the oven and modifying the effect of this region on food. In other methods, a non-uniform heating region is generated and/or non-uniform areas are used. In an exemplary embodiment of the invention, one or more of the following methods is used to provide uniform and/or non-uniform heating:

(a) Provide one or more parts of a platter with materials (e.g., 1512) that prevent radiation from reaching food, for example, by absorption or by reflection. For example, as known in the art, a part of the platter may be covered with aluminum foil, thereby shielding that portion and heating only other parts of the platter.

(b) Provide baffles (e.g., 1412) or other elements in the oven, to keep some radiation away from food. In an exemplary embodiment of the invention, the materials and/or baffles provide a reduction in absorbed energy of between 10% and 100%, for example, 20%, 30%, 40%, 60%, 80%, or intermediate percentages. In an exemplary embodiment of the invention, the oven is controlled so that the energy absorbed by the unprotected region does not go up and/or become non-uniform. As noted above, these baffles optionally move during the heating time.

(c) Use an imager (e.g., 1402) to determine the food shape and drive the RF generation. In an exemplary embodiment of the invention, a simulation is used which accepts as its input the position of the platter, shape of the food and/or its dielectric properties and determines which excitation modes of the oven and/or modification of the oven are required to achieve a desired effect. Optionally, and especially for industrial food which may be relatively regular in shape/size/dielectric constant, a table may be provided on the oven or at a remote location including operating instructions for various "standard" platter shapes and/or food shapes/types arrangements. Optionally, sensors 1410 are used to determine the platter shape and/or other macro-properties. The simulation may be executed locally or remotely. Optionally, when the simulation is executed, billing is carried out, for example, charging according to provision of instructions for uniform/non-uniform heating of an object or per object heated. Optionally, the request for a simulation includes an ID of the heated object which is found on or referenced by element 1518.

In an exemplary embodiment of the invention, a simulation uses the geometry and composition and/or other features of the load (this may be read directly from the load and/or a tag on the load), taken together with the device parameters (that are known in advance). The simulation then calculates the s-parameters and derives from them information on field distribution in the chamber (e.g. e-field calculation, H-field calculation, power flow, current density, power loss density and/or other parameters).

In an exemplary embodiment of the invention, s-parameters are measured during operation the simulation is started based on one real solution to the problem to achieve another interesting solution. For example, based on the s-parameters frequency bands of interest may be defined and the simulation be limited to those regions or to one or more specific frequencies.

(d) Image/measure the food previously and store the relevant information and/or heating profile (e.g., what frequencies at what power levels) on element 1518. In some cases, the information is stored remotely and element 1518 stores an access identifier or index thereto. In an exemplary embodiment of the invention, tray 1406 and/or the platter are designed to enforce a certain position of the platter in the oven. In an exemplary embodiment of the invention, the oven is calibrated to generate a certain heating profile which causes uniform and/or non-uniform heating (zones) according to certain food item/platter types and/or positions. In an exemplary embodiment of the invention, 20 platter layouts and 20 matching non-uniform heating layouts are designed and/or found for an oven. Smaller or later numbers of "standard" layouts may be provided, for example, 100 or more. Optionally, standard layouts are stored and accessible by internet or by another data transmission network.

Optionally the calibration is per oven design. Optionally, the calibration information is modified according to the response of the oven to the signals, for example, by shifting the "expected" uniform location from a calculated position to an actual position. Optionally, such shifting is determined using a phantom where absorption is indicated, for example, by temperature-based color indication and which shows the relative shifting of the uniform heating area as compared to the design.

(e) Modifying the heating profile in real-time using sensors. In an exemplary embodiment of the invention, sensors (e.g., 1520, 1516) generate feedback on the actual RF field and/or temperature at certain points. This input is used to modify the heating profile and/or driving of the RF system to achieve desired heating behavior (e.g., even if a first desired field distribution is achieved, this may not cause a desired final temperature distribution for example because the absorption changes during use and hence the energy input should be updated as well). Optionally, such sensors are used to determine relative locations of platter boundaries (including inter-compartment boundaries) and heating field boundaries (including boundaries between differently heated volumes). In an exemplary embodiment of the invention, the feedback of the RF system is used as a sensor, for example, to detect changing in phases of food-stuffs, which indicates cooking/thawing stage and/or to generate a signal when uniform heating is apparently failing. In case of failure the oven is optionally calibrated and/or a more complex simulation executed. Optionally, heating is stopped and a user is notified of failure to heat correctly. Optionally, the sweep mechanism is used as a reader

to identify objects/tags with known spectral images.

(f) Moving the food in the cavity, to selectively determine the amount of energy reaching different parts of a platter. Optionally, the times in the field are calculated to take into account the expected absorption of different food types. In a particular example, the tray rotates so that parts of the platter change their absorption. The time in the area

(volume) and the energy applied may be used to determine the heating profile of the platter as a whole.

(g) In an exemplary embodiment of the invention, feedback from the food and/or oven is used to determine that a correct amount of heating is applied. For example, changes in dielectric constant of the food and/or feedback from package temperature sensors may be used to determine that food has reached a sufficient temperature (e.g., for flavor reasons or for safety reasons). In an exemplary embodiment of the invention, food heating is stopped when sufficient heating is achieved and/or a user is notified. In an exemplary embodiment of the invention, based on a heating profile of the food, a user is given an alert in advance of the food being ready, for example, several minutes ahead of time (e.g., 1, 3, 5-10), several seconds ahead of time and/or a count-down may be shown. This may be useful for employees that come to pick up their meals at a food preparation site or at a vending machine or for picking up from a busy person in the kitchen. Notification may be provided, for example, using any means known in the art, including sounds, images, SMS messages and e-mail, for example, directly from the oven or from a computer coupled to the oven and/or monitoring it or by a human agency. In an exemplary embodiment of the invention, the advance warning is used for advance preparation of other food stuffs that are part of the meal, for example, a beverage or a salad. In an exemplary embodiment of the invention, this allows a meal to be prepared relatively slowly while still allowing a user to receive the meal with a minimum waiting time. Alternatively or additionally, food heating is stopped or slowed down if other components of the meal are not ready or if a patron announces he will be delayed. In an exemplary embodiment of the invention, multiple platters are heated simultaneously (e.g., side by side and/or stacked), utilizing feedback to ensure that all platters are heated correctly and/or generating signals to a user as a platter is ready to be removed. Optionally, a non-uniform field is applied to selectively heat faster those platters which will be needed sooner and/or to heat platters to different temperatures according to patron preferences and/or according to food heating needs. This allows changing the food readiness time without opening and closing the oven.

**[0176]** According to some embodiments of the invention, a device may include a memory capable of storing a desired heating protocol or a desired heating result to match a patron's (or user's) preferences. The protocol is stored in the device either manually or automatically during use, and is optionally proposed as a default protocol on later use by the same patron (and/or of a same dish). Optionally, the preferences are determined automatically, based on a history of past requests on a same or different heating device (e.g. in a vending machine from a chain of vending machines). Optionally, the user is identified by code, cellular telephone number, social security number and/or a credit card code. Optionally, the credit card is read during payment/ordering and used to set preferences.

**[0177]** In an exemplary embodiment of the invention, the amount of energy applied to a meal is adjusted according to the expected scheduling of the preparation of the meal. Optionally, the scheduling takes into account the desires of multiple patrons, for example, tens or hundreds or thousands or more, all of which come for a meal at approximately the same time (e.g., "lunch hour"). Such scheduling may also take into account, for example, the number of available ovens and/or the desirability for a group of patrons to be served at a same time.

**[0178]** In an exemplary embodiment of the invention, a central (or other) controller is provided which controls a plurality of heaters and assigns tasks for enhancing performance. For example, each heater is assigned a different task (e.g. one prepares meat for several patrons in one batch or in sequence and another machine prepares the greens) so the heaters optimally or near optimally utilize available hardware, for example, to reduce time and/or to improve food delivery timing (parts of a dish should desirably all be ready at a same time, even if heater can "keep warm"). Alternatively or additionally, as a request for a meal arrives, one or more heaters is assigned to the meal, ad hoc. Optionally, this method is used for patrons numbering, for example, between 2 and 10, between 11 and 40, between 40 and 100 or between 100 and 1000 or more. Optionally, the controller of the plurality of heaters also controls one or both of a human scheduling system (e.g., which instructions are provided to which worker) and/or controls one or more food moving systems (e.g., conveyer belts).

#### **Measure (1318), estimate (1322) and Modify (1320, 1324)**

**[0179]** During heating of the food, the parameters of the heating are optionally varied. The effect of the varying may cause non-uniformity in space and/or in time, for example, as will be described below and/or to achieve the effects as described above. In an exemplary embodiment of the invention, a script is provided which defines how and what to vary. Optionally, the script includes decisions made according to time (e.g., estimation of an effect) and/or food state (e.g., measurement). Various measuring methods are described above. Estimation is optionally based on a simulation or on empirical results from previous heating cycles. Optionally, the script is conditional (e.g., modified, generated and/or

selected) on the position of the platter in the oven and/or personal preferences (which may be stored by the oven).

**[0180]** In an exemplary embodiment of the invention, a script is provided on element 1518 or at a remote location. Optionally, a script is selected by a user selecting a desired heating effect. The combination of the desired heating effect and the identification of the food/layout may cause the selection and/or generation of a suitable script.

**[0181]** In an exemplary embodiment of the invention, a desired heating program may set target amounts of energy for different parts of a platter and/or of a single food items and/or may set desired target temperatures. For example, a meat item may be heated to one temperature, while a side order is heated to a lower temperature. In another example, a single food item may experience different power levels for different times, in order to achieve a desired texture/flavor.

**[0182]** In an exemplary embodiment of the invention, a script is used to set different energy levels and/or different times to apply such energies.

**[0183]** In one example, a script is as follows:

- (a) Heat all platter so that the food reaches a relatively uniform temperature of 5 degrees Celsius.
- (b) Uniformly heat whole platter at 80% for 5 minutes and then full power for 10 minutes.
- (c) Heat area A at full power for 3 minutes, while not heating area B at all (e.g., by applying baffles or a matching (optionally specified non-uniform) heating profile).
- (d) Heat the entire platter for 5 more minutes, with area A receiving 80% power and area B receiving 20% power.
- (e) Heat to a uniform temperature of 40 degrees Celsius.
- (f) Maintain temperature for 10 minutes. It is noted that a desired temperature can optionally be maintained by estimating the energy absorption while applying a known amount of cooling. Alternatively, actual heat absorption may be estimated based on a known amount of energy absorption and a measurement of energy leaving the cavity. Optionally, the oven includes a source of cooling air and/or has coolable walls and/or tray.
- (g) Reduce heat to 30 degrees Celsius.
- (h) Wait 10 minutes.
- (i) Report "done" but leave at 30 degrees Celsius until removed.

**[0184]** In an exemplary embodiment of the invention, the script includes other conditions, for example, detecting changes in color (e.g., browning), steaming (e.g., by phase change of water), volume (e.g., dough rising will change the behavior of the cavity in ways that can be anticipated).

**[0185]** Optionally, the script includes a request to the user to add ingredients (e.g., spices), or to mix or reposition package.

**[0186]** In an exemplary embodiment of the invention, the script takes into account the quality of uniformity control achievable by the oven. For example, if a higher level of uniformity is desired than basically provided by the specific oven, heating may include pauses where power is reduced, to allow heat to even out in the object. The length of the delays is optionally pre-calculated for the food substances and a calibrated lack of uniformity of the oven. Alternatively or additionally to reducing power, the food may be moved relative to the cavity and/or heating or field shaping elements so to improve heating.

**[0187]** In another example, a script for preparing a frozen food product until ready for consumption (e.g. a product comprising frozen and viable yeast dough), is as follows:

1. Heat the frozen dough to a yeast-growth temperature (e.g. 10-45°C). This step may be performed in two or more steps, for example:

- a. (optionally) Heat the frozen dough to a thawed temperature (e.g. 4-8°C) and maintain for a period of time, as necessary (e.g., if a user puts the dough in the device and wishes to have it proofed and baked at a later time);
- b. At the later time (or after a delay) heat the thawed dough to yeast-growth or proofing temperature (e.g. 10-45°C).

2. Maintain the dough at a yeast-growth or proofing temperature (e.g. 10-45°C) for a period of time necessary for proofing said dough (e.g. a period of time recommended by the manufacturer or recipe or a period) or using a sensor to sense an predetermined increase in volume (or height), e.g. 2 fold, or an output of volatiles indicating fermentation).

- c. (optionally) Heat the dough to a baking temperature (e.g. 190°C-200°C) and maintain for a desired period of time (e.g. as dictated by the recipe, or based on the detection of a desired temperature achieved in an inside portion of the dough). Optionally at the end (or during) of said period an IR body is activated to brown the pastry. This step of baking may, alternatively, be executed in a conventional oven.

**[0188]** The above script may be embodied, for example, in a bread making machine, into which frozen ingredients are placed, optionally into an insulated compartment, whereafter the ingredients are thawed, mixed, proofed and/or

baked using methods as described herein. Optionally, one or more steps of the above process include controlling the humidity within the oven (optionally maintaining high humidity during proofing and/or warming and/or storage and maintaining low humidity and/or high humidity during baking). At times, the device may maintain a different humidity at different portions of the same step (e.g. high humidity during early baking a low humidity when IR is introduced). Additional details re humidity control are provided below under the heading "Environmental Control".

[0189] As noted above, different portions of the food may have different (desired or specified) absorbed power levels. Alternatively or additionally, different portions may have different target temperatures. Optionally, spatial control is used to achieve selective browning (or other behavior) of a part of a food item, by applying a field which overlap mainly with an outer layer of the food, so that that layer is preferentially heated as compared to the rest of the food item. In another example, a bottom of a food item is made harder, by applying more heat, than an upper part of the food item. Depending on the resolution of the oven and on the size of the food item, the entire outside of an item may be preferentially treated. Optionally, the areas with preferential heating have a smallest dimension of 5 cm, 4 cm, 3 cm, 2cm or less.

[0190] In some embodiments, a user and/or platter specify what a desired spatial and/or temporal heating profile is and the oven determines a suitable set of instructions (e.g., spatial and/or temporal profile). In one example, a best-fit type algorithm is used to select heating ability elements and build a heating program that matches desires. Exemplary heating ability elements optionally used in such a search/construction include, uniform heating methods, baffle movements, platter movements and/or non-uniform heating modes or frequency possibilities.

[0191] In an exemplary embodiment of the invention, no script is provided. Instead, the heating times and/or parameters are based directly on the desired results, measured food properties and/or measured heating properties.

### **Environmental control**

[0192] In an exemplary embodiment of the invention, a heater controller controls not only energy provision but also one or more environmental variables that affect food preparation. In an exemplary embodiment of the invention, the environmental control is applied to achieve a desired cooking result, for example, reducing humidity to enhance crust formation. Alternatively or additionally, environmental control is applied to maintain environmental conditions, for example humidity. Alternatively or additionally, environmental control is applied to compensate for heating effects. For example, humidity may be increased if the heated food appears to be drying out.

[0193] In an exemplary embodiment of the invention, environmental control includes controlling one or more of ambient air temperature (e.g., by providing hot or cold air), air flow rate (e.g., controlled using a fan), ambient humidity (by adding humidity and/or replacing air with dry air and or by causing a water source within the oven to evaporate), ambient gases (e.g., from a gas source, such as a CO<sub>2</sub> balloon), ambient pressure (e.g., increase or decrease using an air pump) and/or UV irradiation (using a UV lamp).

[0194] In an exemplary embodiment of the invention, the environmental control is responsive and maintains the environment within 20%, 10%, 5% or better of desired settings.

[0195] In an exemplary embodiment of the invention, environmental control is carried out dynamically, where the environmental conditions are adjusted based on real time feedback from the heated object and/or the oven environment. For example, when cooking a given food one may measure a property of the food or of the oven environment and adjust the environment in response to the measured property.

[0196] In an exemplary embodiment of the invention, the measured property includes humidity/weight (e.g. loss of water), temperature (e.g., using a TTT) and pressure (e.g., using a pressure sensor internal or external to the food).

[0197] The change in environment may be a one time event (e.g. when the object temperature is above X, add humidity) or a continuous process (e.g. maintain ambient temperature or pressure as equal or slightly above or below that of the object; add 1% to humidity whenever the object heats by 1°C, etc.) or a combination of the above. In some cases, different parts of the oven are provided with different environments (e.g., humidity or air temperature). In some embodiments, control is based on a previous estimate, alternatively or additionally, to using real time measurements.

### **Combined conventional and RF heating**

[0198] In some embodiments of the invention, the heater includes a conventional cooking means, for example, an IR element may be included for brazing or scorching or other surface heating. Optionally, both IR and RF are operate together, thus coking both form inside and from outside. Alternatively or additionally, the heater includes a source of steam or hot air or turbulence within the device. In an exemplary embodiment of the invention, the steam or hot air are heated using waste heat generated by the RF generating system. Such utilization of waste heat may also be practiced in conventional ovens. Alternatively or additionally, a conventional microwave heater is provided.

**Eat/Classify (1326)**

**[0199]** Once the food is ready, it is optionally consumed. In some cases, consumption is delayed, for example, if the prepared food is further stored. In some cases, the food is thawed at 1316 for cooking at a later time using any known method or the present described methods.

**[0200]** In an exemplary embodiment of the invention, the food is classified according to the process it went through and/or any glitches along the way. For example, such classification may include the quality and/or type of freezing, thawing and/or heating. For example, if a heating script was not followed properly or above-desired temperatures achieved, this may reduce the quality. Similarly, if thawing is identified as being problematic in a manner which may affect texture and/or flavor, this is noted. Optionally, for each food-stuff, there is defined a score system which links a quality value to various imperfections along a process. Optionally, this score is combined with a score indicating an original quality of the food stuff, for example, based on storage conditions or, for natural items, a fat content (for example). It should be noted that fat/water content may be important inputs to the processing, for example, suggesting what heating times, profiles and/or powers would be useful.

**[0201]** Optionally, dedicated sensors are provided to track storage conditions, for example, sensors that measure and/or latch a pH value, a temperature change and/or which detect gas release.

**[0202]** Optionally, while the description has in some cases focused on food, the methods described herein are optionally used for non-food materials, for example, organs for implantation, tissue and/or artificial implants. In general, food processing has higher requirements regarding texture and flavor, while organs for implantation, tissue and/or artificial implants have more stringent constraints on viability and lack of contamination. While these requirements may overlap with those of the food as described above, it is noted that a tissue may be viable for implantation as long as it has sufficient viable cells and/or blood vessels remain intact. Flavor, as such, is immaterial for implantation.

**[0203]** Fig. 16 shows a food processing line 1600 including quality classification, in accordance with an exemplary embodiment of the invention.

**[0204]** A food item 1616, for example a fish, is provided frozen and ready for processing (e.g., into cans, fillets, etc.). A tag 1618 is optionally attached to the fish, for example, to track storage conditions and/or to include information about the fish, for example cooking-related properties such as water content, size and/or shape and/or food properties, such as fish type, age and/or growth method. An imager or a reader 1604 provides information about the fish to a controller 1612. A microwave array 1606 represents one or more radiation sources controlled by an RF system 1608, which generates a known (e.g., uniform or non-uniform) heating area, indicated in the figure as a series of areas surrounded by dashed lines. The areas could be contiguous and/or have various shapes. The fish is conveyed, for example, using a conveyer belt 1602 along the areas and heated appropriately. Optionally, the heated areas are moved and/or fish motion slowed down, as needed, for example, for different fish sizes and/or compositions. Along the way, one or more of the methods described above may be applied, in particular tracking of the fish temperature and/or heat treatment.

**[0205]** A reader/writer 1610 is optionally provided to read from and/or record the properties of the fish on tag 1618. In an exemplary embodiment of the invention, controller 1612 uses the information obtained from the fish and/or the process to classify the fish. The classification is optionally written to tag 1618. In an exemplary embodiment of the invention, a further processing stage 1614 is controlled by (or receives suitable indication from) controller 1612 according to the quality. For example, fish which was improperly thawed may be sent to lower quality canning while well thawed fish is sent for making sushi/sashimi. Optionally, the final product is marked with the quality. Optionally, when the final product is a packaged product, the thawing heating instructions (e.g., machine readable and/or human readable) are modified to match the processing. For example, if, as a result of improper thawing a food item was (or should have been) forcefully heated to a pasteurization temperature, the preparation instructions will include a shorter cooking time and/or recommend well done type cooking.

**Industrial and non-industrial settings**

**[0206]** The methods as described herein have various ramifications and/or advantages for industrial and non-industrial settings.

**[0207]** In one example, taking advantage of "thaw on demand" option (also for large/thick portions) can change methods of stock management. In the art, prior thawing needs to be done significantly before orders are placed or before cooking should commence (e.g. a day in advance or at least several hours in advance), especially where the thawed portions are bulky, having small surface/volume ratios. Typical associated problems include:

- (a) long overall process (e.g. begin a day in advance);
- (b) need to thaw excess amounts so as to guarantee meeting peak demands and avoid losing business; and
- (c) need to discard thawed and unused food (due to food safety regulations and hygiene).



**[0208]** A heater according to the present invention may thaw food "on demand" to provide food that is potentially as good as fresh (e.g., no over heated hot spots), and in very short time periods (e.g., less than 10 minutes for a 1Kg meat portion or even faster, such as less than 3 minutes, 1 minute or tens of seconds).

**[0209]** In an exemplary embodiment of the invention, there is provided a stock management system (e.g., software and/or hardware) where a user's order for immediate preparation drives the immediate thawing of a portion (e.g., including expensive cuts of meat or other food) for that patron and/or for use in cooking within 15 or 20 minutes). Moreover, thawing may be delayed according to preparation of other food for that patron and/or according to the cook's workload, for example delayed for several minutes, such as 2-3 or 5 minutes or longer. Optionally, such delaying is supported by fast thawing and/or keep-warm functions as described herein.

**[0210]** In an alternative scheme, a restaurant may have limited stock of thawed items (e.g., fewer than 10, fewer than 5, fewer than 2 of a type of item) and when an item is used from the small stock a new item is thawed (or when a new order is placed and the use of an item for which thawing is expected is already ordered). Thawing can be automatic or semi-automatic (e.g. as soon as the order is entered in a computer in one location the instructions to thaw are provided to a person at another location who executes the thawing or to a device (e.g., a vending machine like freezer and heater) that executes them automatically. Alternatively, the process may be manual - as in current kitchens, but the cook, rather than using a pre-thawed portion, uses a frozen portion as a starting point.

**[0211]** In an exemplary embodiment of the invention, software is provided for use as a meal planning assist device (e.g., at home or in a restaurant or other commercial site), either for planning the thawing and/or heating of several different meals or for a meal comprising several food types/courses. Optionally, usage is as follows: a user inputs the information. The heater software takes into account the desired relative timing of preparation (e.g., what needs to be ready at a same time and what in a certain sequence) and provides a schedule that may also take into account the desired relative cooling rates/preparation time.

**[0212]** For example, for a dish of meat and mashed potatoes, where one cools at a different rate than the other, the slower-cooling dish may be heated first.

**[0213]** The oven may then regulate the order of heating and the rate of heating. Optionally, the oven may select the timing to begin heating, the order of placing the foods in the device or the relative timing of operating multiple devices or, if heating "simultaneously" in a single oven, the oven may begin with heating one of the foods and then heat both such that they finish heating together. The device may include a sensor of room temperature which is optionally used to provide an ambient temperature for advising a user to reheat the food after a given period of time.

**[0214]** Other settings are possible as well. For example, a small commercial setting might use the methods described herein to prepare a meal on the spot. A large-scale industrial setting may use the methods described herein to heat/cook a batch (e.g., 2, 10, 30, 100 or intermediate or greater numbers of portions) or a continuous flow of products. In an exemplary embodiment of the invention, a flow-through oven uses relatively low cost heating elements, for example, using an antenna array with multiple feeds. The array is thus fed by multiple amplifiers (each amplifier having a relatively low output power, but the power is combined on the heated object).

**[0215]** The range of weights which may be heated varies as well, from sizes considered too large for "standard" microwave heaters, to objects considered too small. For example, objects in the weight range of 1000-0.1 Kg may be heated in accordance with various embodiments of the invention. Similarly, a wider range of volumes may be treated, for example, 2 cubic meters or more, down to 2 cubic centimeters or less. Optionally, for small objects, overheating of a power source (e.g., magnetron) is avoided, using matching methods as described herein.

**[0216]** In an exemplary embodiment of the invention, a higher percentage than conventional of a cavity may be used, for example, above 40%, above 50%, above 70% or above 80% or intermediate values. For example, within a cylindrical volume of 52 cm diameter and 52 cm height, the following heating examples were performed: (a) two large chunks of meat, placed one on the other, with a total weight of 9.5 Kg were defrosted from ca. -10°C to -0.6 - 0.5°C (uniformity being within 1.1°C). (b) 24Kg of apples were cooked in a single batch with a final temperature between about 50°C and 66°C.

**[0217]** In an industrial setting, it may be desirable that all portions have exactly the same characteristics, at least after processing. In a restaurant-type establishment, some variance may be desirable. Furthermore, personalization per patron preferences may be desirable. In a home use, even more repeatability may be desirable; however, for a particular user it may be desirable to test various settings to determine an optimal set of settings. Optionally, a user provides feedback to the oven, for example "too hot", "too moist", "undercooked", "just right", which is used by the device as input how to vary heating parameters for the next usage. This may be applied, for example, every usage, on device initiative and/or on periodically. Optionally, a user can apply an override. Optionally, the input is corrected for changes in food weight between heating events.

### **Rate of heating**

**[0218]** In an exemplary embodiment of the invention, the rate of heating can be controlled. For example, the rate of

heating depends on the specific heat and the absorbed power.

[0219] It is possible to heat 300gr meat to cooking temperature within 1 second, provided that 27KWatts are provided. Amplifiers that output such power (and even a higher power) may be produced by any person skilled in the art, based for example, on the teachings of US provisional application of May 2007, the disclosure of which is incorporated herein by reference. A lower power can provide a slower heating, which may be intentional. Knowing the food's specific heat (e.g., read from a tag, inputted by a user or read from a table), the device can be programmed to reach the final temperature at a desired slower rate.

[0220] Example: In conventional IR oven methods, baking a chicken of ca. 1.13-1.36 Kg at 177°C normally takes about 1.25 to 1.5 hours (about 15 minutes longer for stuffed chicken), beginning with a thawed chicken. In an experiment, a frozen (ca. -20°C) stuffed chicken was cooked in 18.5 minutes (ca. 15 minutes for cooking only) at 250-300 Watts.

[0221] At this rate heating (Thawing) can be very uniform. For example, Fig. 17 shows heating of meat while maintaining a uniformity (of maximum achieved temperature) of  $\pm 0.3^\circ\text{C}$ . In this example, For example, a 1.3Kg cylinder of meat (ca. 30 cm long/ca. 10cm diameter) was heated by  $13^\circ\text{C}$  within 10 minutes at 400 Watts.

#### **Oven with accuracy tradeoff**

[0222] The inventors also realized that in ensuring uniform heating, the heating may be somewhat prolonged. Therefore, any heating mode may have a different balance between velocity of heating and uniformity. At times a user may be willing to sacrifice uniformity somewhat, such as in the case of a liquid (e.g. consommé) being heated, which may be stirred before serving, in order to achieve faster heating. In such cases one may prefer to have a faster heating and would be willing to have up to  $10\text{-}20^\circ\text{C}$  temperature variation, or even  $40^\circ\text{C}$  or more or even  $100^\circ\text{C}$  variation (this may be acceptable for some applications, for example while utilizing energy efficiency features as described herein). At other times (e.g. defrosting dough or viable material) uniformity is more crucial and the heater may be operated at a mode having greater uniformity (e.g. less than  $10^\circ\text{C}$  variation or even less than  $1.5^\circ\text{C}$  variation or even less than 0.5). For example, for quicker heating one may choose a narrower band of frequencies having better dissipation, while for more isothermal heating the bandwidth would be larger, allowing also lower dissipation (potentially using also a "reverse image" of the spectral image within the band).

[0223] In an exemplary embodiment of the invention, the following method is used. Typically for a band around a given peak of dissipation, the narrower the band, the better the average dissipation at the transmitted frequencies. If the band is wider, the RF is transmitted at lower dissipation (i.e. the frequencies that are further from the peak) in addition to the transmission of the narrow band. In an exemplary embodiment of the invention, a wider band is transmitted about one peak and a narrower band about a second peak. Since each peak is associated with a different portion of an object (or a different location on a dish) you may have fast (narrow band, high efficiency, less isotherm) heating in one region (e.g. soup) while you would have slower (broad band, less efficiency but higher isotherm) in a second region (e.g. bread). In this example, you can provide hot soup (non-uniform, but mixable) and only a warm bun.

[0224] In an exemplary embodiment of the invention, a heater has two or more accuracy/rate settings each having a different balance between heating velocity and uniformity, and the user may operate the device to choose the desired mode of activation. Alternatively, the device may use information obtained from the food (or user input) to set (or propose) a heating mode.

#### **Energy efficiency**

[0225] In an exemplary embodiment of the invention, the heater is capable of detecting whether or not there is a load within the device (based on a frequency sweep) thus preventing operation of the device when empty, open and/or damaged.

[0226] In an exemplary embodiment of the invention, the heater selectively applies energy at frequencies where it is expected to be absorbed, thus increasing energy efficiency. Optionally, energy efficiency is traded off with uniformity, for example, as described above.

[0227] In an exemplary embodiment of the invention, such selective application of energy is more efficient by avoiding warming the environment and/or surface currents. Alternatively or additionally, efficiency is made higher by avoiding emitting energy into the environment (and selecting frequencies where absorption by object is higher. Alternatively or additionally, efficiency is enhanced by reducing water evaporation and/or heating time (and thus heat radiation time). Reduction of water evaporation may also be useful for reducing weight loss, maintaining product size, product shape and/or product texture.

[0228] In an exemplary embodiment of the invention, evaporation is reduced by maintaining all object parts at temperatures below evaporation (e.g., due to uniformity or due to controlling non-uniformity).

[0229] In an exemplary embodiment of the invention, cooling rate is reduced because there is less evaporation and/or smaller temperature gradients (within object and/or between object and environment).

[0230] It should be noted, that in general, reducing temperature variance allows heating time to be shortened and maximum energy deposition rates (which often correlate with evaporation) to be reduced.

[0231] In an exemplary embodiment of the invention, higher efficiency allows a heat transfer media (e.g. boiling water to cook eggs as necessary in conventional cooking) to be avoided.

#### **Example of intentionally uneven heating**

[0232] Into a chunk of meat (cylinder of ca. 30 cm long/ca. 10cm diameter, at about 30°C) three optic fibers were inserted and heating begun at 400W. During heating the temperature change at each fiber was measured. After scanning for the dissipation, the RF frequencies that would provide the best absorption were selected. Within these frequencies power was transmitted in sequence at bands of ca. 20MHz about each of the relevant peaks. The following method was applied. If there is no heating (detected almost immediately) this means that none of the sensed areas are heating, and then a different subband is assayed. If heating is detected, it is followed until there is a rise of up to 2°C and the temperature is followed in all sensed areas. If none of the peaks provides the desired differential heating, peaks of lower dissipation may be assayed. Once the proper sub-bands are selected, heating may commence, and the energy provided in each frequency defines how sharp the temperature gradient would be. In an actual experiment, the frequencies chosen for transmission were between 810-850MHz, and between 900-930MHz, which corresponded to two of the sensors. The third sensor was relatively non-heating at these frequencies. The meat was heated non-uniformly, until the warmest spot was about 42°C and the coldest about 30.5°C. This is shown in Figs. 19A and 19B. It should be noted that in accordance with some embodiments of the invention, a hot spot can be moved (to obtain a greater area of uniformity by modifying the frequency by a small amount.

[0233] Then, the mode of operation was changed and provided the same energy (calculated to compensate for the different dissipation) to all the meat. As can be seen in Fig. 19A, the meat heated linearly at all measured locations and as seen in Fig. 19B, the temperature differences between pairs of sensed locations were almost constant, with a slight decline after about 550 seconds, when the meat was heated already by about 13 °C. Also seen from these Figs., is that the heat conduction between the locations was on a smaller order of magnitude than of the RF heating, (had the rates been comparable, the temperature differences would have significantly reduced). In Figs. 18A and 18B, the experiment was performed similarly, but one sensor was placed in a fat portion and one in meat. The meat was a steak of about 150gr. As seen in the fig. 18B, the portions were first heated uniformly and then the mode was changed to non-uniform heating (indicating that the non-uniformity is controlled) Fig. 19A depicts the temperature during a portion of the process.

#### **Use of RF energy to dry a target**

[0234] In some exemplary embodiments of the invention, (see for Example Fig. 20) an RF oven and/or methods, for example, as described herein according to an embodiment of the invention is made to accommodate drying (e.g. clothes drying or waste drying), optionally with some modification. Modifications include, but are not limited to addition of an agitator (e.g., rotating drum), a condenser, a forced air source and/or a controller responsive to a measure of drying progress.

[0235] In an exemplary embodiment of the invention, RF energy directly evaporates water without significantly affecting fabric. Optionally, the RF energy is selected so that a dry garment stops absorbing RF energy and RF heating stops automatically when garments are dry, even if RF energy continues to be applied to the feed. In an exemplary embodiment of the invention, use of RF heating contributes to a reduction in damage due to excessive heating. In an exemplary embodiment of the invention, this technique is used so fabrics of diverse types and/or of different degrees wetness can be dried together. In an exemplary embodiment of the invention, items in a mixed load which dry faster will not overheat while slower drying items continue to dry.

[0236] In other exemplary embodiments of the invention (figs. 22-27), a conventional clothes dryer is modified to incorporate one or more RF feeds to dry clothes in a hybrid system combining heated forced air and RF heating. Optionally, an insert adapted to hold at least one item of clothing is provided to adapt a conventional dryer design to RF based drying.

[0237] Typical conventional clothes dryers force a flow of heated air through clothes in a rotating drum. Often the rotation alternates directions to reduce wrinkling. Both closed and open system forced air dryers are available. In an open system, heated air absorbs moisture from clothes and is vented out of the system, carrying moisture with it. In a closed system, hot air with absorbed moisture is routed to a condenser which removes a significant portion of the moisture and the air returned to the rotating drum to absorb additional moisture, optionally after reheating. According to various embodiments of the invention described in greater detail herein below, RF drying is incorporated into an open system or a closed system forced air clothes dryer.

[0238] Optionally, integration of RF and forced air drying into a hybrid system can offer (and is optionally configured

to provide and/or optimize for) one or more of several advantages. Among these advantages are a significant savings in electric power consumption and/or a significant reduction in drying time and/or a possibility to tightly regulate maximum temperature in consideration of fabric type and/or assurance of uniform drying of different fabric types (e.g. items containing different fabrics and/or mixed loads) and/or drying in presence of non-fabric items (e.g. rubber, metal, plastics, lighters). Optionally, the non fabric items are part of items of clothing (e.g. rubber soles, metal buckles, buttons, fasteners or zippers and/or plastic buttons or decorations).

**[0239]** Advantages may stem, at least in part, from the unique capability of RF energy to directly heat water without heating fabric to a significant degree and/or from the fact that water may absorb part of latent heat from fabric during evaporation. Optionally, this absorption of latent heat, cools fabric, optionally to a significant degree. Optionally, a reduction in heating of fabric during drying contributes to increased garment life, another potential advantage.

**[0240]** Alternatively, or additionally, use of RF energy for clothes drying can contribute to a reduction in wrinkling of delicate fabrics without "step down" cooling at end of cycle and/or can automatically end a drying cycle at a predefined humidity level without humidity measurement and/or can implement an individual dynamic and/or automatic drying program without a substantial reduction in drying efficiency.

**[0241]** Optionally, the RF dryer is constructed with a moving system that may automatically insert and remove objects to and from the dryer (e.g. a conveyer belt). This may be especially useful in order to move a series of cloths in hanging position through the dryer. Optionally, the speed of the conveyer belt is controlled by sensed (e.g., RF sensed humidity levels of the clothes).

#### Exemplary modified RF oven

**[0242]** Fig. 20 depicts a modified RF oven 2000 adapted to function as a dryer, optionally a clothes dryer. Dryer 2000 comprises a housing 2010 with an openable door 2016 axially rotatable with respect to a hinge 2014. Dryer 2000 is depicted as a "front (2012) loading" machine, although "top loading" configurations are also within the scope of the invention.

**[0243]** As will be described in greater detail herein below, a controller 2040 coordinates operation of various components of dryer 2000, including, but not limited to, one or more RF feeds (two are shown 2030 and 2032). RF feeds 2030 and 2032 are pictured in Fig. 20 as single units, although the antenna and power source may be physically separate in some embodiments of the invention. In an exemplary embodiment of the invention, each RF feed (e.g. 2032) is positioned to direct RF energy into a cavity 2020 into which one or more items of clothing 2110 (a shirt is pictured) can be placed for drying. During operation of dryer 2000, RF energy emanating from feed 2032 and/or 2030 increases a rate of evaporation of water from clothing 2110.

**[0244]** In some exemplary embodiments of the invention, controller 2040 controls one or more characteristics of the RF energy to heat water within and/or on fibers of the at least one item of clothing 2110.

**[0245]** Optionally, controller 2040 is configured to operate RF feed 2032 so that the RF energy is deposited in the at least one item of clothing at a relative uniform deposition rate of within  $\pm 30\%$  over at least 80% of the volume, or of a wet portion, of the at least one item of clothing 2110.

**[0246]** Optionally, controller 2040 is configured to operate RF feed 2032 so that no object associated with item of clothing 2110 is heated to a temperature exceeding an average temperature of the at least one item of clothing by more than 70, 60, 50, 40, 30, 20, 10, 5 or 1 degree centigrade (or lesser) or intermediate values. Objects associated with the one item of clothing include but are not limited to non-fabric objects (e.g. metal, plastic, rubber and wood). Optionally, the non fabric objects are part of item 2110 (e.g. buttons, zippers) or are not related (e.g. items in pockets). In an exemplary embodiment of the invention, a difference between the hottest non-fabric object and an average temperature of item 2110 approaches 0 degrees Celsius. Previously available RF dryers were unable to assure a comparable degree of temperature uniformity in the fabric and/or among disparate materials hence the maximal amount of RF energy that load can absorb without damage is significant lower than the maximal amount of RF than can be absorbed by the proposed embodiments. Non RF dryers have the same problem with metal parts since they absorb the conducted heat from the hot air much faster than other materials in the drying object. In an exemplary embodiment of the invention, reduction in temperature discrepancy between non fabric objects and adjacent fabric of a garment contributes to a reduction in garment damage.

**[0247]** Optionally, controller 2040 is configured to operate RF feed 2032 so that RF energy is not concentrated on non-fabric objects associated with said at least one item of clothing.

**[0248]** In an exemplary embodiment of the invention, a spectral image of a feed to a cavity, containing the at least one item of clothing is obtained and one or more relevant frequency bands are selected for drying. Optionally, reduction, or elimination, of problematic narrow peaks is undertaken. Problematic narrow peaks may be indicative of, for example metal on clothing (e.g. zippers, buckles, and buttons) and other low dissipative material such as surface currents in a resonator. Optionally, color(s) of fabric influence heating of water in/on the fabric at a given frequency only insubstantially. The spectral image of a cavity with a dry load is different than that of the same cavity with the same load when it is wet.

This difference correlates with the amount of water that is in the cavity when the spectral image is acquired. Accordingly, in some embodiments of the invention, a spectral image of a cavity, containing the at least one item of clothing is obtained and the humidity is calculated. Optionally, before performing said calculation, narrow peaks are eliminated from the acquired image. Optionally, a table showing spectral images for various humidity levels, object types and/or objects, is provided and used for the estimation.

**[0249]** In some exemplary embodiments of the invention, controller 2040 enforces a maximum temperature over at least 80% of at least one item of clothing 2110. Optionally, the maximum temperature is 20, 25, 30, 35, 40, 45, 50, 55, 60, 65 or 70 degrees centigrade (or intermediate or greater temperatures). In an exemplary embodiment of the invention, enforcement of a lower maximum temperature contributes to increased fabric life and/or allows dryer 2000 to handle loads containing different fabric types more easily.

**[0250]** In some exemplary embodiments of the invention, controller 2040 controls the RF energy so that at least 80% of at least one item of clothing 2110 receives the RF energy at a level which does not exceed a desired maximum energy deposition density. In an exemplary embodiment of the invention, the desired maximum energy deposition density does not heat the at least one item of clothing to a degree which causes fabric damage. In an exemplary embodiment of the invention, the desired maximum energy deposition density the temperature does not exceed a safe temperature for item of clothing 2110 (e.g. nylon must be cooler than cotton). Optionally, a temperature sensor (e.g. IR; depicted generally as a cavity sensor 2062) is used to detect temperature and assure that they remain in acceptable ranges.

**[0251]** In an exemplary embodiment of the invention, maximum energy deposition density contributes to increased fabric life and/or allows dryer 2000 to handle loads containing different fabric types more easily.

**[0252]** In some exemplary embodiments of the invention, controller 2040 is adapted to control feed(s) 2032 so as to maintain a temperature of item of clothing 2110 to within 10 degrees Celsius of a defined temperature. Optionally, assuring that all items 2110 are above a minimum temperature contributes to a reduction in drying time. Optionally, some embodiments of the invention enforce a maximum temperature with its advantages as described above. In an exemplary embodiment of the invention, controller 2040 shuts off feed 2032 when clothing 2110 is dry. Optionally, detection of dryness is done using a measuring sweep. Optionally or additionally, dryness is detected by measuring air humidity in Cavity 2020 by sensor 2070 and/or air humidity in water vapor vent 2050 by the sensor 2060. Optionally, controller 2040 adjusts one or more drying parameters in response to detected changes in dielectric properties in the sweep result or the air temperature or humidity. As described below with respect to Fig. 34, RF measurement of humidity in clothes can be more precise and/or a better source of control than air humidity. Optionally, RF measurement can indicate the amount of water that still exists in cavity 2020 and may be used to make a decision of changing the operational profile (e.g. termination of drying, increase in energy input, reduction of agitation, etc.). Optionally, dryer 2000 comprises a load weight sensor.

**[0253]** In some embodiments, RF measurement is used to estimate humidity even if most or all of the energy used for drying is not provided as RF energy, for example, being provided as hot air.

**[0254]** In some exemplary embodiments of the invention, cavity 2020 includes at least one passive source 2080. Clothing 2110 placed in cavity 2020 is in proximity (e.g., for contact, radiation and/or convection based transfer of heat from passive source 2080 to clothing) to passive source 2080. According to these exemplary embodiments of the invention, controller 2040 controls the RF energy so that passive source 2080 is heated and transmits at least a portion of the heat to item of clothing 2110 in proximity thereto. For convective heating, proximity may be lower and an air current between source 2080 and clothes may be designed and/or enforced in dryer. Optionally, controller 2040 selects RF frequencies from among a first set of frequencies which are coupled to passive source 2080 and a second set of frequencies which are not to passive source 2080. Optionally, frequencies are selected not to heat the clothing at all.

**[0255]** In an exemplary embodiment of the invention, passive source 2080 is a resonant structure detectable by the controller 2080. Detection can be, for example, using two passive sources 2080 characterized by a "signature" indicating frequencies for heating or not heating thereof. In various exemplary embodiments of the invention, passive source 2090 can be used to heat a delicate place and/or for tracking a temperature of a fabric to be dried and/or for insuring, drying of all parts of the dried item.

**[0256]** In an exemplary embodiment of the invention, dryer 2000 includes a spectral imaging module 2030 and/or 2032 adapted to provide a spectral image of the at least one item of clothing. A spectral image is optionally acquired by measuring RF energy absorption in successive RF frequency bands of the broadband RF energy. Imaging module 2030 and/or 2032 communicates the image to controller 2040. In an exemplary embodiment of the invention, controller 2040 is responsive to the received image and adjusts a heating policy (e.g., RF frequency and/or RF distribution) in accord with the received image. Optionally, spectral imaging module 2030 and/or 2032 can produce the spectral image within about 10 to 20 milliseconds. In an exemplary embodiment of the invention, a response time in milliseconds allows accurate delivery of desired amounts of energy to desired portions of item 2110 at relevant times. In an exemplary embodiment of the invention, controller 2040 responds to a received spectral image by reducing or increasing an amount of energy directed to any problem areas in the spectral image. Optionally, controller 2040, optionally using spectral image analysis, allocates the RF energy to different RF bands such a spatial profile of energy delivery to the drying

object is created. Optionally, the profile avoids over-heating and/or energy provision some areas such as areas with dry fabrics or metal objects. Optionally, the profile can concentrate energy deposition in areas containing for example wet fabrics and/or areas with certain fabric types and/or dimensions (e.g., collars or other parts which are more uncomfortable when wet). Optionally, controller 2040 allocates the RF energy also in time to create a temporal temperature schedule that heats areas in the object to specific temperatures in specific time segments and/or avoids heating areas in the object in some specific time segments. Optionally, a time segment is included for bringing the object to a desired temperature at the end of the drying process.

**[0257]** Optionally, by heating only part of the object at any given time, a smaller RF source may be used and/or only wet clothes and/or portions heated, optionally reducing energy consumption.

**[0258]** In an exemplary embodiment of the invention, dryer 2000 includes a water vapor vent 2050 in fluid communication with an environment outside cavity 2020. In the depicted embodiment, an optional positive pressure source (shown as fan 2058) increases pressure in cavity 2020 by causing air to flow through intake vent 2056. This air flow produces a flow from cavity 2020 into water vapor vent 2050. Alternatively, or additionally, dryer 2000 includes a negative pressure source (shown as fan 2054 adapted to cause a flow into water vapor vent 2050 from cavity 2020. Vent 2050 is shown covered by optional shielding 2052 adapted to reduce leakage of RF energy from vent 2050. Alternatively or additionally to a vent, a different humidity removal system may be used, for example, a condenser or a desiccant unit, which is optionally regenerated by RF heating.

**[0259]** In an exemplary embodiment of the invention, vents 2050 and 2056 are each individually sealable by closure valves (not visible). Optionally, closure of vent 2056 followed by operation of fan 2054 in vent 2050 while door 2016 is closed reduced pressure in cavity 2020. Vent 2050 can then be closed to maintain the reduced pressure. RF heating by RF feeds 2032 and/or 2030 in concert with the reduced pressure increases vaporization of water in the clothing. Opening of vents 2050 and/or 2050 can the release the vaporized water. Optionally, operation of fans 2054 and/or 2058 contributes to removal of the vaporized water via the vents. Optionally, vent 2050 and/or vent 2056 comprises a plurality of openings to increase air circulation in the cavity. Alternatively, or additionally air flow is directed by passages to increase circulation of air in cavity 2020.

**[0260]** In an exemplary embodiment of the invention, dryer 2000 includes one or more sensors which provide data to controller 2040. In an exemplary embodiment of the invention, controller 2040 modifies drying conditions responsive to the data. Sensors can include, but are not limited to Temperature Transmitting Tag (TTT) as described hereinabove, infrared sensors and relative humidity sensors.

**[0261]** In an exemplary embodiment of the invention, at least one vent sensor 2060 adapted to monitor a condition in the water vapor vent is provided therein. Optionally, vent sensor 2060 measures temperature and/or relative humidity. Alternatively, or additionally, dryer 2000 includes at least one clothing sensor (e.g. spectral image module 2030) adapted to monitor a condition of item of clothing 2110. Optionally, the clothing sensor monitors fabric temperature (e.g. a TTT) and/or degree of dampness. Alternatively, or additionally, dryer 2000 includes at least one cavity sensor 2070 adapted to monitor a condition within cavity 2020. Sensor 2070 may monitor, for example, air temperature and/or relative humidity. Multiple (or imaging) sensors may be used to generate an indication of uniformity.

**[0262]** In an exemplary embodiment of the invention, dryer controller 2040 controls the RF power and the airflow intensity. This may be used to set a predefined temperature and/or predefined drying rate at substantially any time during operation. For example, increasing the RF power while keeping airflow intensity constant typically increases the object temperature. Controlling the airflow intensity may also affect the temperature of the object, because it increases evaporation. For example, decreasing the airflow intensity may reduce evaporation hence increase object temperature. Therefore, one may set the RF energy input and the airflow in such manner so as to obtain a desired temperature. Optionally, the RF energy and air flow may be increased concomitantly in such manner that object temperature remains essentially constant, while evaporation increases.

**[0263]** In an exemplary embodiment of the invention, dryer controller 2040 controls the RF power and the air pressure in cavity 2020. Decreasing the air pressure increases evaporation, this in turn can decrease the temperature of the drying object. Increasing air pressure is used to increase the temperature of the drying object.

**[0264]** In an exemplary embodiment of the invention, dryer controller 2040 controls RF radiated power and/or airflow intensity and/or air pressure and/or air heating. Joint control of several parameters optionally enables dryer controller 2040 to control the drying object and the environment condition to the desired drying profile setup. Optionally, dryer 2000 induces a predetermined drying profile for the temperature in cavity 2020. Alternatively, or additionally, dryer 2000 generates a predetermined drying profile for the humidity (e.g. linear decreasing function) in cavity 2020.

**[0265]** In an exemplary embodiment of the invention, dryer 2000 sets one or more sterilization phase during the drying process. Sterilization is optionally achieved by short time (e.g. 10, 50, 100 seconds) of high temperature (e.g. 70, 80, 90, 100 degrees Celsius) in the drying. Such high temperature can be set, for example, by increasing the RF power, non-RF heating, increasing the air heating, decreasing the airflow intensity and/or combining these settings together.

**[0266]** Optionally, the sterilization step is performed at a time when the fabric water content is within a predefined range; for example, when the cloth is nearly dry. Lower water content means that the sterilization temperature may be

reached using a lower amount of energy. Sterilization is optionally augmented by adding a liquid (e.g. spraying water) followed by a burst of RF energy (optionally without or with very little air flow). When the desired temperature is reached and was maintained for the necessary period, RF input may be reduced (or ceased) while airflow will be increased, to allow drying of the object. In an exemplary embodiment of the invention, dryer 2000 is setup to a specific time duration (e.g., no less than a minimal time needed as set by the system design) for drying and controller 2040 ensures drying profile for minimum total energy consumption, e.g., maximum efficiency.

**[0267]** In an exemplary embodiment of the invention, a temperature of clothing and water there with is changed by faster than 10 degrees in 2 minutes, 1 minute, 30 seconds, 10 seconds, 1 second or intermediate times, optionally at a state when water content is greater by weight than the weight of laundry. Optionally, at laundry loads of, for example, 0.5 Kg, 1 Kg, 2 Kg, 4 Kg, 10 Kg, or intermediate or greater weights. Optionally or alternatively, drying from soaking (non-dripping) clothing to dry (e.g., 30% humidity) for such loads is provided, within 20 minutes, 10 minutes, 5 minutes, 1 minute, 30 seconds or less or intermediate times. Optionally, such drying is provided with same or less energy than used by forced heated air dryers in ambient conditions, for example, less than 90%, less than 50%, less than 20% or intermediate energy percentages.

**[0268]** In an exemplary embodiment of the invention, dryer 2000 is setup to specific amount of energy to be spend on drying (no less than the minimal amount of energy needed to increase the object temperature by at least 1 °C) and controller 2040 ensures the drying profile for fastest drying duration.

**[0269]** In an exemplary embodiment of the invention, dryer 2000 includes an agitator adapted to move at least one item of clothing 2110 within cavity 2020. In the depicted embodiment, cavity 2020 is provided as a rotating drum which serves as an agitator.

**[0270]** In a clothes dryer which relies to a great extent on RF energy, the function of may be different than in a conventional clothes dryer. Agitation in an RF dryer serves to remove water vapor generated by RF heating from with fabric. Conventional forced air heating employs agitation primarily to introduce heat to fabric. In an exemplary embodiment of the invention, RF heating is conducted for a period of time, followed by a brief period of agitation, the heating/agitation cycle can be repeated at any desired rate and/or any desired number of times. In an exemplary embodiment of the invention, a reduction in amount of agitation contributes to a reduction in mechanical damage to fabric and/or a reduction in creasing and/or a reduction in energy consumption by the agitation mechanism and/or an increase in evaporation efficiency and/or reduction of wrinkling.

**[0271]** In an exemplary embodiment of the invention, dryer 2000 includes a heating module adapted to heat a target placed in the dryer (e.g. RF feed 2032) and a spectral imaging module 2030 adapted to produce a spectral image of the target and produce a spectral image signal and controller 2040 adapted to receive the spectral signal, translate the signal into an indication of moisture content and stop heating by the heating module when a desired moisture content is achieved. This configuration can also be used with dryers that use non-RF heating (e.g. forced air dryers)

**[0272]** Figs. 33a, 33b, 33c and 33d are spectral images of an empty dryer cavity, a dryer cavity containing wet clothing, a dryer cavity containing semi-dry clothing and a dryer cavity containing dry clothing in accord with an exemplary embodiment of the invention.

**[0273]** Fig. 33a illustrates that an empty dryer cavity according to an exemplary embodiment of the invention produces a spectral image with sharp peaks at characteristic frequencies.

**[0274]** Fig. 33b illustrates that introduction of wet clothing into the same dryer cavity invention produces a spectral image a noticeably different pattern of broad peaks at characteristic frequencies.

**[0275]** Fig. 33b illustrates that the same clothing in the same cavity in a semi-dry state produces a spectral image intermediate between the images of Figs. 33a and 33b.

**[0276]** Fig. 33d illustrates that the same clothing, when fully dried, in the same dryer cavity produces a spectral image nearly identical to that of an empty dryer cavity (Fig. 33a).

**[0277]** Figs. 33a, 33b, 33c and 33d illustrate that spectral image feedback can be used to determine when one or more items of clothing in a dryer cavity are dry.

**[0278]** Figs. 33a, 33b, 33c and 33d each include two plots of:

$\text{Log}_{10} [\text{Power}_{\text{Return}} / \text{Power}_{\text{Applied}}]$  as a function of frequency.

**[0279]** The plots are marked efficiency 1 and efficiency 2.

**[0280]** Efficiency 1 represents use of a same RF antenna (e.g. 2032 in Fig. 20) to both apply RF power for heating and provide spectral image data.

**[0281]** Efficiency 2 represents use of a second RF antenna (e.g. 2030 in Fig. 20) to provide spectral image data for applied RF power from a first RF antenna (e.g. 2032 in Fig. 20).

**[0282]** Figs. 33a, 33b, 33c and 33d demonstrate that it is feasible to integrate the spectral imaging module into an RF feed or to separate the spectral imaging module from the RF feed. Optionally, the two strategies are combined. While the example presented here considers only two RF feeds, additional embodiments of the invention include greater

numbers of RF antennae, each of which can function as an RF feed and/or a spectral imager.

**[0283]** Optionally, dryer 2000 includes analytic circuitry (e.g., within controller 2040) adapted to calculate a drying time. In an exemplary embodiment of the invention, the drying time, or remaining drying time, is displayed to a user on display 2015 on an outer side of door 2014 of cavity 2020.

**[0284]** In some embodiments of the invention, dryer 2000 is configured as a clothes dryer as described hereinabove. In other embodiments of the invention, dryer 2000 is configured as a waste dryer. Configuration for waste drying optionally includes a larger cavity 2020 and/or a larger motor to agitate the cavity and/or a greater output capacity for RF feeds 2032 and/or a large number of RF feeds. (e.g. tens, hundreds or thousands). Optionally, increasing a number of RF feeds contributes to an increase in total applied RF power. In an exemplary embodiment of the invention, waste drying includes evaporation of a high percentage of moisture so that a high power input can be advantageous. Depending on waste type, the high percentage of moisture can be 50, 60, 70, 80, 85, 90 or 95% (or intermediate values). As the high percentage increases, importance of a high power input becomes more important in order to achieve a short drying time.

**[0285]** In an exemplary embodiment of the invention, a label reader 2090 adapted to read machine-readable drying instructions is provided as part of dryer 2000. Reader 2090 communicates drying instruction to controller 2040 which operates RF feed(s) 2032 and/or other dryer components in accord with the instructions.

**[0286]** Fig. 34 presents measurements by the inventors demonstrating temperature and humidity in the air exits from vent 2050 in dryer 2000 as compared to the temperature and humidity in the air exits from a conventional home appliance clothes dryer.

**[0287]** As described herein, these measurements show how control of various drying parameters may be achieved, using an RF dryer in accordance with an exemplary embodiment of the invention. In particular, in a conventional dryer, air humidity stays relatively stable during most of the drying process and then falls sharply when drying is complete. In an RF dryer in accordance with an exemplary embodiment of the invention, air humidity and/or air temperature can be controlled in a flexible manner, for various reasons.

**[0288]** As shown in Fig. 34, the air humidity in both dryers starts from 70% when drying starts and decreases to 30% when the drying process finished. The humidity in conventional dryer 3410 drops sharply to about 50% during the initial phase of drying, stays constant during most of the drying process and when most of the water is drawn out of the clothes the air humidity suddenly drops toward zero. The air temperature in conventional dryer 3420, rises sharply during the initial phase of drying from 15 degrees centigrade initially up to about 40 degrees centigrade, stays at this temperature for most of the drying process and at the end of the process when most of the water is drawn out of the clothes the temperature rises since water evaporation ceases and no longer pumps the heat from the vented air.

**[0289]** The air humidity in the dryer according to an embodiment of the invention 3430, measured with constant RF power radiated to energy into a cavity 2020 and constant air current, declines linearly with time. Overall, the time to dry the same clothing load to a predetermined humidity is substantially shorter. The air temperature in the dryer according to an embodiment of the invention 3440, rises during the initial phase of drying from 15 degrees centigrade initially to about room temperature of around 18 degrees centigrade. The air temperature 3440 stays at room temperature for the rest of the drying process. It should be noted that various other temperature profiles, humidity profiles can be provided, while in a conventional dryer, the temperature and humidity profiles are restricted.

**[0290]** In an exemplary embodiment of the invention, dryer 2000 is configured to a drying profile that prevents (or reduces) damage such as wrinkling, shrinking, deformation, loss of elasticity, color change and/or any other damage that might reduce the garment's life and/or usability. Optionally, the settings are provided by preprogramming, remote access and/or reading laundry tags. Optionally, a user can select one of several programs or settings to achieve a desired effect.

**[0291]** In an exemplary embodiment of the invention, dryer 2000 is configured to a spatial profile that treats different parts of the clothes, (e.g. thicker portions such as collar, belt and/or specific items in the load) with preference to ensure drying of these parts or items.

#### Experiment interpretation in conventional dryer

**[0292]** It is believed that the drying mechanism in a conventional dryer is that the hot air evaporates water on the clothes during the passage of hot air through a clothes tumbler. The capacity of water evaporation depends both on the strength of the airflow and the temperature of the air. However, these parameters in conventional dryer are linked since the air is heated using a hot plate and increasing the airflow rate reduces the hot air temperature. Fast airflow at a low temperature may have the same energy as slower airflow with high temperature, but the conduction at a low temperature is reduced. Therefore, in order to improve the drying rate in conventional dryers, relatively high temperatures are used. Also, water is heated to the higher temperatures and this heat is vented and wasted.



Possible experimental results interpretation in a dryer according to an embodiment of the invention

**[0293]** Without being limited to a particular theory, it is hypothesized that the microwave radiation heats the water in the fabric but not the fabric itself. The water molecules temperature rises faster when radiation is directly applied to them than by convection when hot air is applied. Contact with airflow causes the molecules to evaporate much faster to the air. Optionally, increased airflow can increase drying rate. It is possible that molecules can be substantially unheated with all or most of the deposited energy going towards providing latent heat for evaporation. That way, cool drying is achieved without increasing the time needed to dry the object. At times, the drying time at this low temperature is significantly lower than the time needed for drying in conventional dryers at a much higher temperature.

**[0294]** In some exemplary embodiments of the invention, dryer 2000 directs the RF energy only to evaporate water in the object to maintain maximum efficiency. Optionally, dryer 2000 directs the RF energy only to specific positions containing the water, such as outer parts of the clothes or fabrics and/or inner parts of the clothes or fabrics and/or thick clothes or fabrics, to further increase drying efficiency.

Exemplary special items of clothing

**[0295]** In an exemplary embodiment of the invention, an item of clothing 2100 comprising a label 2120 bearing machine-readable drying instructions for implementation in a clothes dryer of the general type described in the context of Figs. 20 and 22-27 is provided.

**[0296]** Fig. 21a depicts the machine readable label 2120 as a bar code. In other embodiments of the invention, the machine readable label can include, for example, an RFID tag and/or a magnetic stripe. In some cases, label 2120 encodes complete washing instructions. In other cases, label 2120 contains a cycle code. In an exemplary embodiment of the invention, controller 2040 employs a lookup table of cycle codes and operates dryer 2000 in accord with instructions in the lookup table. In an industrial setting, the label may indicate care instructions provided by a customer and/or an identification of ownership.

**[0297]** While different dryers may implement different cycles in response to a same code, each implemented cycle is believed (by the manufacturer of a specific dryer) to be suitable for clothing of the type indicated by the cycle code on label 2120. Optionally, cycle codes contain information including but not limited to fabric type, color, color density and garment weight.

**[0298]** In an exemplary embodiment of the invention, dryer 2000 handles multiple types of fabrics together where each fabric type and/or each fabric lump is treated differently to accommodate different drying rates and/or different temperature or other drying constraints.

**[0299]** In an exemplary embodiment of the invention, dryer 2000 controls the rate of drying. Applying RF energy and/or hot air energy and/or airflow and/or air pressure energies on the drying object affect the drying rate. Drying rate can be setup for fastest drying or for most efficient drying or for completion of drying in specific duration.

**[0300]** In an exemplary embodiment of the invention, dryer 2000 controls the total energy invested on drying. Efficient drying achieved by proper dynamic allocation energy between RF energy and/or hot air energy and/or airflow and/or air pressure energies.

**[0301]** In an exemplary embodiment of the invention, dryer 2000 keeps the drying object cool. Cool drying is useful in some cases, for example if clothes are dirty and get wet, cool drying may avoid setting a stain on the clothes.

Exemplary dryer insert

**[0302]** Fig. 21b depicts an insert 2150 adapted to hold one or more items of clothing 2110 within a cavity of an RF oven. In an exemplary embodiment of the invention, insert 2150 contributes to an ability of the oven to function as a clothes dryer.

**[0303]** Depicted exemplary insert 2150 includes a garment receptacle 2152 (depicted as a planar surface) and a plurality of supports 2154 (depicted as cylindrical legs. Optionally, use of insert 2150 positions item of clothing 2110 advantageously within the cavity to receive RF radiation.

**[0304]** In an exemplary embodiment of the invention, insert 2150 includes at least one passive element 2155 which causes a local increase in temperature in some portion of at least one item of clothing 2110 when the RF energy is applied.

**[0305]** Optionally, the insert includes a tag with heating instructions. Optionally, the tag is a mechanically manipulated tag (e.g., dielectric or metal elements which may be used), so that a user can manually set drying instructions.

**[0306]** Depicted exemplary insert 2150 includes optional desiccants reservoir 2158 and optional water reservoir 2156.

**[0307]** In an exemplary embodiment of the invention, desiccant placed in desiccant reservoir 2158 absorbs and/or adsorbs water vapor release from item 2110 during drying. In an exemplary embodiment of the invention, the desiccant has sufficient capacity to absorb substantially all water released from item 2110 during drying. Optionally, use of desiccant contributes to a reduction in reliance upon venting of vapors during drying.

**[0308]** In an exemplary embodiment of the invention, water placed in water reservoir 2156 is released by a targeted pulse of RF energy near the end of a drying cycle. Optionally, the pulse comprises frequencies different from those used during drying. Optionally, the reservoir is constructed of materials that are heatable at specific frequencies. Alternatively, or additionally, the pulse is aimed at the reservoir. The targeted pulse creates steam which is absorbed by item 2110. Removal of item 2110 promptly after steam absorption and hanging on a hanger contributes to a reduction in wrinkling of item 2110. Optionally, a need for ironing is at least partially obviated.

**[0309]** Optionally, insert 2150 can include one or more chemical reservoirs. Deodorant and/or fragrances and/or fabric softeners can be placed into these reservoirs and vaporized using RF energy. Optionally, water reservoir 2156 can be used as a chemical reservoir.

**[0310]** These features may also be used as part of a non-insert dryer.

#### Exemplary Desiccants

**[0311]** For purposes of this specification and the accompanying claims, "desiccant" refers to a hygroscopic substance that induces or sustains a state of dryness (desiccation) in its local vicinity in a moderately-well sealed container. Pre-packaged solid desiccants are available and packages of a desired size can be employed in exemplary embodiments of the invention. Thus, the phrase "desiccant reservoir" encompasses a packet of desiccant.

**[0312]** In general, solid desiccants work through absorption and/or adsorption of water. Common solid desiccants include, but are not limited to, Silica gel, calcium sulfate, chalk, montmorillonite clay, and molecular sieves can also be used as effective desiccants.

**[0313]** Desiccants can be rated as to their efficiency in terms of the ratio (or percentage) of water storable in the desiccant, relative to the mass of desiccant. In general, performance of a desiccant varies with temperature and both relative and absolute humidity. In the context of embodiments of the invention described herein, selecting a suitable type and amount of desiccant for a garment of a given type is based upon routine calibration experiments. To some extent the performance can be described, but most commonly the final choice of which desiccant best suits a given situation, and how much of it to use, and in what form, is made based on testing and experience.

**[0314]** Desiccants can typically be recycled numerous times by thermally-induced drying, for example in a conventional kitchen oven or in an RF oven as described herein. Optionally, a humidity indicator indicates, by color changes, a degree of water-saturation of the desiccant. Cobalt chloride ( $\text{CoCl}_2$ ) is commonly employed for this purpose. Anhydrous cobalt chloride is blue and the dihydrate is purple. Further hydration results produces a hexahydrate which is pink. Color indicators of this type allow monitoring of drying for purposes of recycling.

#### Exemplary Open Hybrid Systems

**[0315]** Fig. 22 depicts a conventional clothes dryer modified to incorporate one or more RF feeds 2032 (one is pictured) to dry clothes (or other materials) in a hybrid system 2200 combining heated forced air and RF heating. In the depicted embodiment RF energy provided by one or more RF feeds 2032 installed on a resonator 2220 surrounding rotating drum 2020. In the depicted embodiment, RF feed 2032 is positioned outside drum 2020. In the depicted configuration, it is advantageous to construct drum 2020 of a material that is substantially transparent with respect to relevant RF frequencies. One example of a material substantially transparent with respect to RF frequencies useful for drying laundry is Teflon - Polytetrafluoroethene (PTFE). Air from outside the dryer is introduced into the system via conduit 2255 and pumped by pump 2058 (e.g. including a fan as in Fig. 20 or turbine) via conduit 2056 onto clothing 2110 tumbling within rotating drum 2020. As the air passes through drum 2020, it absorbs moisture which is vented out of the dryer from an exhaust conduit 2050. Optionally, moisture in drum 2020 is released from clothing 2110 due to RF energy from feed 2032 and/or due to heat supplied by a conventional heating element (not shown). A conventional heating element can be deployed, for example, in pump 2058.

**[0316]** In an exemplary embodiment of the invention, a flow of air passing through drum 2020 is increased by increasing a flow from pump 2058. In contrast to standard forced air dryers, increasing flow from pump 2058 can be undertaken without increasing a required heating capacity. This is possible because heating from RF source 2032 is airflow independent. In an exemplary embodiment of the invention, increased airflow contributes to an increase in evaporation rate without an increase in applied heating energy.

**[0317]** Fig. 22 shows that RF feed 2032 is powered by RF source 2232. Optionally, cooling air is supplied to source 2232 via cooling conduit 2234. As the air flows across source 2232 it is heated and exits via conduit 2236. This depicted exemplary arrangement cools RF source 2232 but contributes to an increase in total energy consumption.

**[0318]** Fig. 23 depicts an exemplary hybrid system 2300 which offers increased drying efficiency relative to the embodiment depicted in Fig. 22. In the embodiment depicted in Fig. 23, RF source 2232 serves as a source of heat for air being pumped via conduit 2236 into rotating drum 2020. A bypass switch 2310 allows regulation of how much heated air from RF source 2232 is mixed with ambient air to be pumped into drum 2020. This arrangement offers reduced

energy consumption without a substantial sacrifice in ability to control air temperature.

**[0319]** In an exemplary embodiment of the invention, clothing can be heated to a first evaporation temperature (e.g. from 20°C to 50°C) using heat from RF source 2232. This heating may be augmented for example using warm air as depicted in Fig. 23. In an exemplary embodiment of the invention, the warm air is provided at no incremental energy cost (e.g. by absorbing heat from an amplifier that is being used as an RF source). Optionally, flow of warm air is stopped and/or repeated, as needed using bypass valve 2310. This "turbo" configuration can significantly reduce drying time, e.g. by, 25, 30, 35, or 40% or lesser or greater or intermediate amounts). Optionally, turbo-heating at least partially offsets a cooling effect of water evaporation. Optionally, turbo-heating contributes to faster evaporation of water heated by RF energy.

**[0320]** In an exemplary embodiment of the invention, a degree of input energy to RF source 2232 diverted to turbo-heating of air is regulatable. One exemplary way of changing an amount of diverted input energy is by changing a voltage supplied to a transistor of RF source 2232. Under certain conditions (e.g. at the beginning of a drying cycle) it may be advantageous to reduce available RF energy from feed 2032 in favor of increased turbo-heating from RF source 2232.

#### Exemplary Closed Hybrid Systems

**[0321]** Fig. 24 depicts an exemplary closed hybrid system 2400. This system is similar to system 2200 except that exhaust vent 2050 and intake conduit 2255 are combined.

**[0322]** In the depicted embodiment, pump 2058 serves to both introduce hot dry air into drum 2020 and to draw moist air out of the drum. The moist air is routed through an external condenser 2410, where water vapors condense to liquid water 2412 which flows through a drain 2420, optionally due to gravity. Pump 2058 routes the de-moisturized air back into rotating drum 2020. Optionally, heat generated by the condensing system (only the condenser 2410 is shown) is used to heat the de-moisturized air contributing to increased drying efficiency.

**[0323]** In an exemplary embodiment of the invention, RF source 2232 receives cool air via an intake vent 2234 and expels hot air via an exhaust vent 2236 as in Fig 22.

**[0324]** Fig. 25 depicts an additional closed hybrid system 2500 in which resonator 2220 serves also as an integrated condenser 2410. In the depicted embodiment, drain 2420 is attached directly to the resonator. In the depicted embodiment, cooling fluid circulates via the condenser line which contacts the resonator.

#### Additional exemplary systems which combine condensation and recycling of heat

**[0325]** Fig. 26 depicts another exemplary closed hybrid system 2600 in which dehumidified air exiting condenser 2410 can be routed towards RF source 2232 and/or towards pump 2058 which recirculates the air into drum 2020. In the depicted embodiment, a series of bypass valves 2310 direct airflow. The depicted exemplary embodiment of the invention allows heat generated from RF source 2232 to be routed into drum 2020 to aid in drying. Optionally, this contributes to increased drying efficiency.

**[0326]** Fig 27 shows an additional exemplary system 2700 similar to system 2600 except that condenser 2410 is integrated into resonator 2220 as in Fig. 25.

#### Exemplary considerations in selecting a condenser type

**[0327]** Optionally, integrated condensers of the general type depicted in Figs. 25 and 27 can contribute to operational advantages, such as condensation efficiency, relative to the external condenser configuration of Figs. 24 and 26. Increased condensation efficiency can stem, at least in part, from increased condensation. Alternatively, or additionally, integrated condensers can be incorporated into a dryer with a smaller increase in overall dimensions than an external condenser.

**[0328]** In some cases, commercial availability of external condensers can contribute to a reduction in production costs. Optionally, a reduced production cost at least partially offsets the operational advantages of integrated condensers.

#### Exemplary Methods of drying clothing

**[0329]** RF dryers according to various embodiments of the invention, including but not limited to those specifically described herein can be used to implement a large number of RF based drying methods. Exemplary methods are described herein for purposes of illustration.

**[0330]** Fig. 28 is a simplified flow diagram of an exemplary method 2800 of controlling an RF clothes dryer. Method 2800 begins with drying 2810 at least one item of clothing in a RF clothes dryer. During drying 2810, feedback is received 2820 by the dryer. The dryer responds by automatically changing 2830 heating in response to the feedback. According to various embodiments of the invention, automatically changing 2830 can take one or more different forms.

**[0331]** Optionally, automatically changing 2830 includes directing RF energy to an amount of water 2840 so that at least a portion of the amount becomes steam which contacts the at least one item of clothing. Steam released just prior to removal of clothing can contribute to wrinkle reduction.

**[0332]** Optionally, automatically changing 2830 includes directing RF energy to a chemical agent 2850 so that at least a portion of the chemical agent becomes chemical vapors which contacts the at least one item of clothing. Chemical agents can include, for example, stain removal agents and/or deodorants and/or fragrances and/or fabric softeners.

**[0333]** Optionally, automatically changing 2830 includes increasing 2860 a uniformity of said heating. Optionally, automatically changing 2830 includes reducing 2870 a uniformity of said heating. Uniformity of heating can refer to physical distribution of RF energy in the dried object volume and/or temporal patterns of RF energy application to the dried object volume and/or to a frequency/power distribution of the applied RF energy.

**[0334]** Fig. 29 is a simplified flow diagram of an exemplary method 2900 of drying clothing. Method 2900 includes placing 2910 at least one item of clothing into a cavity and directing 2920 RF energy into the cavity for a first period of time under specified conditions. During a second period of time, data is acquired 2930 and a heating drying) output is produced. According to some embodiments of the invention, the first period of time and the second period of time are temporally distinct. In other embodiments, the first period of time and the second period of time temporally overlap.

**[0335]** According to the depicted method, a controller modifies 2940 the specified conditions of the RF energy responsive to the drying output.

**[0336]** Different types of data acquisition 2930 are practiced in different optional variants of method 2900. Optionally, the acquired data can relate to the reflection frequencies of a metal item (e.g. a zipper) which changes due to agitation of the clothing. Optionally, acquiring data 2930 includes acquiring a spectral image 2950 of the at least one item of clothing and the drying output includes 2960 a spectral image of the at least one item of clothing. Optionally, acquiring data 2930 includes ascertaining 2980 whether a portion of the at least one item of clothing is above or close to a desired maximum temperature. Optionally, acquiring data 2930 includes ascertaining 2982 whether a portion of the at least one item of clothing is below a desired minimum temperature. In an exemplary embodiment of the invention, the controller responds by adjusting heating to compensate for temperatures which are too high and/or too low.

**[0337]** In an exemplary embodiment of the invention, the controller responds 2970 by adjusting RF power and/or RF frequencies directed to a specific area of the at least one item of clothing delimited in the spectral image.

**[0338]** In an exemplary embodiment of the invention, drying output 2930 indicates a position of at least one problematic portion of the at least one item of clothing and wherein the controller responds 2988 by reducing an amount of the RF energy directed to the problem area or avoiding the problematic frequencies or frequency bands.

**[0339]** Optionally, water vapor is periodically removed 2990 from the cavity. Removal can be passive or active and optionally includes use of a condenser as described hereinabove.

**[0340]** In some embodiments of method 2900, monitoring 2992 a temperature of air in the cavity and/or a temperature the at least one item of clothing is conducted. In an exemplary embodiment of the invention, the controller modifies specified conditions of the RF energy responsive to the temperature. Optionally, a TTT is employed in temperature monitoring.

**[0341]** In some embodiments of method 2900, monitoring 2992 of a relative humidity of air in the cavity and/or a degree of dampness of the at least one item of clothing produces an indicator of drying completion. In an exemplary embodiment of the invention, the controller modifies specified conditions of the RF energy responsive to the indicator of drying completion.

**[0342]** Optionally, using relative humidity of air in the cavity as an indicator of drying completion can contribute to a longer drying time. Optionally, the longer drying time occurs because moisture will be present in the cavity after no moisture remains in the clothing. In an exemplary embodiment of the invention, this discrepancy can be at least partially overcome by using a rate of change in relative humidity of air in the cavity as a drying indicator. This possibility is included in "relative humidity of air in the cavity".

**[0343]** Fig. 30 is a simplified flow diagram of an exemplary method 3000 of drying clothing. Method 3000 includes providing 3010 at least one item of clothing, selecting 3020 a desired temperature profile for the at least one item of clothing and applying 3040 RF energy via the clothes dryer so that two or more portions of the at least one item of clothing comprising different materials each adhere to the temperature profile. Temperature profile can be defined in terms of minimum temperature and/or maximum temperature and/or average temperature and/or uniformity of temperature and/or a temporal relationship including one or more of these factors.

**[0344]** An exemplary temperature profile includes heating the specific item to a specific temperature using RF energy and then stopping application of RF energy and heating cavity 2020 with hot air and iteratively repeating until a desired degree of dryness is achieved.

**[0345]** Optionally, the at least one item of clothing includes 3050 two or more items of clothing, each one of which is subjected to a separate temperature profile.

**[0346]** Fig. 31 is a simplified flow diagram of an exemplary method 3100 of increasing evaporation in an RF clothes dryer. Depicted method 3100, includes providing 3110 at least one item of clothing to be dried and heating 3120 the at

least one item while ensuring that at least 50% optionally 80% (3150) of the at least one item remains within 10 degrees centigrade of a threshold temperature where increased evaporation occurs. Optionally, ensuring involves use of one or more feedback mechanisms as described hereinabove.

[0347] Optionally, method 3199 includes placing 3130 a quantity of desiccant in proximity to said at least one item of clothing. In some embodiments of method 3100 drying 3140 of the desiccant using RF energy is conducted before and/or after use. Alternatively, the desiccant can be dried using other means (e.g. a conventional oven).

[0348] Fig. 32 is a simplified flow diagram of an exemplary method 3200 of drying clothing. Exemplary method 3200 includes heating 3210 clothing by means of RF energy until water in the clothing reaches a desired evaporation temperature. Optionally, the evaporation temperature can be 20, 30, 40, 50, 60, or 70, 80, 90 degrees centigrade or lesser or intermediate or greater temperatures. In general, a degree of evaporation increases as the temperature increases. However, some fabrics must be dried at lower temperatures to reduce fabric damage. Method 3200 includes stopping 3220 heating 3210 and agitating the clothing to facilitate evaporation. Optionally, agitation facilitates evaporation by exposing clothing surface to air.

[0349] Method 3200 includes repeating 3230 heating 3210, stopping 3220 and the agitating until a desired degree of dryness is achieved.

[0350] In an exemplary embodiment of the invention, dryer 2000 keeps humidity in cavity 2020 between a minimum humidity and a maximum humidity. Optionally, a drying phase is activated if and when maximum humidity reached. Optionally, a drying process stops when the minimum level is reached, and then the dryer is kept in off state until maximum humidity reached again, for example, for several minutes (e.g., 1-5), several hours (e.g., 1-5), several days (e.g., 1-5), several months (e.g., 1-5) or other intermediate or greater periods of time. Optionally, this type of dryer is used for storage purposes, and maintaining humidity levels in a storage space and/or in-placed objects. Optionally, an alert is sounded when the dryer is activated. Optionally or alternatively, a switch is provided to enter such a drying mode.

[0351] The present invention has been described using detailed descriptions of embodiments thereof that are provided by way of example and are not intended to limit the scope of the invention. The described embodiments comprise different features, not all of which are required in all embodiments of the invention. Some embodiments of the present invention utilize only some of the features or possible combinations of the features. Variations of embodiments of the present invention that are described and embodiments of the present invention comprising different combinations of features noted in the described embodiments will occur to persons of the art. For example the present invention has been described mainly in the context of drying clothing. The inventors believe that based on the results shown above, it can be expected that the methods of the present invention, possibly at different frequencies, can be used for other types of drying (e.g. waste drying) and/or industrial processes which include solvent evaporation.

[0352] Additionally, components and/or actions ascribed to exemplary embodiments of the invention and depicted as a single unit may be divided into subunits. Conversely, components and/or actions ascribed to exemplary embodiments of the invention and depicted as sub-units may be combined into a single unit with the described/depicted function (e.g. integration of an RF feed and spectral imaging module).

[0353] Alternatively, or additionally, features used to describe a method can be used to characterize an apparatus and features used to describe an apparatus can be used to characterize a method.

[0354] Furthermore, the terms "comprise," "include," and "have" or their conjugates shall mean: "including but not necessarily limited to." The scope of the invention is limited only by the following claims:

## Claims

1. A dryer, comprising:

a cavity (10) adapted to receive at least one object to dry;  
at least one broadband RF source (96) configured to radiate RF energy into the cavity; and  
a controller (130) for controlling the RF source to dry the object;

**characterized by** a spectral imaging module for providing a spectral image of items in the dryer, and in that the controller is configured to adjust the RF energy in response to the spectral image.

2. A dryer according to claim 1, wherein the controller (130) is configured to adjust the RF energy by changing a heating policy defined in terms of one or more transmitted frequencies.

3. A dryer according to claim 1 or 2, comprising a frequency sweeper which sweeps the RF source (96).

4. A dryer according to any one of claims 1 to 3, comprising a plurality of RF feeds (16,18,20) located in the cavity (10).

5. A dryer according to any one of claims 1 to 4, further comprising a forced air intake (2056,2058) having a path configured to contact the object with intaken air, and the controller (130) being configured to control RF radiated power and air heating to maintain the drying of the object within a predetermined drying profile.

6. A dryer according to claim 5, wherein the drying profile comprises one or more of a time period for drying, a maximum agitation rate and a final dryness.

7. A dryer according to any one of the preceding claims, wherein the controller (130) is further configured to adjust, in response to the spectral image, at least one of:

transmitted frequencies, and matching powers for matching times.

8. A dryer according to any one of the preceding claims, wherein the controller (130) is further configured to vary the intensity of at least one frequency band in the RF energy.

9. A method of drying an object in a cavity using RF energy radiation, the method comprising:

radiating RF energy into the cavity (10) using a broadband RF source (96);  
**characterized by:**

obtaining a spectral image of items in the cavity; and  
adjusting RF energy in response to the spectral image.

10. A method according to claim 9, which includes selecting one or more frequency bands for drying based on the spectral image.

11. A method according to any one of claims 9 or 10, wherein the radiating of RF energy into the cavity is through a plurality of RF feeds (16,18,20) located in the cavity (10).

12. A method according to any one of claims 9 to 11, further comprising forcing air intake (2056,2058) through a path configured to contact the object with intaken air, and controlling RF radiated power and air heating to maintain the drying of the object within a predetermined drying profile.

13. A method according to claim 12, wherein the drying profile comprises one or more of a time period for drying, a maximum agitation rate and a final dryness.

14. A method according to any one of claims 9 to 13, further comprising adjusting, in response to the spectral image, at least one of: transmitted frequencies, and matching powers for matching times.

15. A method according to any one of claims 9 to 14, further comprising varying the intensity of at least one frequency band of the RF energy.

## Patentansprüche

1. Trockner, mit:

einem Hohlraum (10), der eingerichtet ist, um mindestens einen zu trocknenden Gegenstand aufzunehmen;  
mindestens einer Breitband-HF-Quelle (96), die konfiguriert ist, um HF-Energie in den Hohlraum zu strahlen; und  
einer Steuerung (130) zur Steuerung der HF-Quelle zum Trocknen des Gegenstands;  
**gekennzeichnet durch** ein spektrales Abbildungsmodul zur Lieferung einer spektralen Abbildung von Artikeln im Trockner, und dass die Steuerung konfiguriert ist, um die HF-Energie in Reaktion auf die spektrale Abbildung einzustellen.

2. Trockner nach Anspruch 1, wobei die Steuerung (130) konfiguriert ist, um die HF-Energie durch Veränderung einer in Bezug auf eine oder mehr übertragene Frequenz(en) festgelegte Heizstrategie einzustellen.

3. Trockner nach Anspruch 1 oder 2, mit einem Frequenzwobbler zum Wobbeln der HF-Quelle (96).

4. Trockner nach einem der Ansprüche 1 bis 3, mit einer Mehrzahl von in dem Hohlraum (10) angeordneten HF-Einspeisungen (16, 18, 20).
5. Trockner nach einem der Ansprüche 1 bis 4, weiters mit einem Gebläselufteinlass (2056, 2058), dessen Bahn konfiguriert ist, um den Gegenstand mit eingelassener Luft zu kontaktieren, wobei die Steuerung (130) konfiguriert ist, um die HF-Strahlungsleistung und Lufterwärmung derart zu steuern, dass das Trocknen des Gegenstands innerhalb eines vorherbestimmten Trocknungsprofils aufrechterhalten wird.
6. Trockner nach Anspruch 5, wobei das Trocknungsprofil eine Trocknungszeit, eine maximale Bewegungsgeschwindigkeit und/oder eine Endtrockenheit umfasst.
7. Trockner nach einem der vorhergehenden Ansprüche, wobei die Steuerung (130) weiters konfiguriert ist, um als Reaktion auf die spektrale Abbildung Übertragungsfrequenzen und/oder entsprechende Leistungen für entsprechende Zeiträume einzustellen.
8. Trockner nach einem der vorhergehenden Ansprüche, wobei die Steuerung (130) weiters konfiguriert ist, um die Stärke mindestens eines Frequenzbands der HF-Energie zu variieren.
9. Verfahren zum Trocknen eines Gegenstands in einem Hohlraum unter Verwendung von HF-Energiestrahlung, welches Verfahren umfasst:

Strahlen von HF-Energie in den Hohlraum (10) unter Verwendung einer Breitband-HF-Quelle (96);  
**gekennzeichnet durch:**

Erhalten einer spektralen Abbildung von Artikeln im Hohlraum; und  
Einstellen der HF-Energie als Reaktion auf die spektrale Abbildung.

10. Verfahren nach Anspruch 9, umfassend das Auswählen von einem oder mehr Frequenzbändern zum Trocknen auf Basis der spektralen Abbildung.
11. Verfahren nach einem der Ansprüche 9 oder 10, wobei das Strahlen von HF-Energie in den Hohlraum durch eine Mehrzahl von HF-Einspeisungen (16, 18, 20) erfolgt, die in dem Hohlraum (10) angeordnet sind.
12. Verfahren nach einem der Ansprüche 9 bis 11, weiters umfassend das Einlassen von Gebläseluft (2056, 2058) über eine Bahn, die konfiguriert ist, um den Gegenstand mit eingelassener Luft zu kontaktieren, und das Steuern der HF-Strahlungsleistung und Lufterwärmung derart, dass das Trocknen des Gegenstands innerhalb eines vorherbestimmten Trocknungsprofils aufrechterhalten wird.
13. Verfahren nach Anspruch 12, wobei das Trocknungsprofil eine Trocknungszeit, eine maximale Bewegungsgeschwindigkeit und/oder eine Endtrockenheit umfasst.
14. Verfahren nach einem der Ansprüche 9 bis 13, weiters umfassend das Einstellen von Übertragungsfrequenzen und/oder entsprechende Leistungen für entsprechende Zeiträume als Reaktion auf die spektrale Abbildung.
15. Verfahren nach einem der Ansprüche 9 bis 14, weiters umfassend das Variieren der Stärke mindestens eines Frequenzbands der HF-Energie.

## Revendications

1. Séchoir, comprenant :

une cavité (10) adaptée pour recevoir au moins un objet à sécher ;  
au moins une source de RF à large bande (96) configurée pour rayonner de l'énergie RF dans la cavité ; et  
un dispositif de commande (130) pour commander la source RF pour sécher l'objet ;  
**caractérisé par** un module d'imagerie spectrale pour fournir une image spectrale d'articles dans le séchoir, et  
en ce que le dispositif de commande est configuré pour régler l'énergie RF en réponse à l'image spectrale.

2. Séchoir selon la revendication 1, dans lequel le dispositif de commande (130) est configuré pour régler l'énergie RF en changeant une politique de chauffage définie en termes d'une ou de plusieurs fréquences transmises.
3. Séchoir selon la revendication 1 ou 2, comprenant un balayeur de fréquence qui balaye la source RF (96).
4. Séchoir selon une quelconque des revendications 1 à 3, comprenant une pluralité d'alimentations en RF (16, 18, 20) situées dans la cavité (10).
5. Séchoir selon une quelconque des revendications 1 à 4, comprenant en outre une admission d'air forcé (2056, 2058) comportant un trajet configuré pour mettre en contact l'objet avec de l'air admis, et le dispositif de commande (130) étant configuré pour commander une puissance RF rayonnée et un chauffage d'air pour maintenir le séchage de l'objet au sein d'un profil de séchage prédéterminé.
6. Séchoir selon la revendication 5, dans lequel le profil de séchage comprend un ou plusieurs parmi une période pour le séchage, un taux maximum d'agitation et une siccité finale.
7. Séchoir selon une quelconque des revendications précédentes, dans lequel le dispositif de commande (130) est en outre configuré pour régler, en réponse à l'image spectrale, au moins une parmi : des fréquences transmises, et des puissances assorties pour des temps assortis.
8. Séchoir selon une quelconque des revendications précédentes, dans lequel le dispositif de commande (130) est en outre configuré pour faire varier l'intensité d'au moins une bande de fréquence dans l'énergie RF.
9. Procédé de séchage d'un objet dans une cavité en utilisant un rayonnement d'énergie RF, le procédé comprenant :  
le rayonnement d'énergie RF dans la cavité (10) en utilisant une source de RF à large bande (96) ; **caractérisé par** :  
l'obtention d'une image spectrale d'articles dans la cavité ; et  
le réglage d'énergie RF en réponse à l'image spectrale.
10. Procédé selon la revendication 9, qui comprend la sélection d'une ou de plusieurs bandes de fréquence pour le séchage en fonction de l'image spectrale.
11. Procédé selon une quelconque des revendications 9 ou 10, dans lequel le rayonnement d'énergie RF dans la cavité est par l'intermédiaire d'une pluralité d'alimentations en RF (16, 18, 20) situées dans la cavité (10).
12. Procédé selon une quelconque des revendications 9 à 11, comprenant en outre le forçage d'admission d'air (2056, 2058) à travers un trajet configuré pour mettre en contact l'objet avec de l'air admis, et la commande de la puissance RF rayonnée et du chauffage d'air pour maintenir le séchage de l'objet au sein d'un profil de séchage prédéterminé.
13. Procédé selon la revendication 12, dans lequel le profil de séchage comprend un ou plusieurs parmi une période pour le séchage, un taux maximum d'agitation et une siccité finale.
14. Procédé selon une quelconque des revendications 9 à 13, comprenant en outre le réglage, en réponse à l'image spectrale, d'au moins une parmi :  
des fréquences transmises, et des puissances assorties pour des temps assortis.
15. Procédé selon une quelconque des revendications 9 à 14, comprenant en outre la variation de l'intensité d'au moins une bande de fréquence de l'énergie RF.



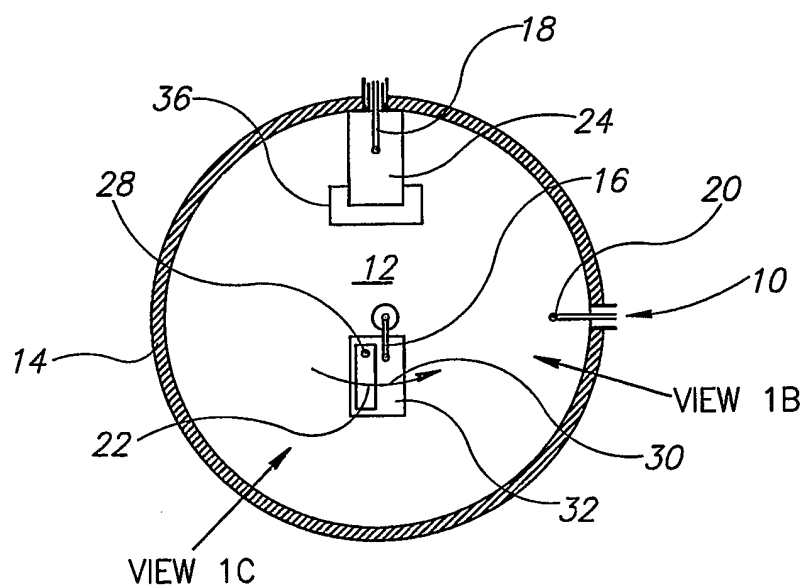


FIG. 1A

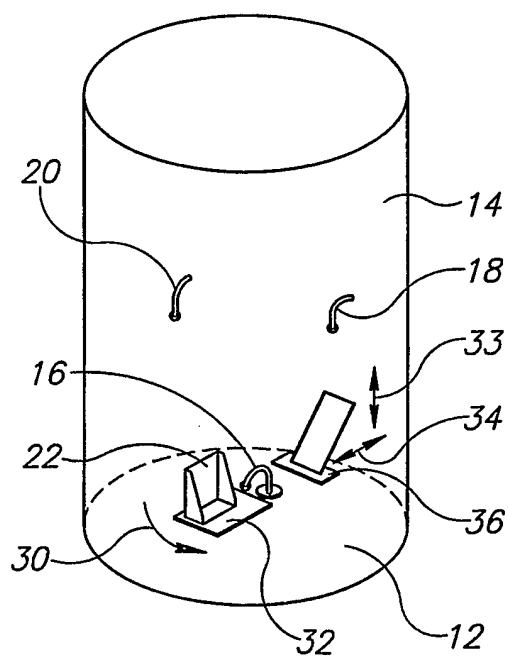


FIG. 1B

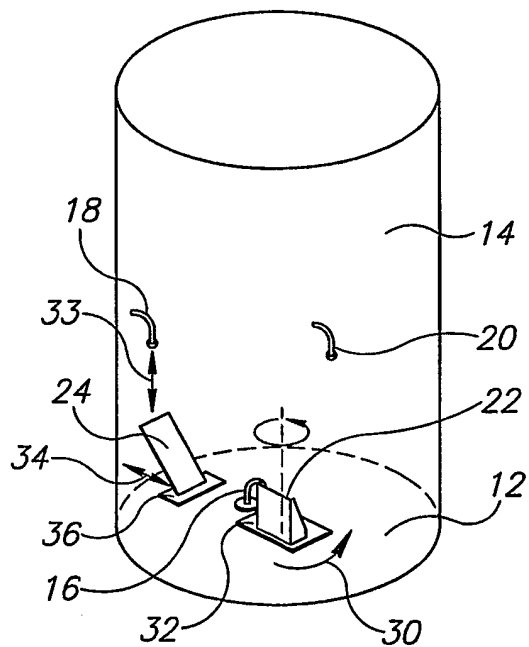


FIG. 1C

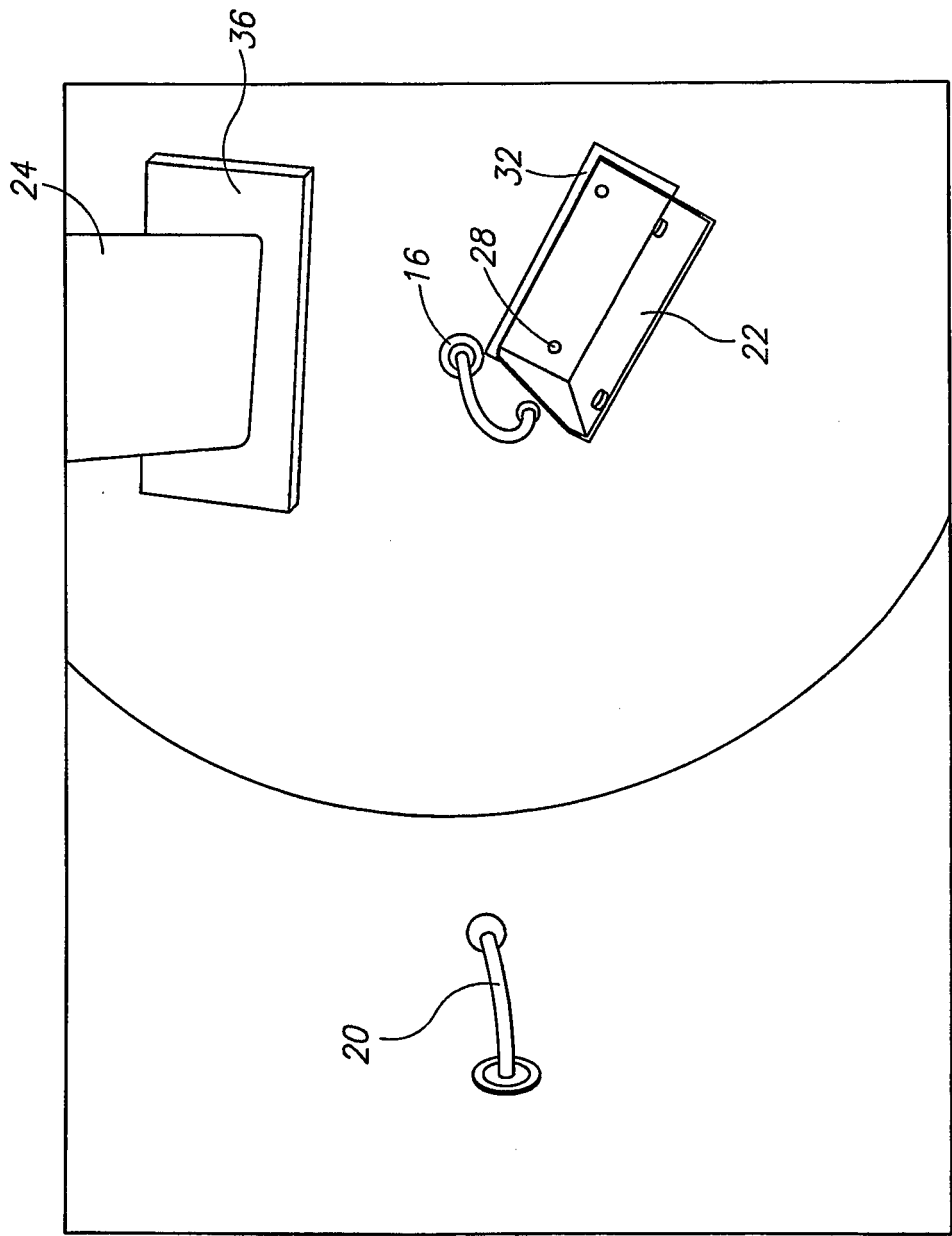


FIG.2A

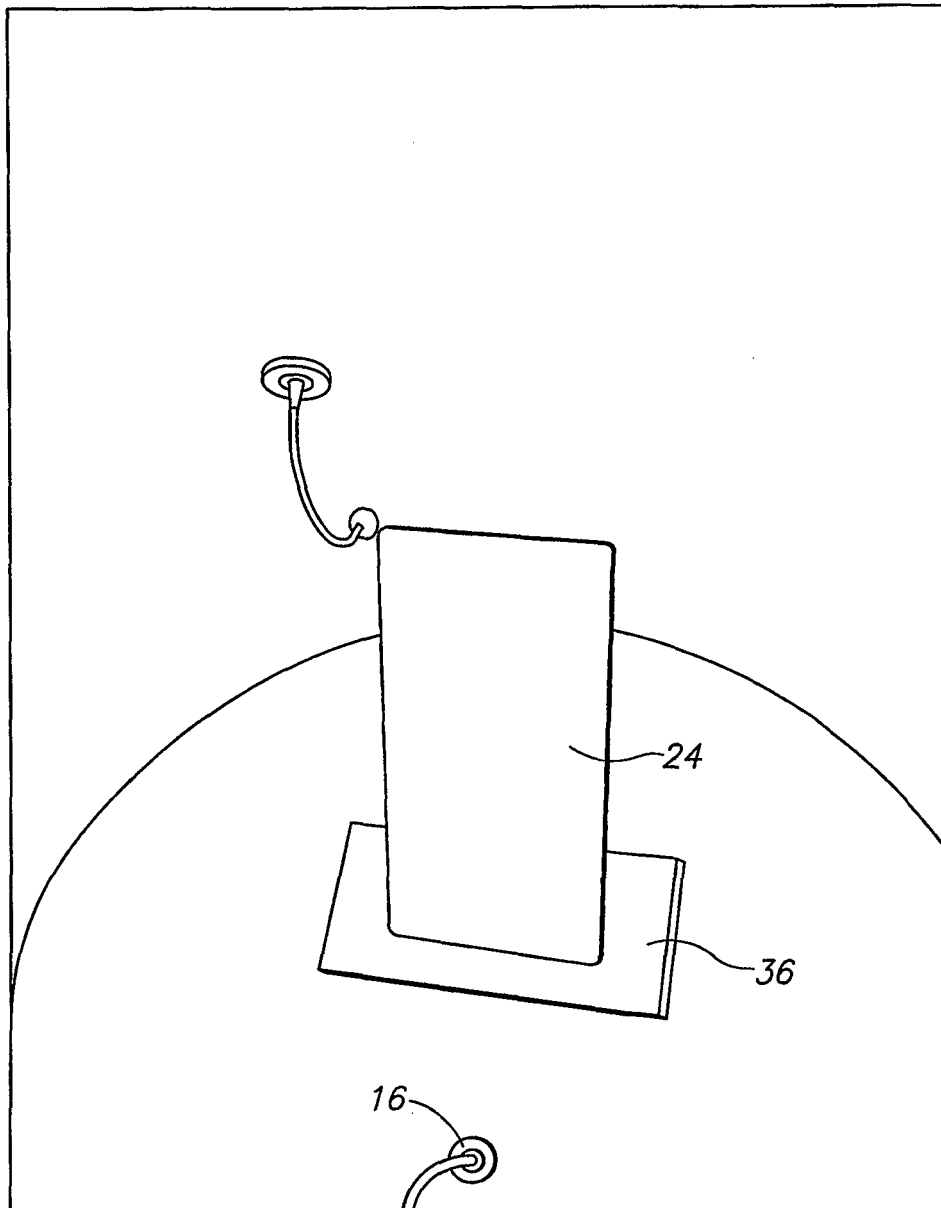


FIG.2B

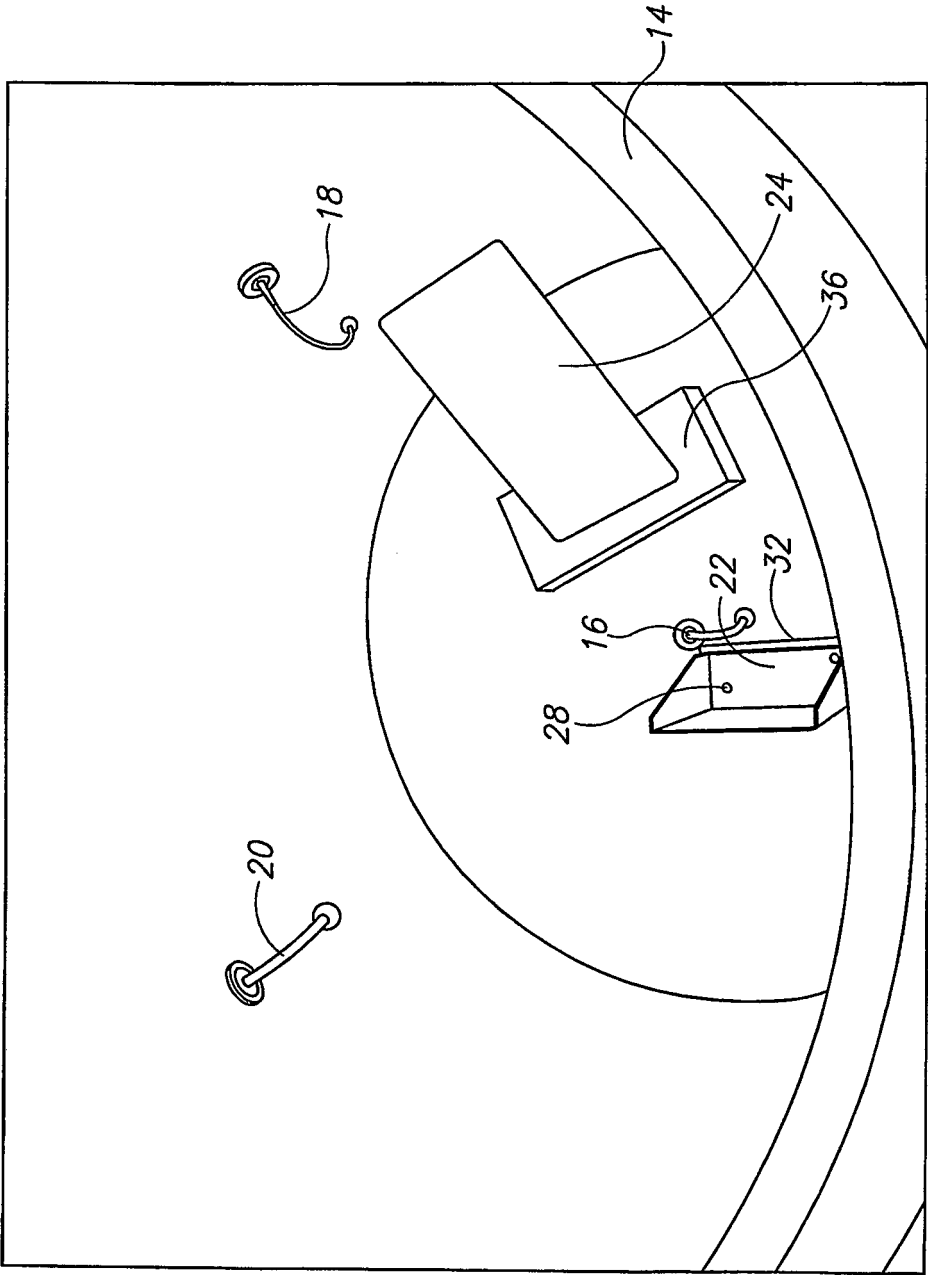


FIG.3

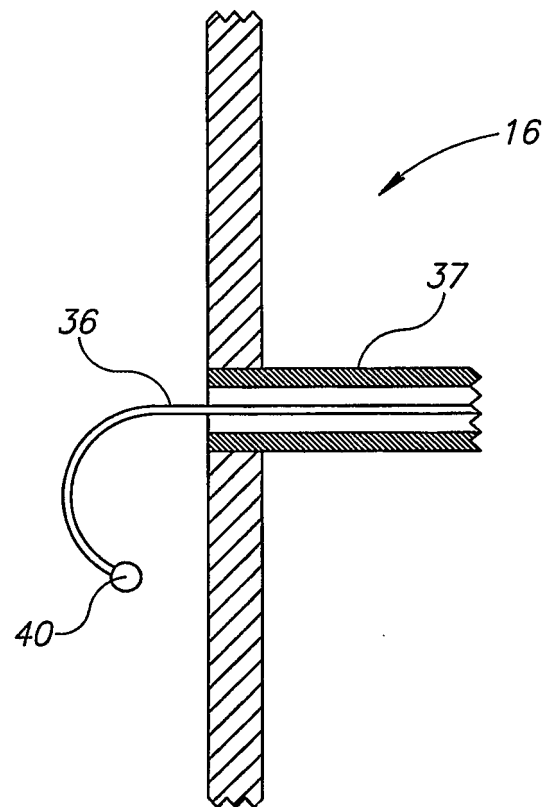


FIG.4A

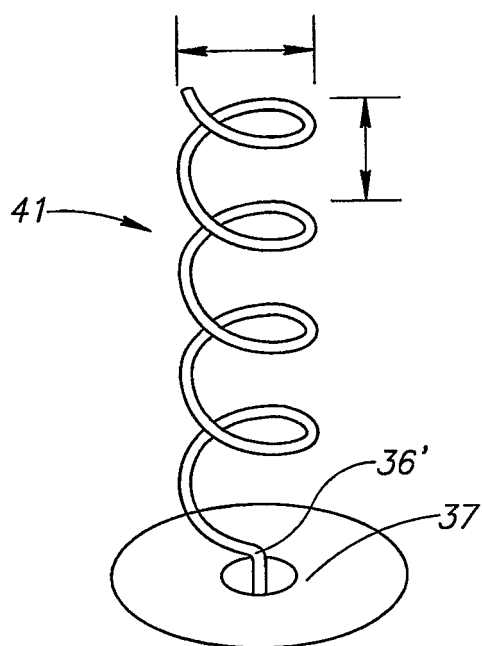


FIG.4B

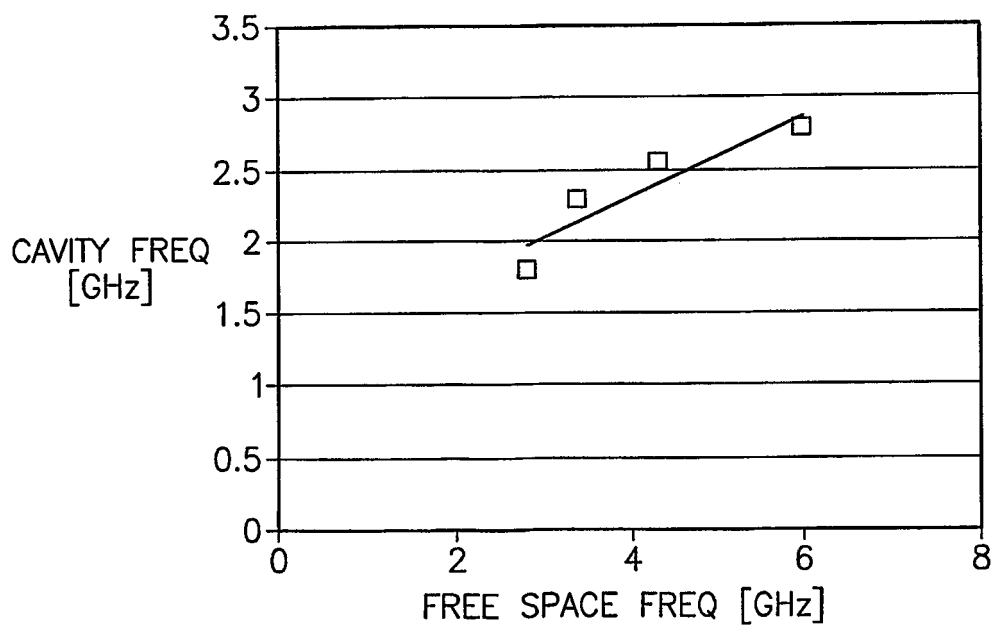


FIG.4C

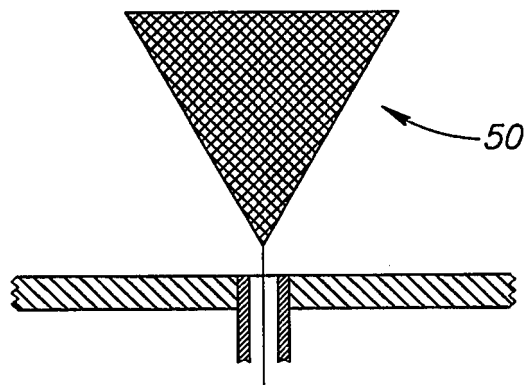


FIG. 4D

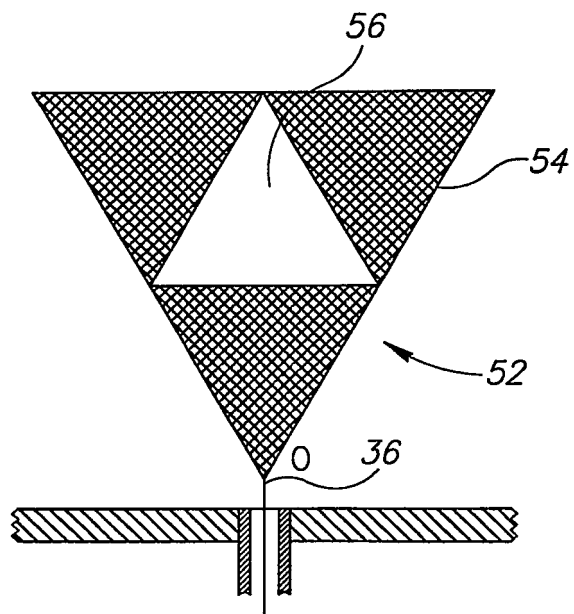


FIG. 4E

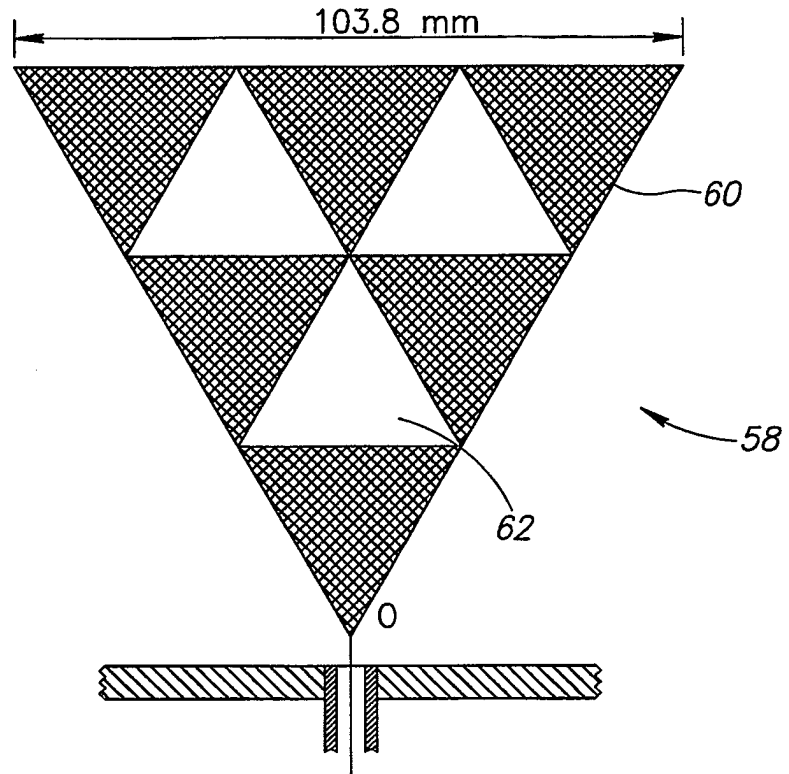


FIG. 4F

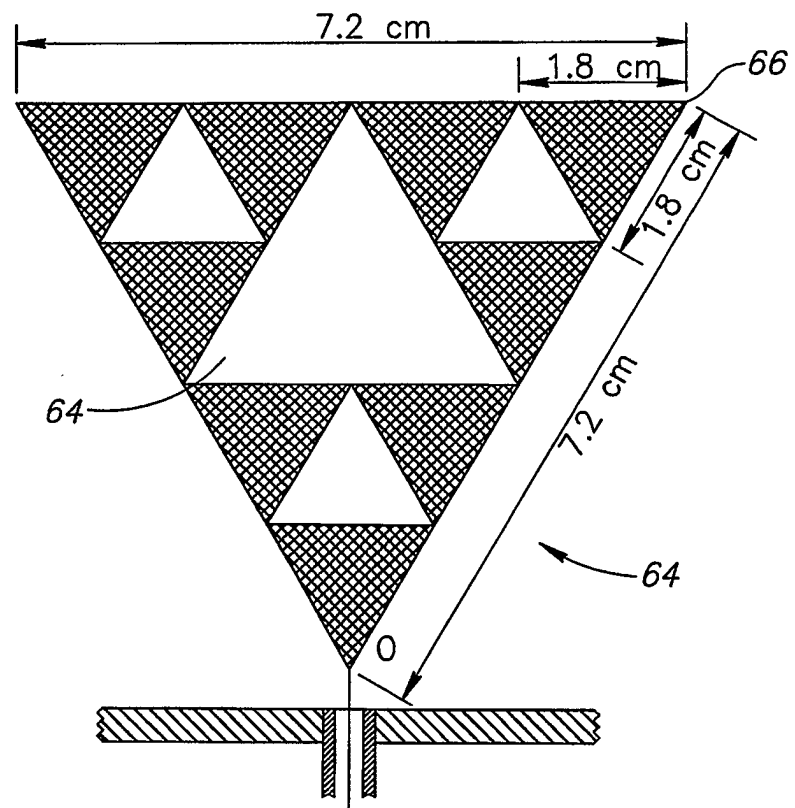


FIG. 4G



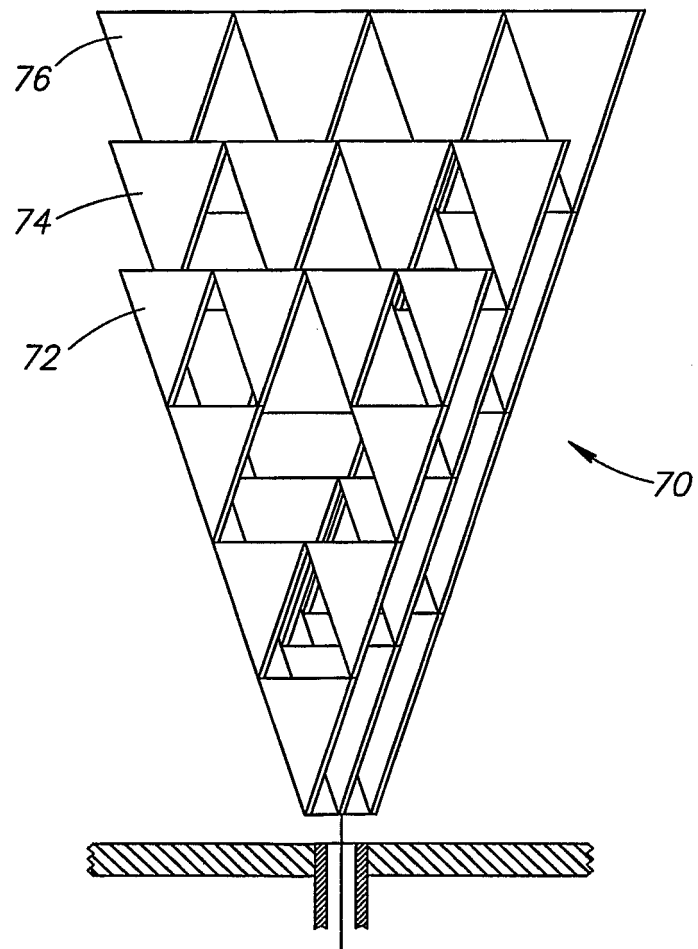


FIG. 4H

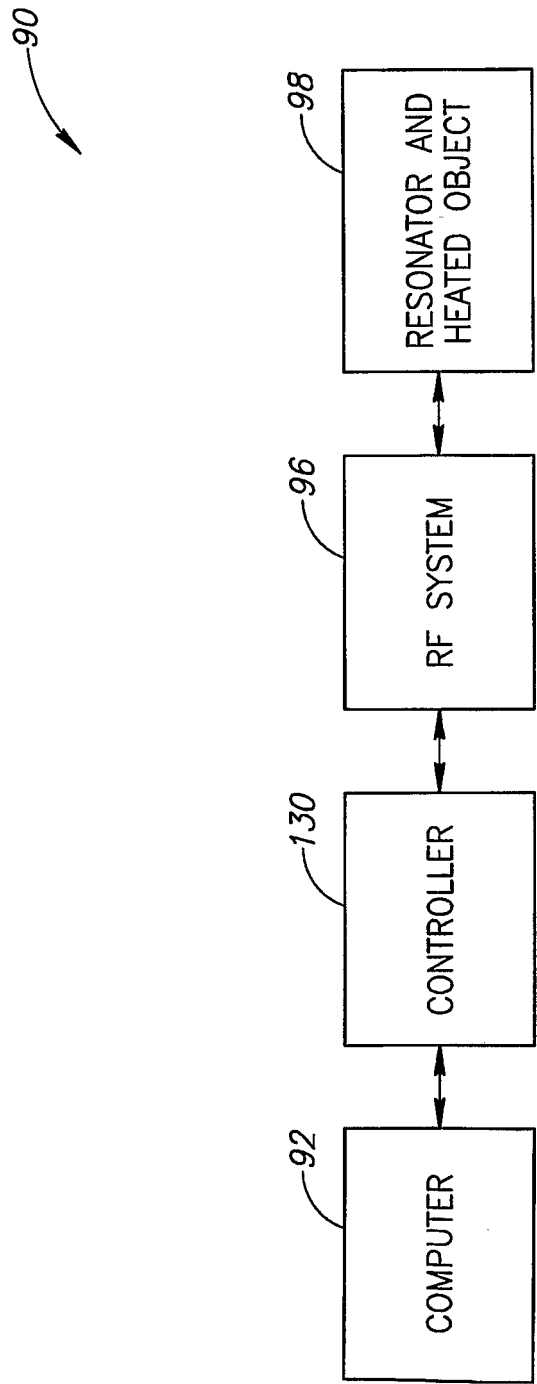


FIG. 5A

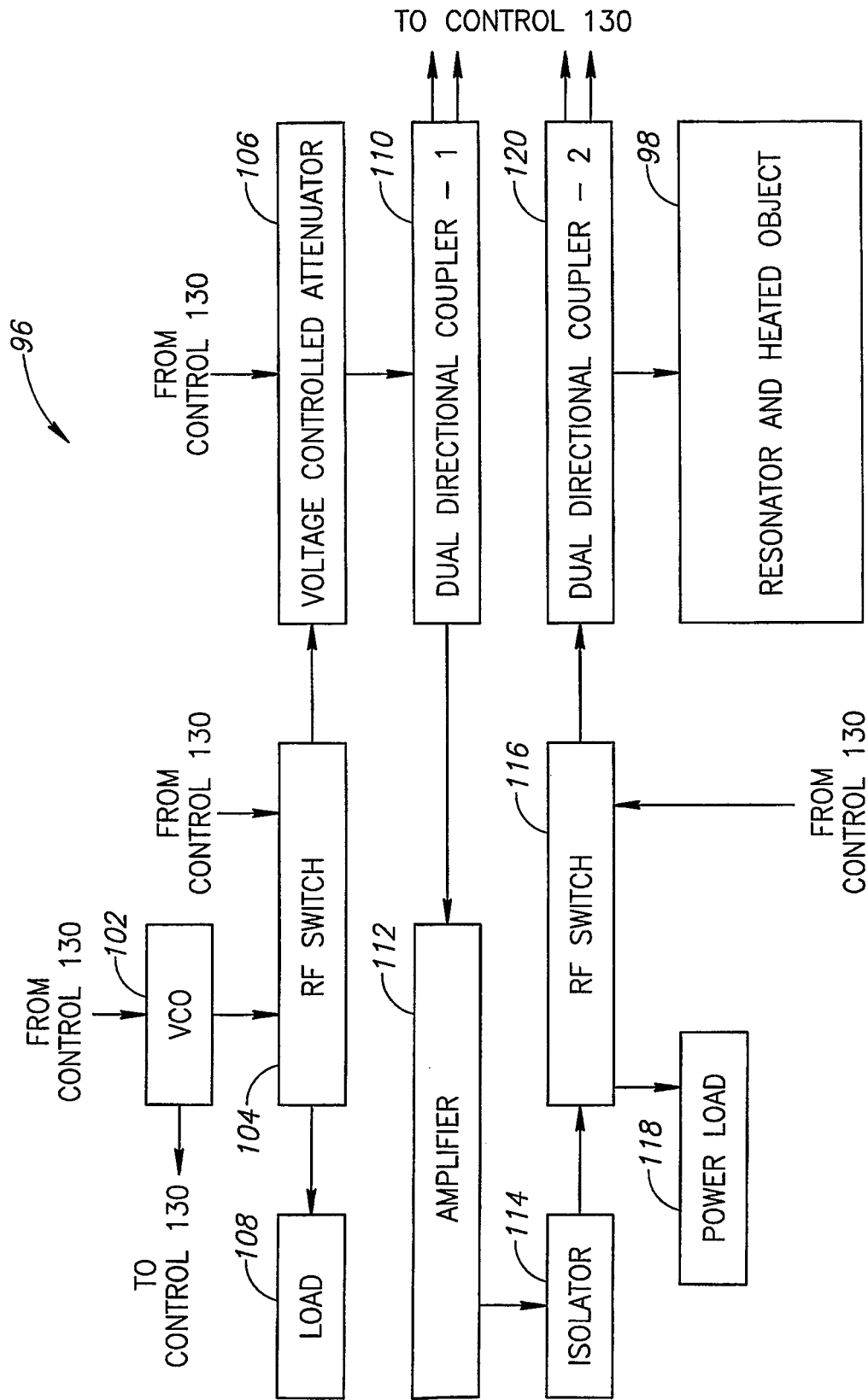


FIG.5B

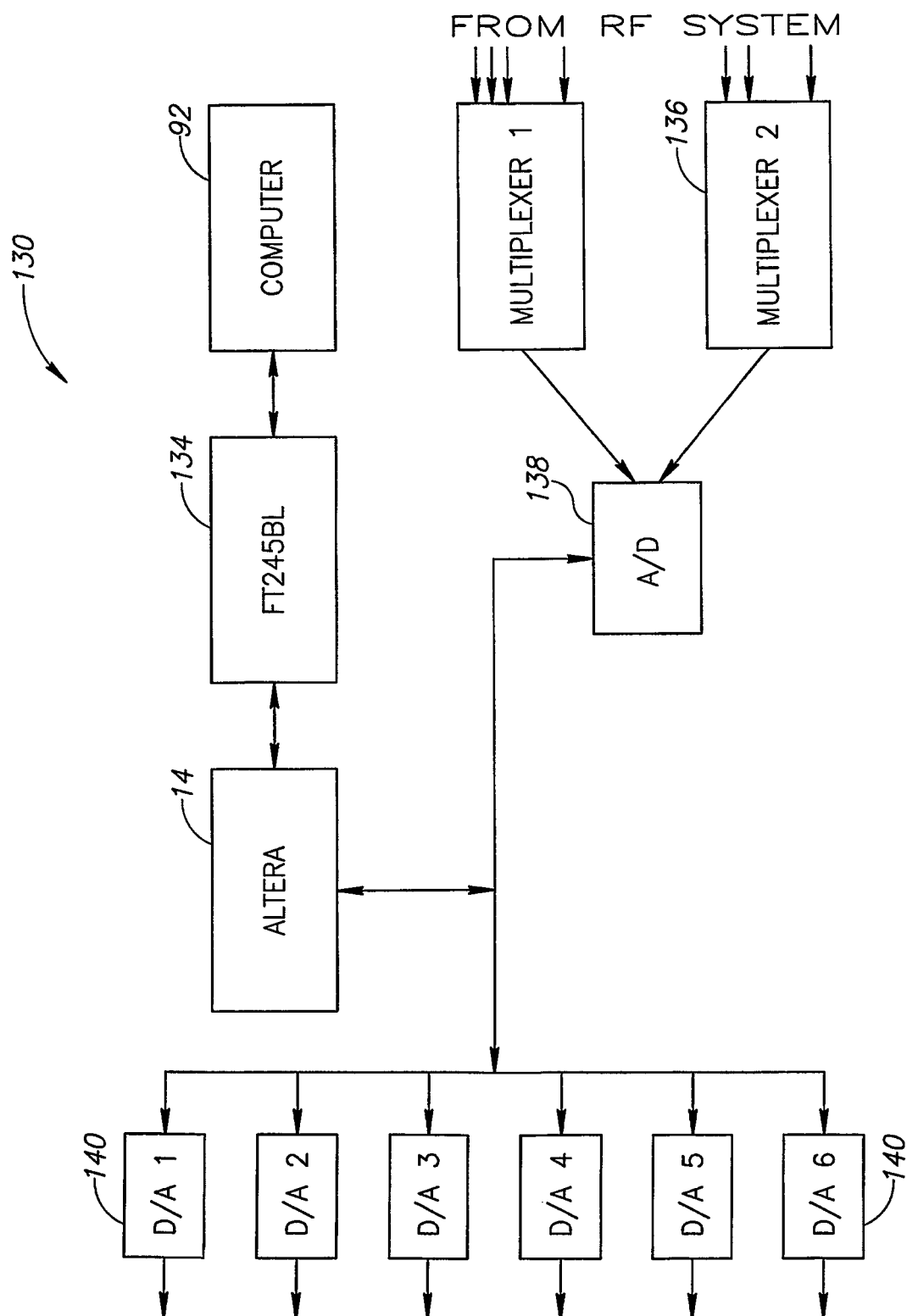


FIG.5C

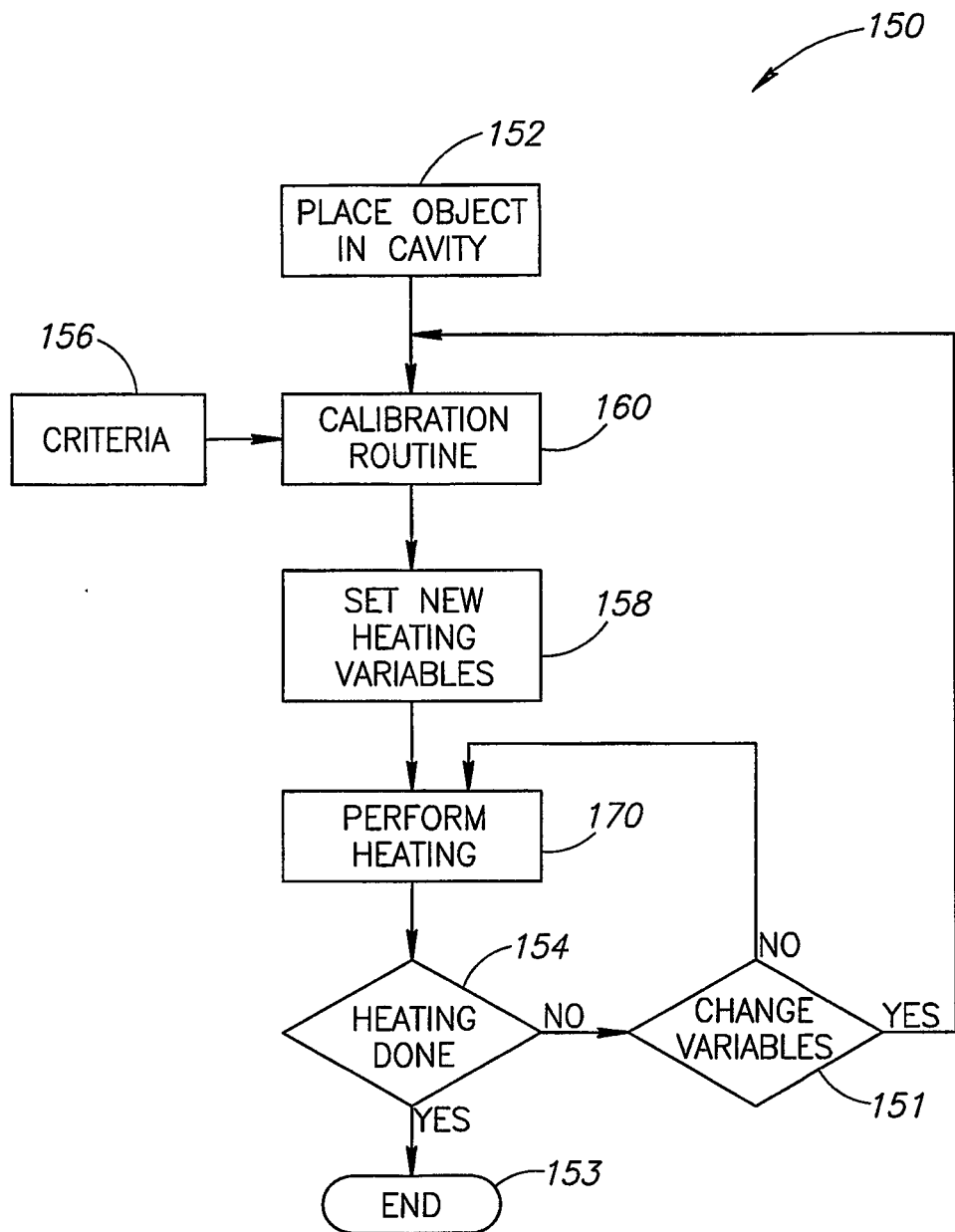


FIG.6

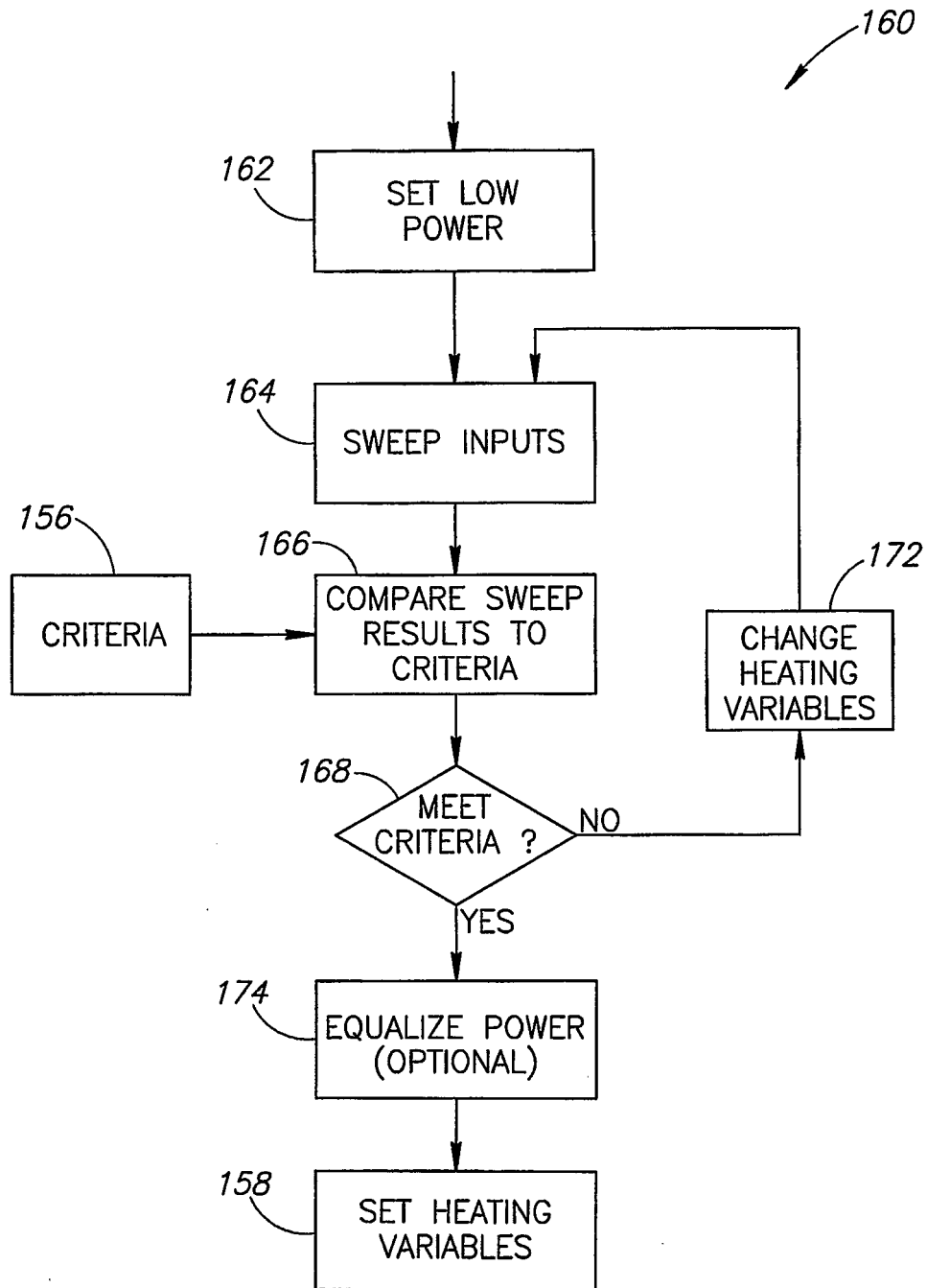


FIG. 7

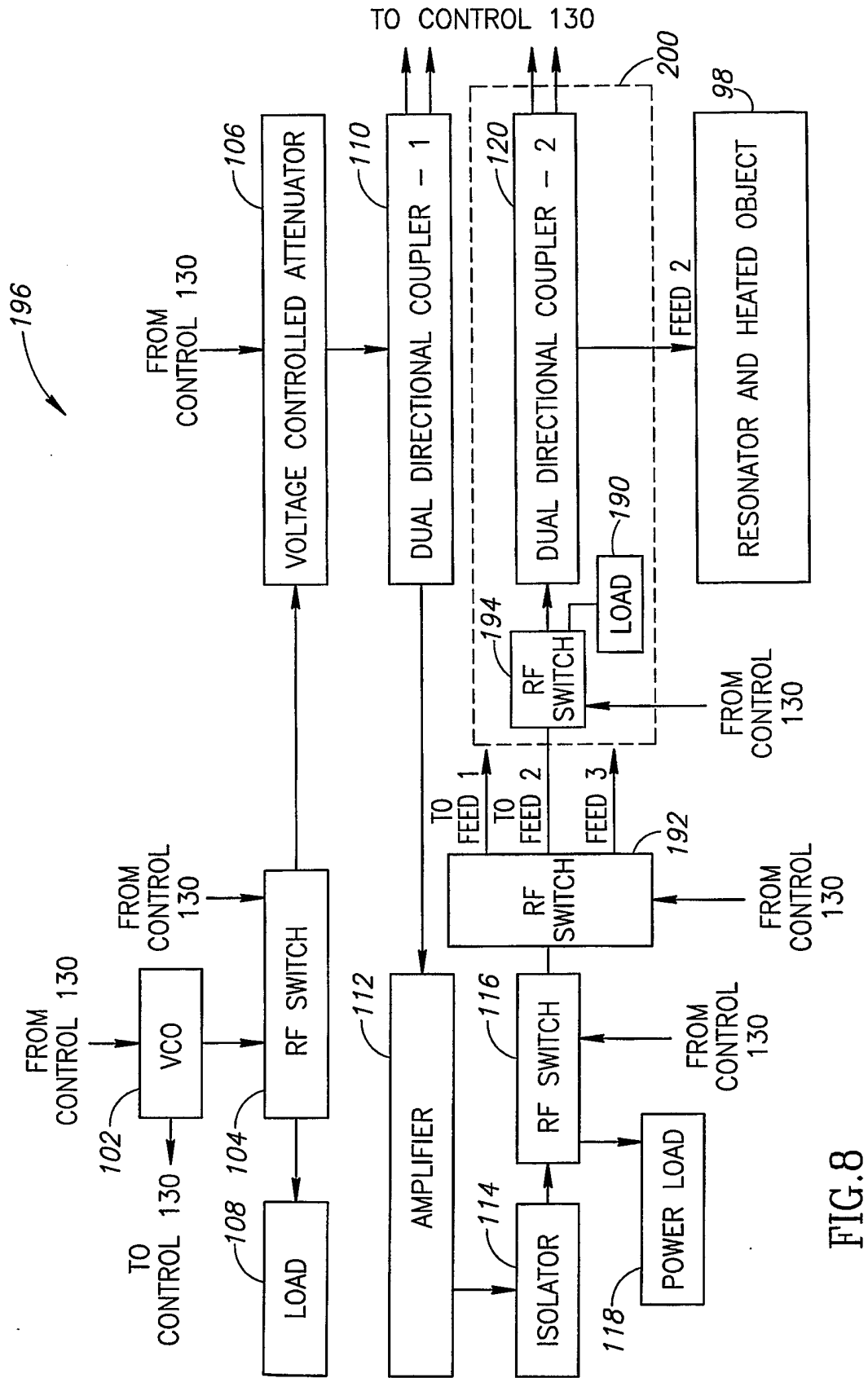


FIG.8

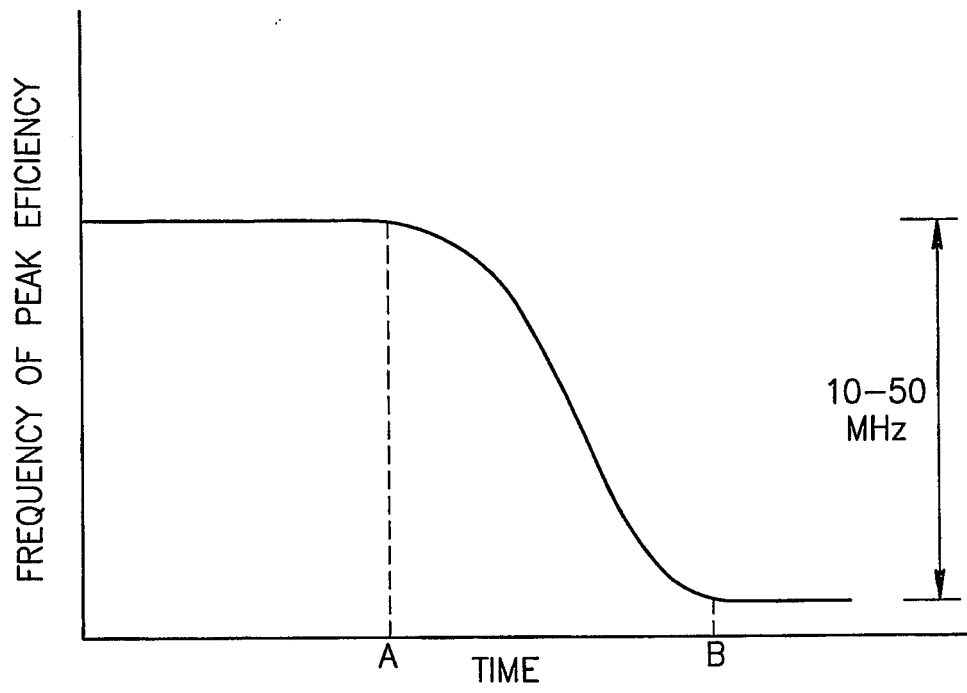


FIG.9

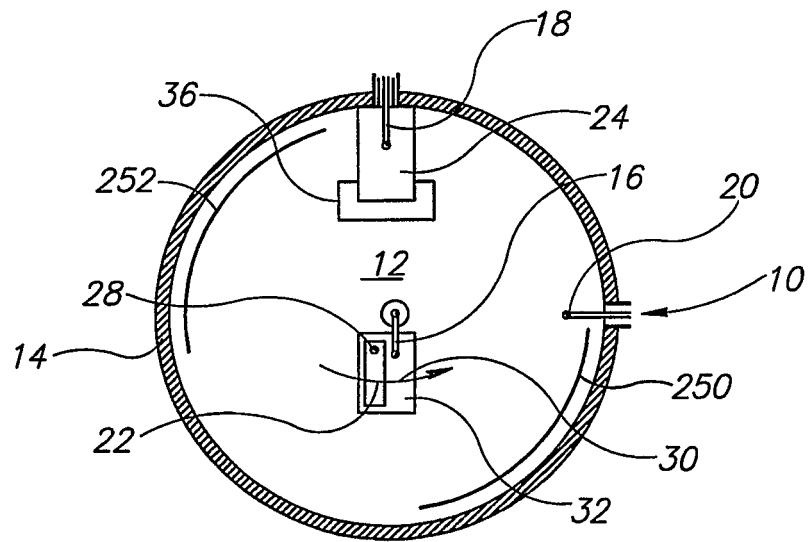


FIG.10



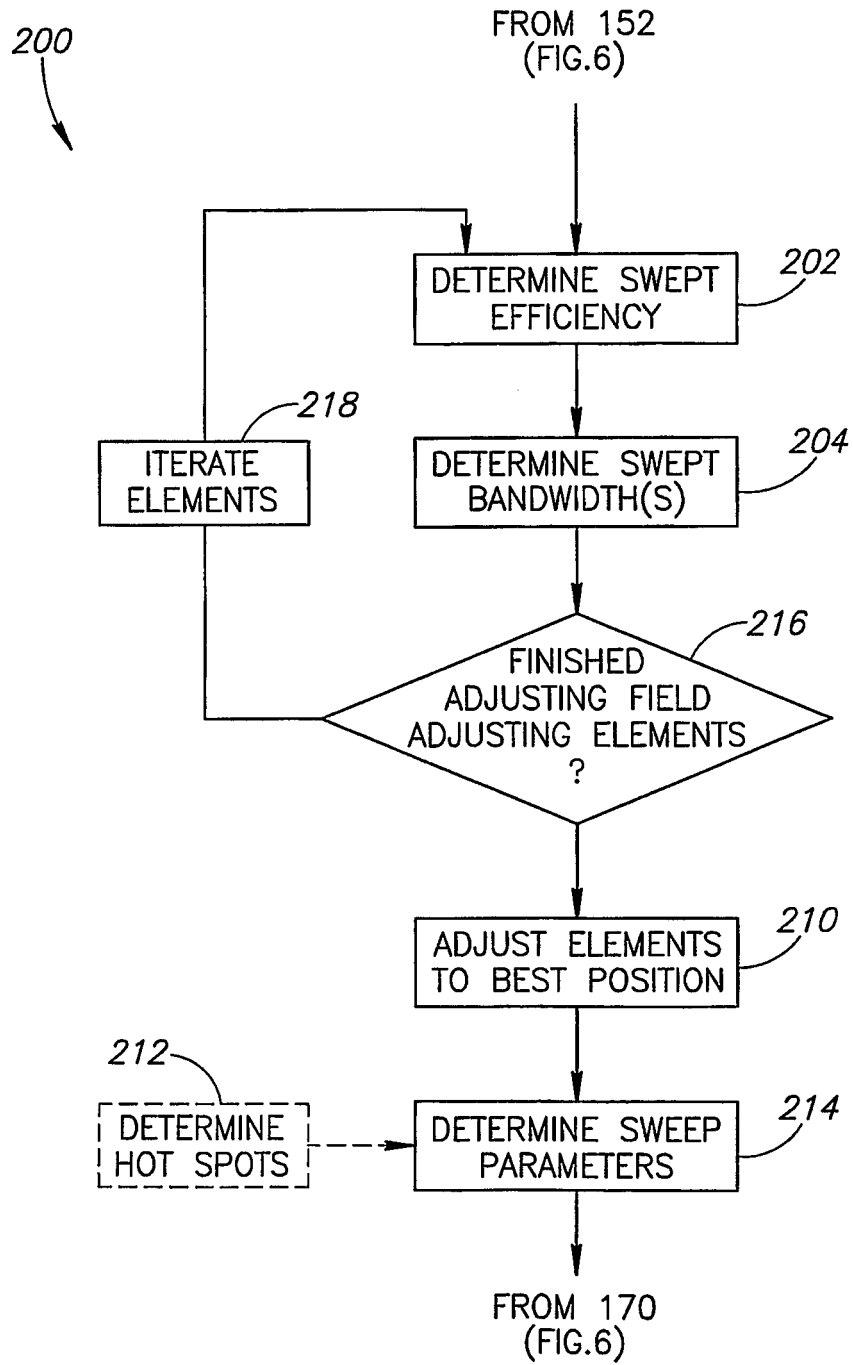


FIG.11A

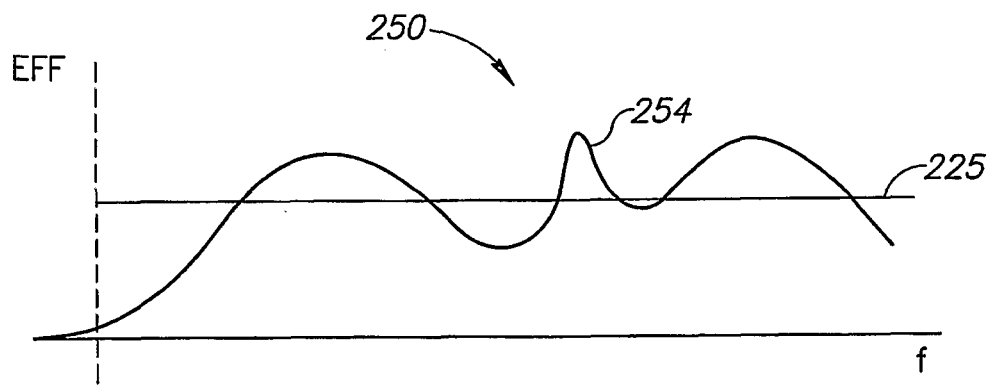


FIG.11B

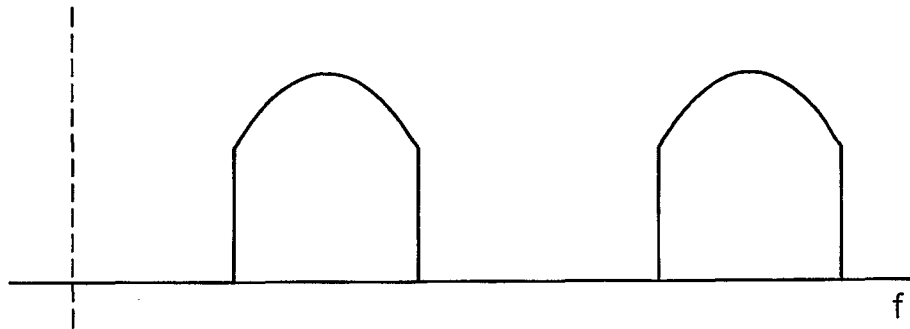


FIG.11C

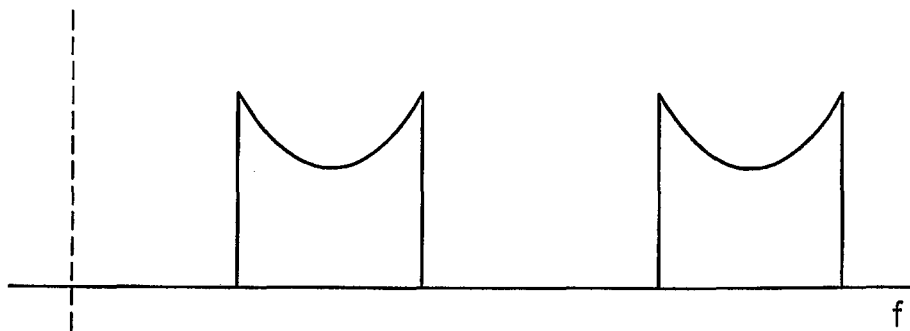


FIG.11D

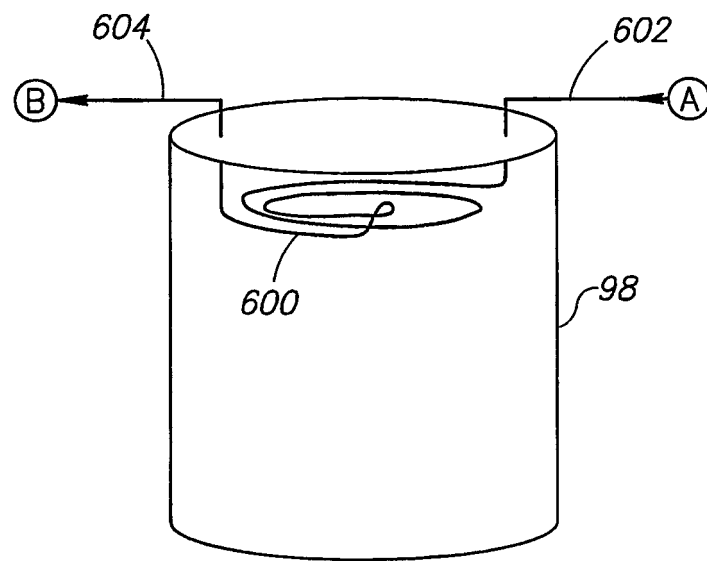


FIG.12A

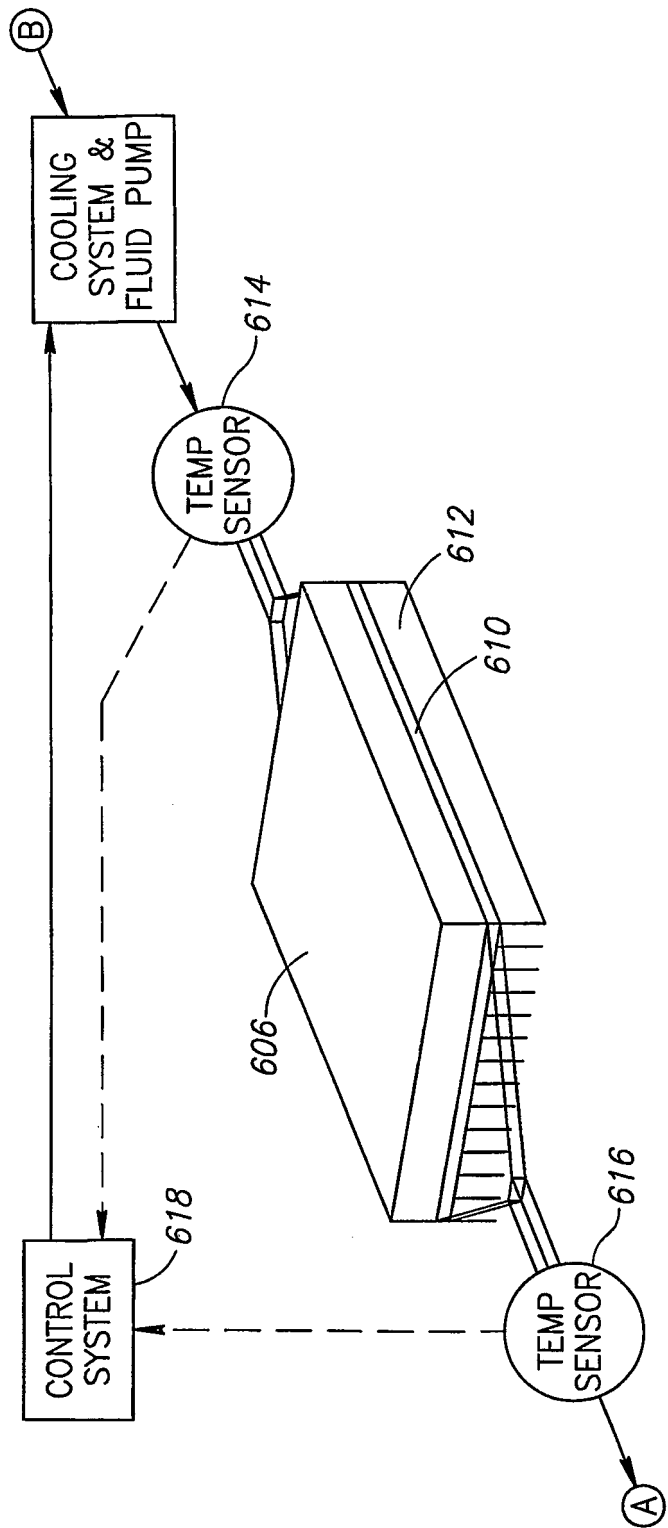


FIG.12B

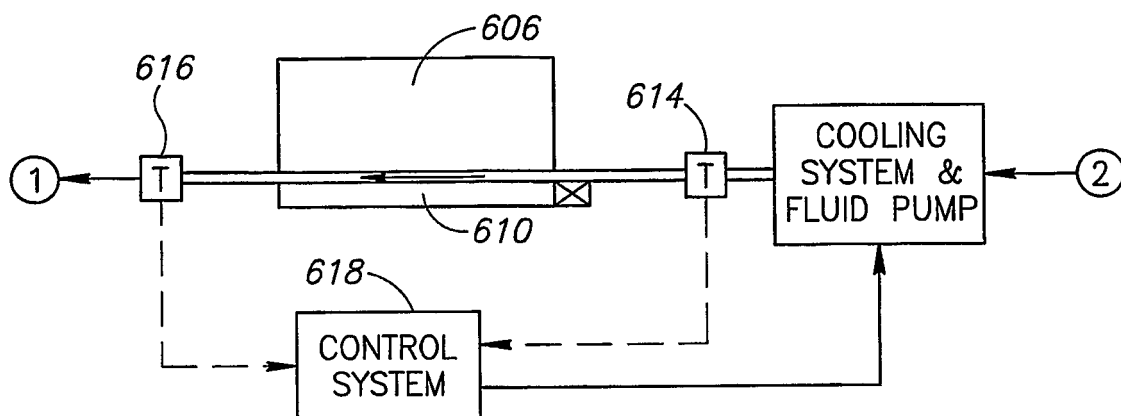


FIG.12C

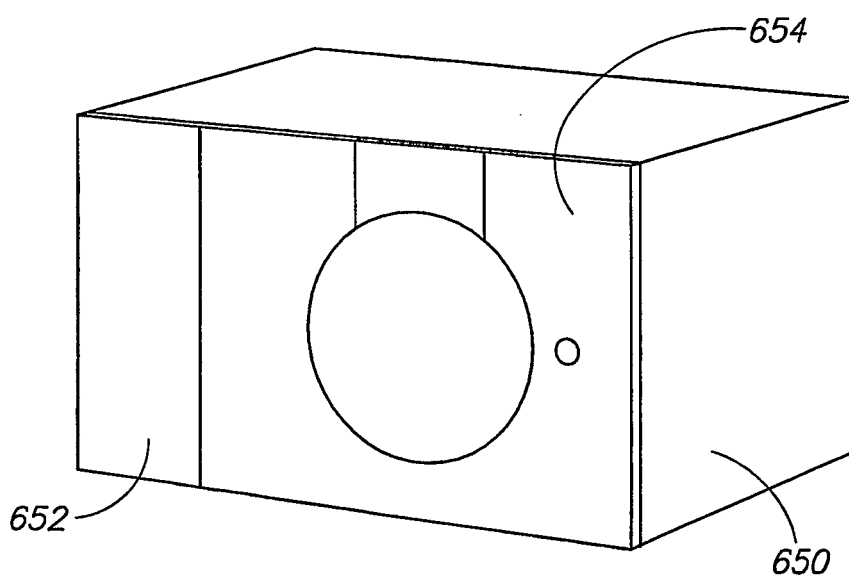


FIG.12D

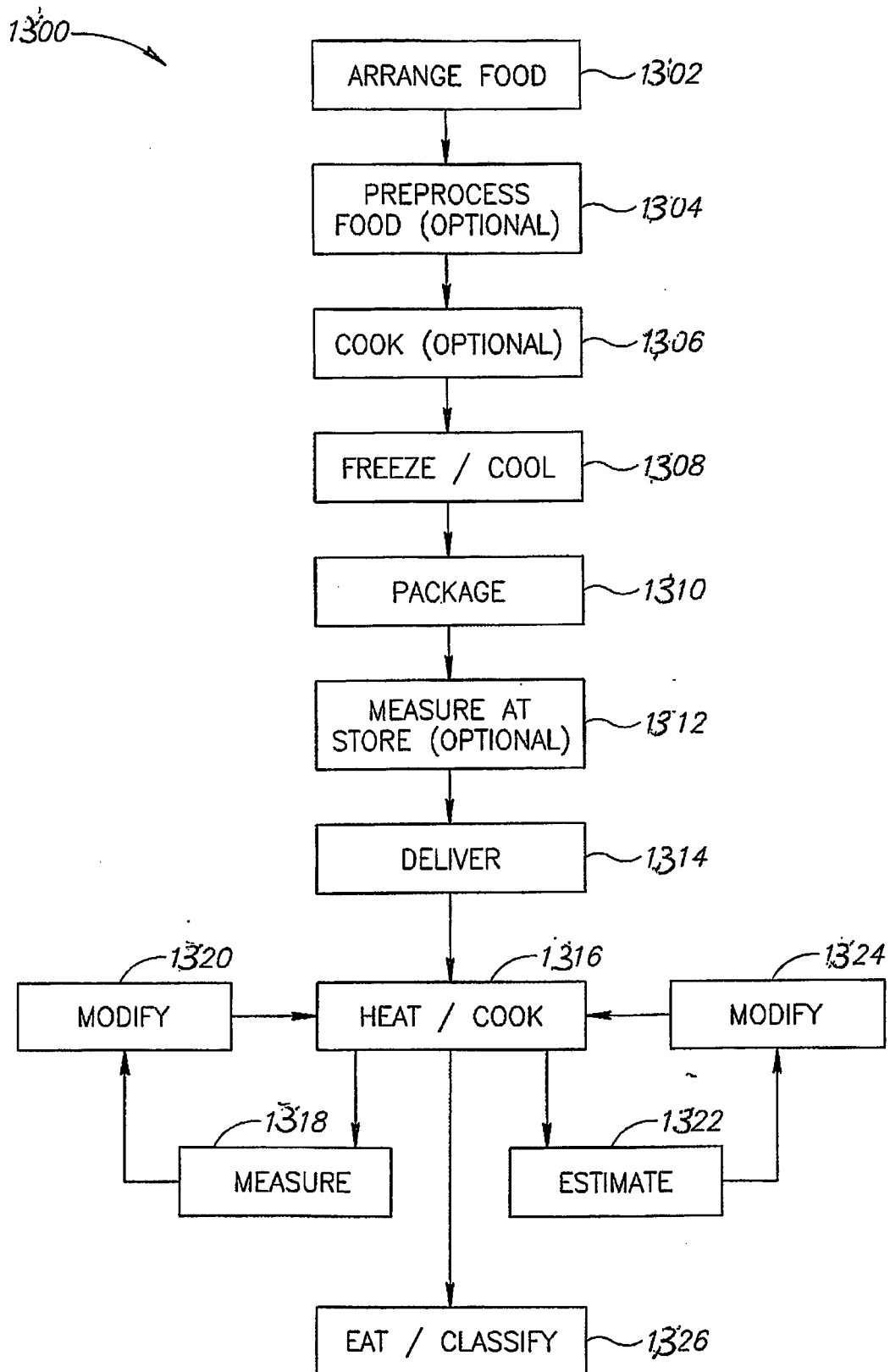


FIG.13

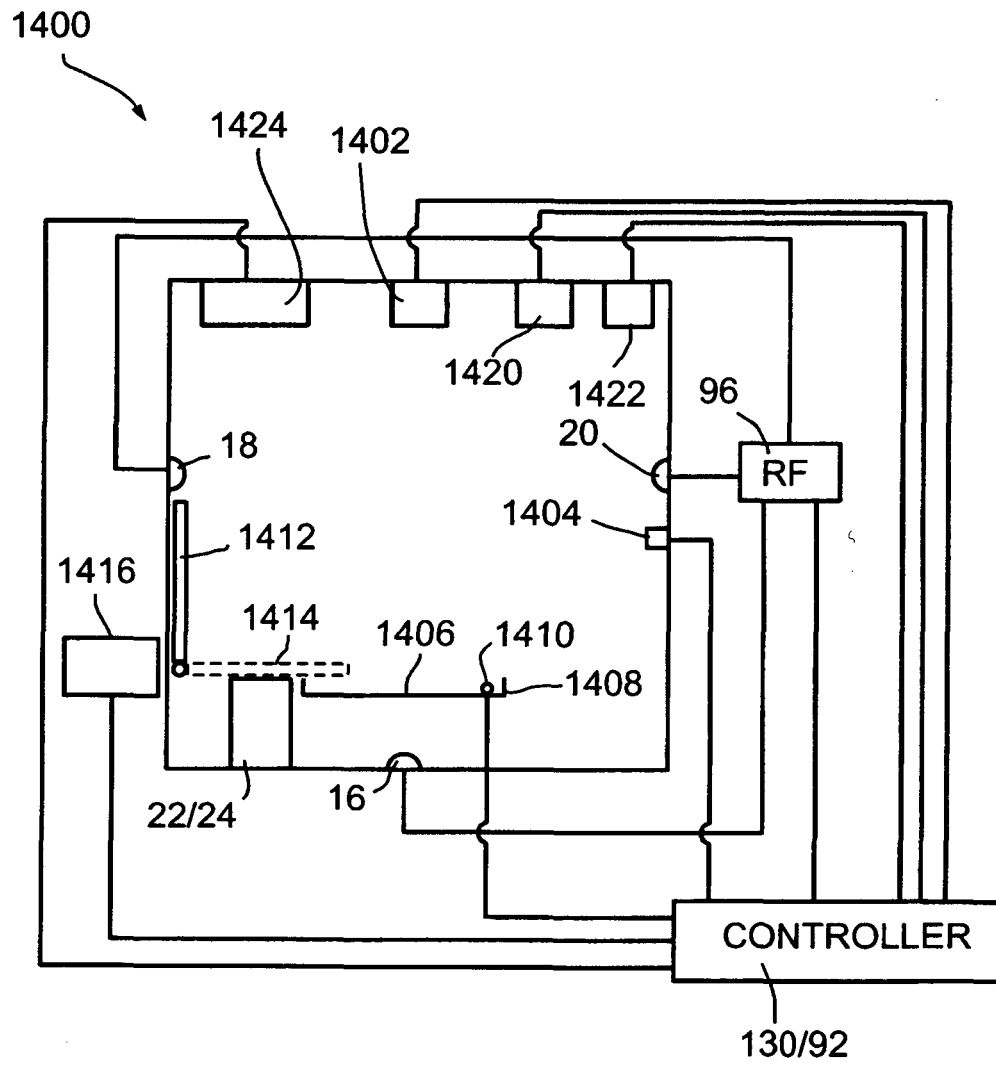


Fig. 14

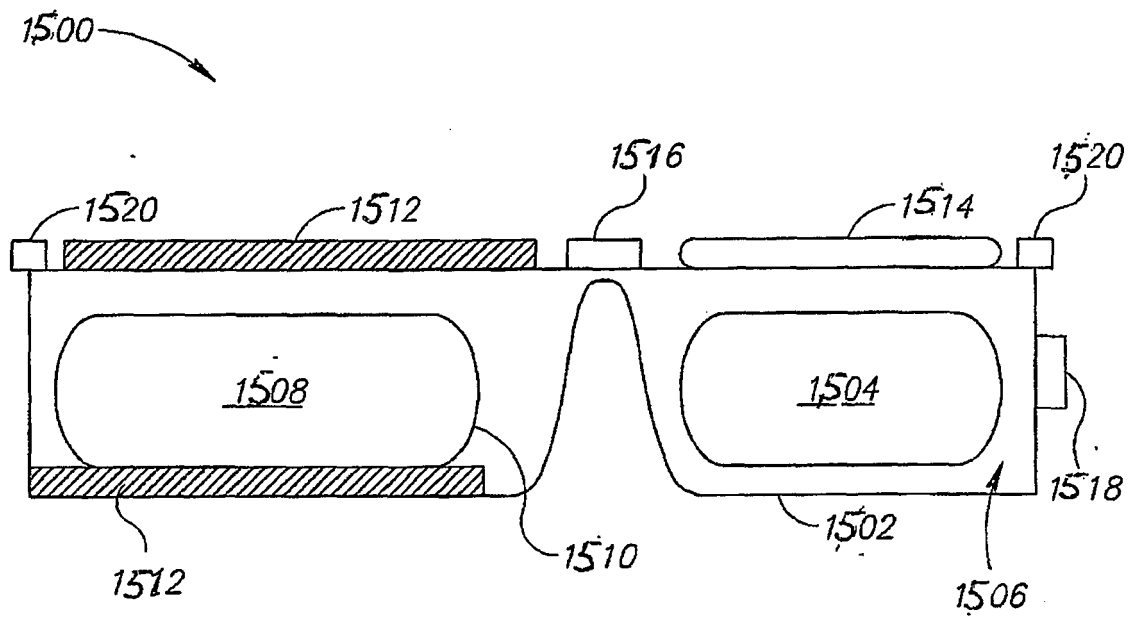


FIG.15

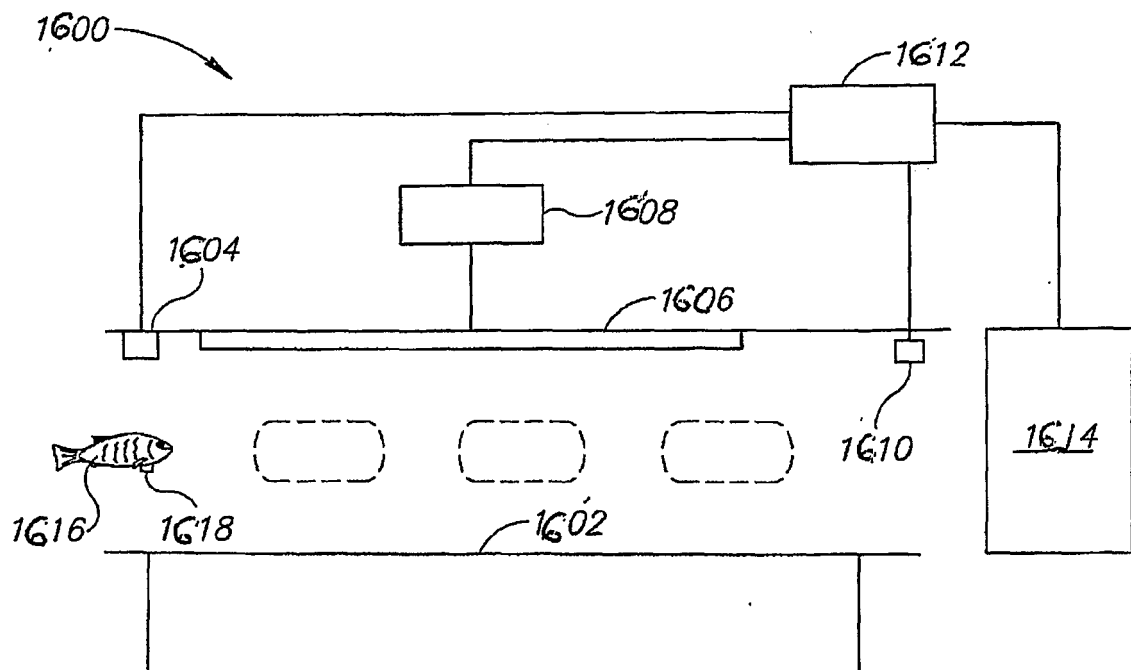
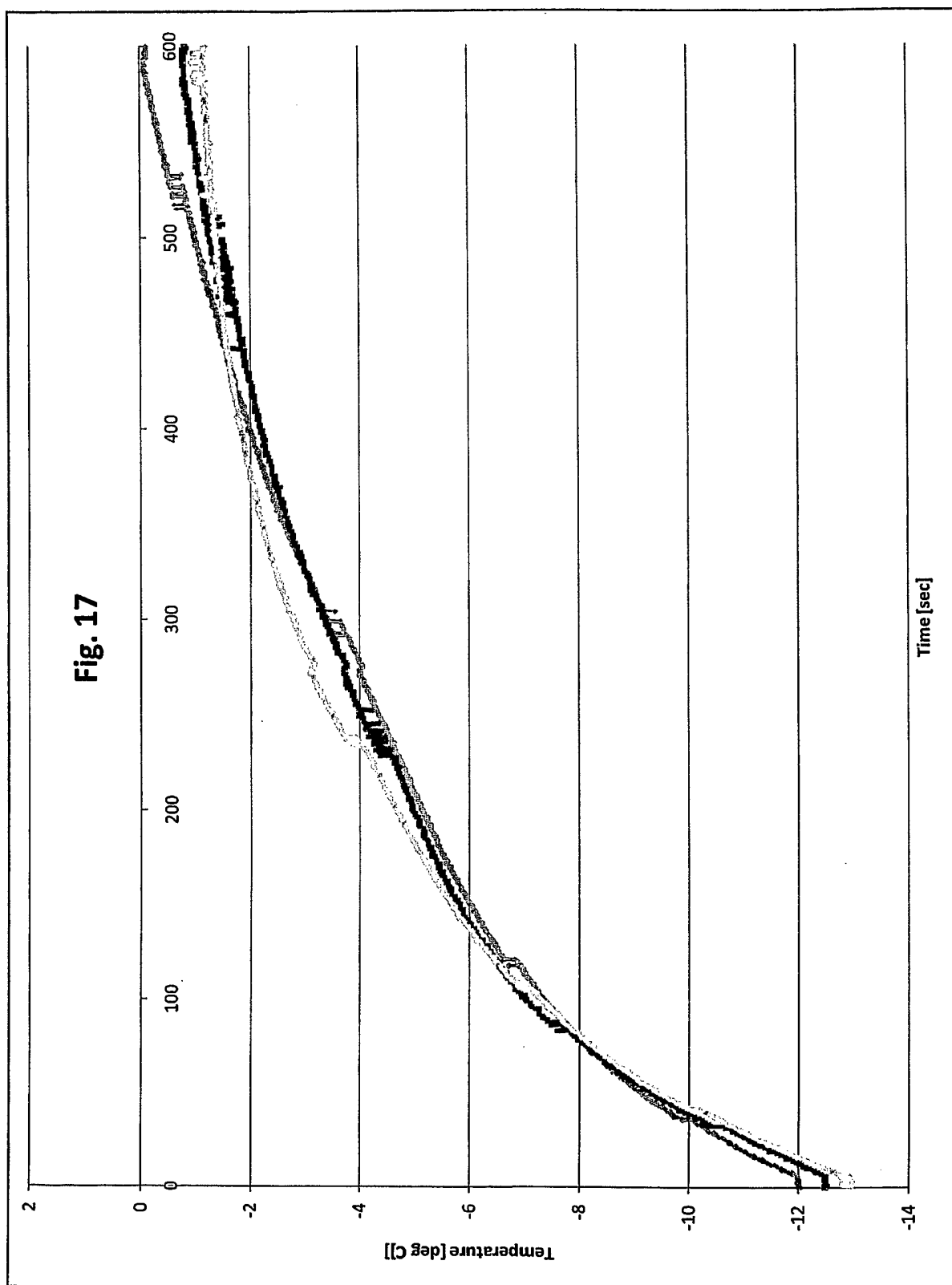
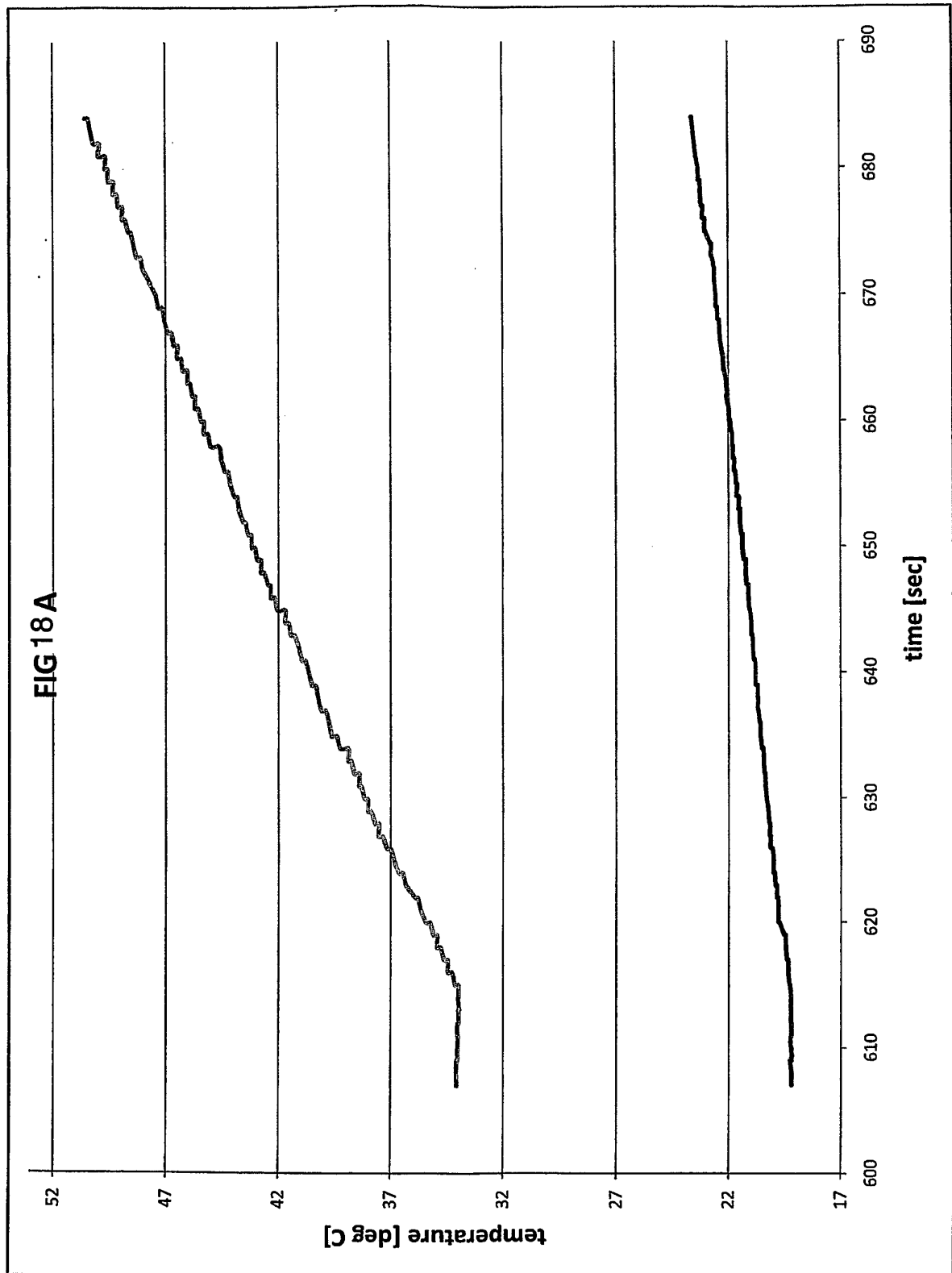
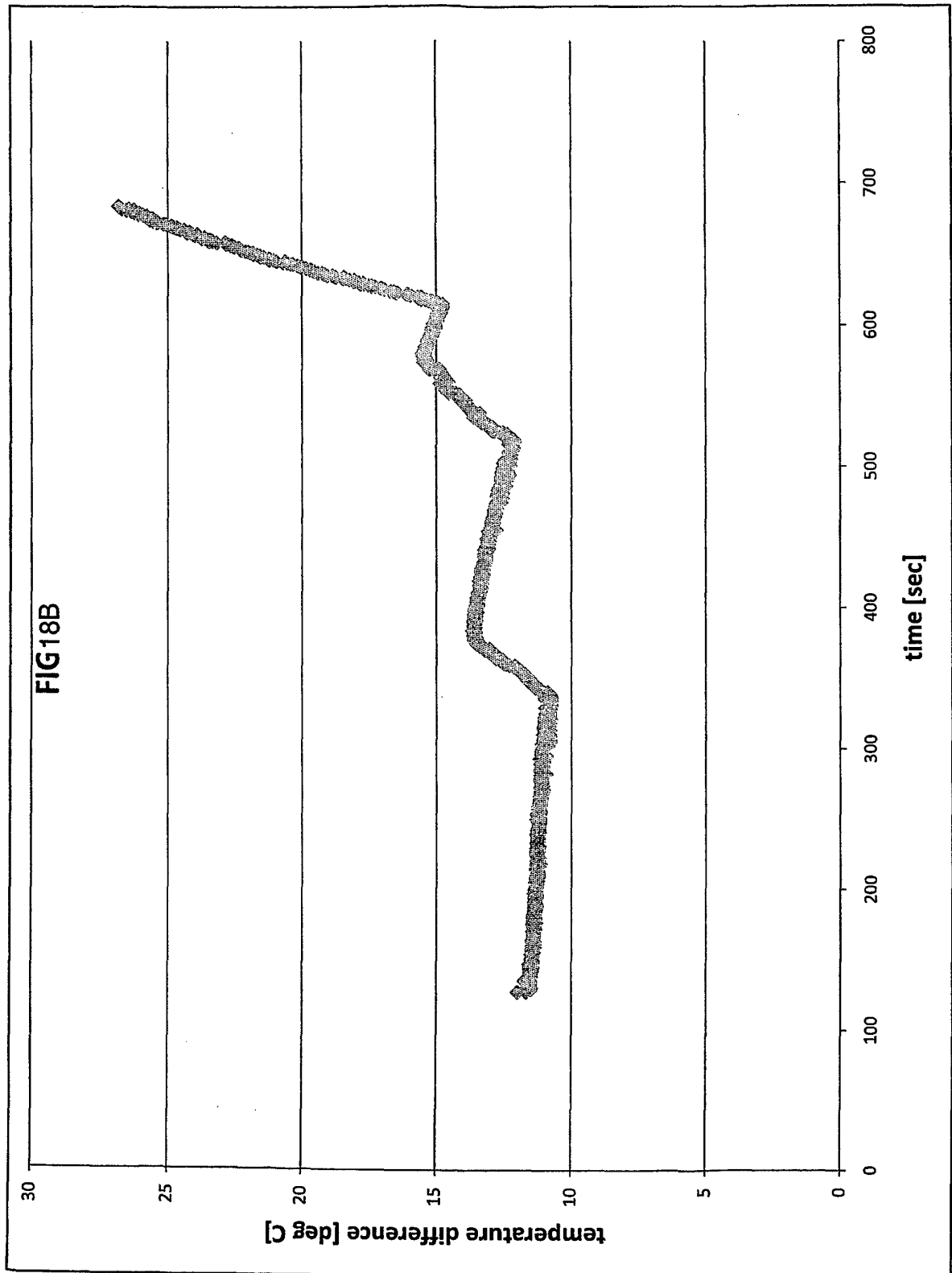


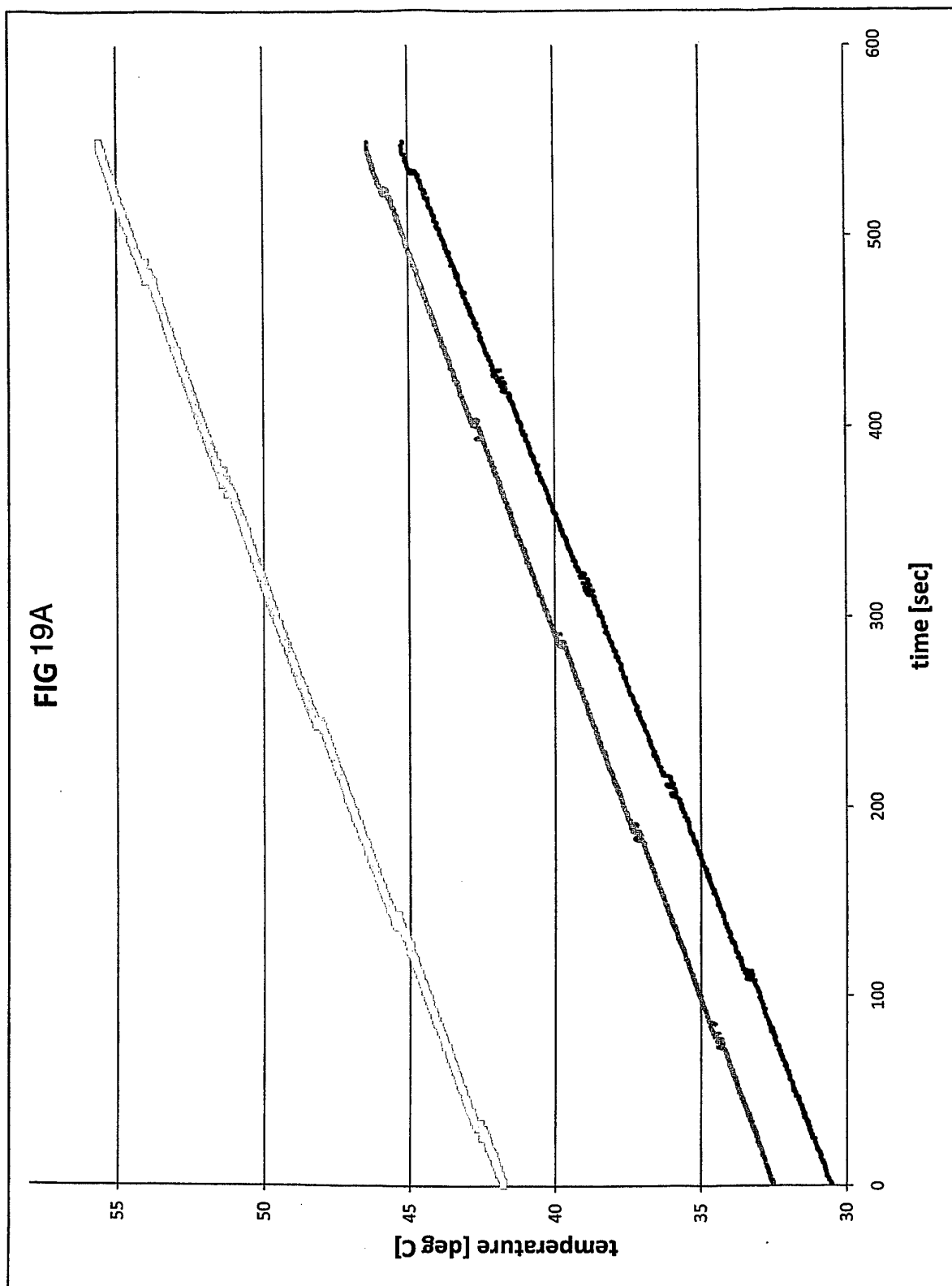
FIG.16

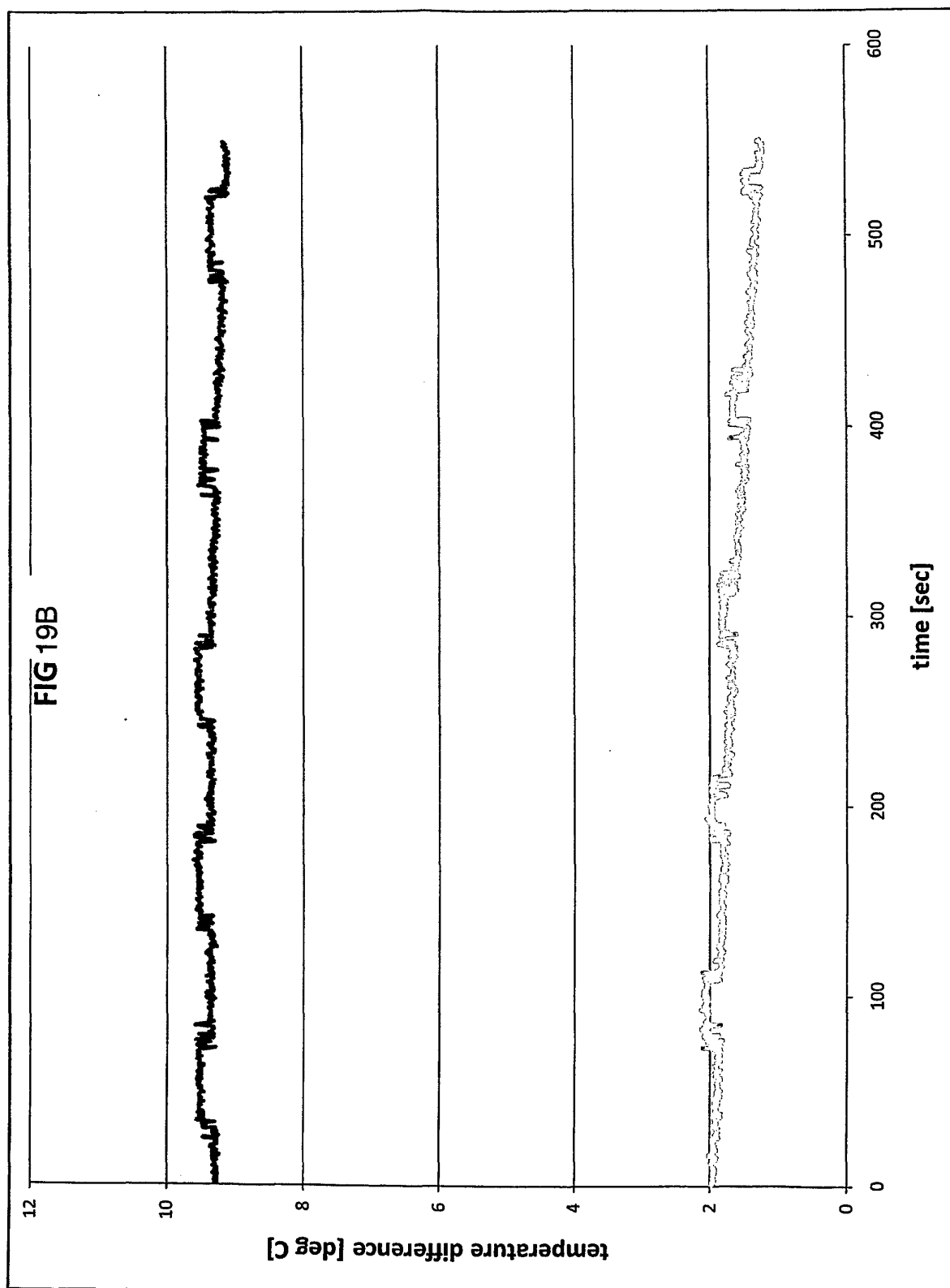












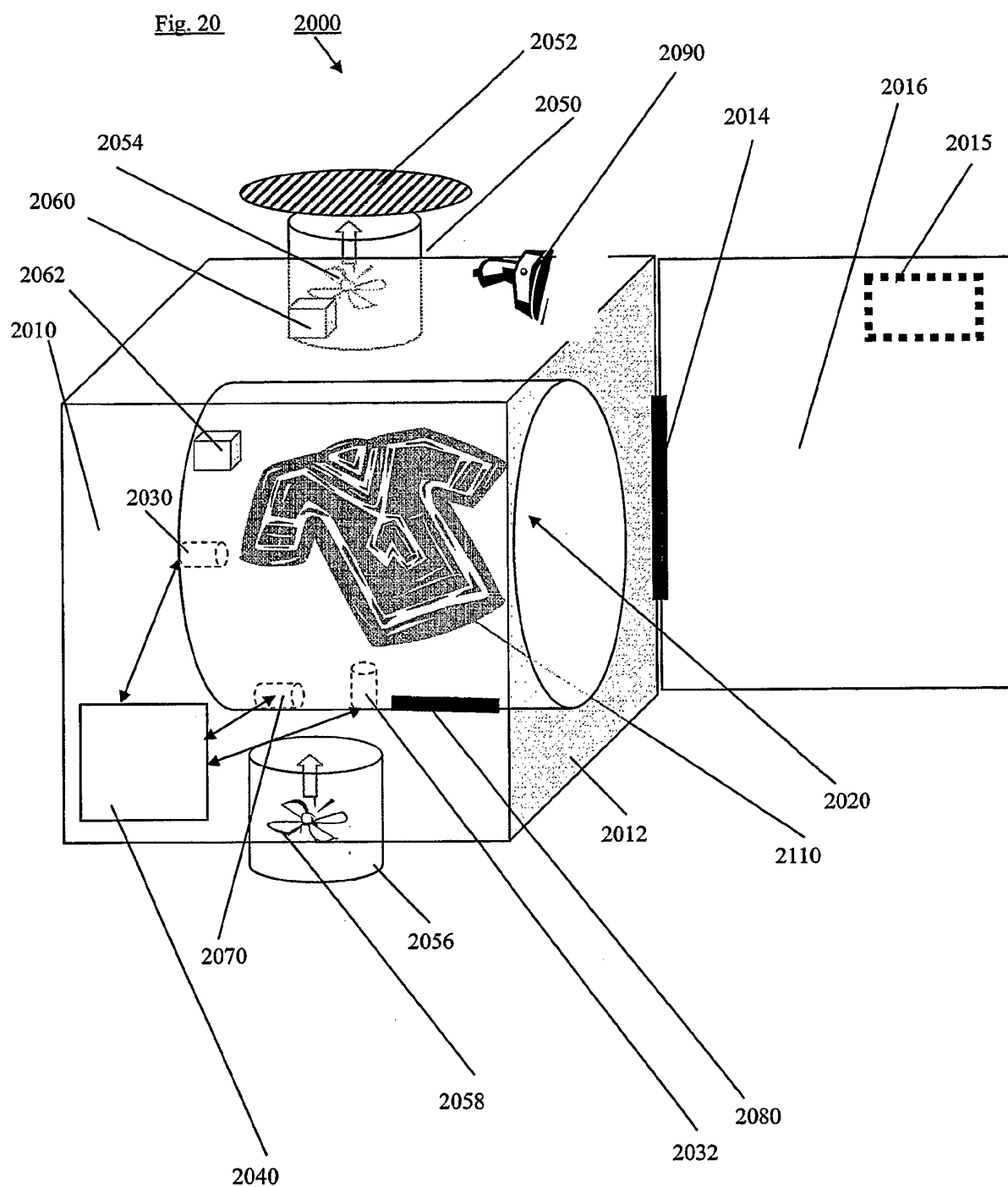


Fig. 21a

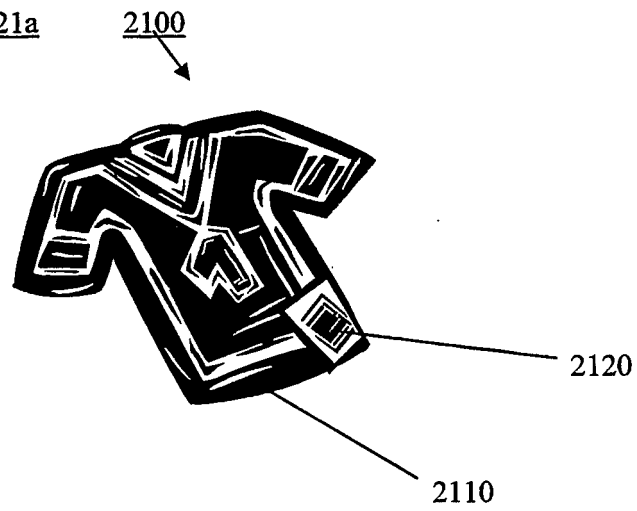
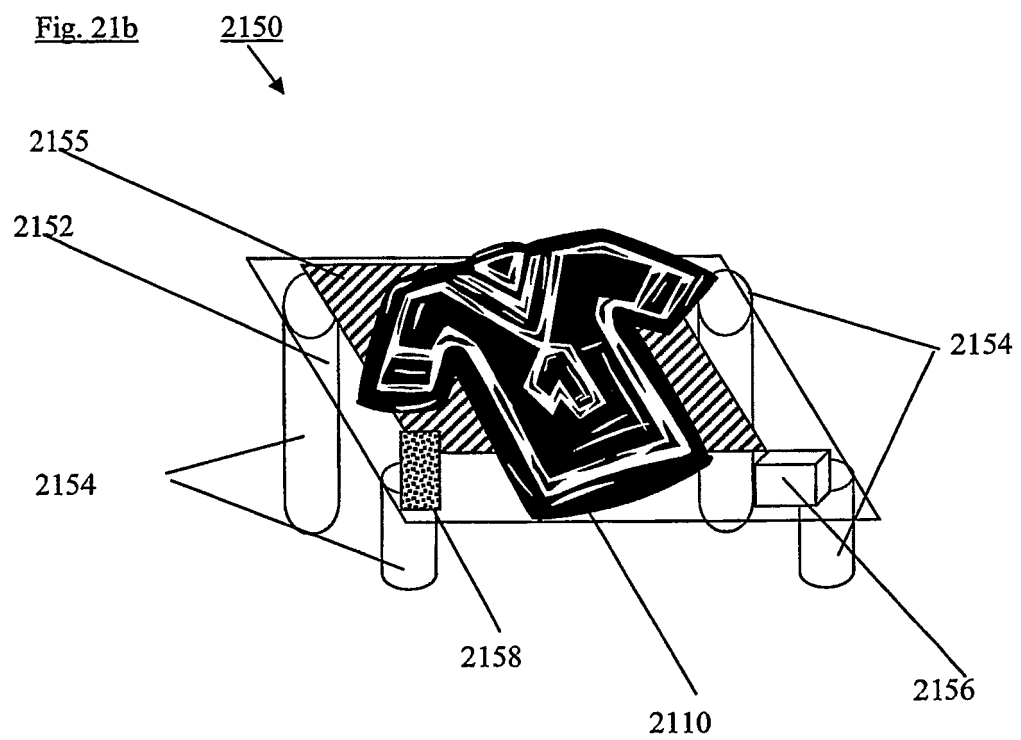
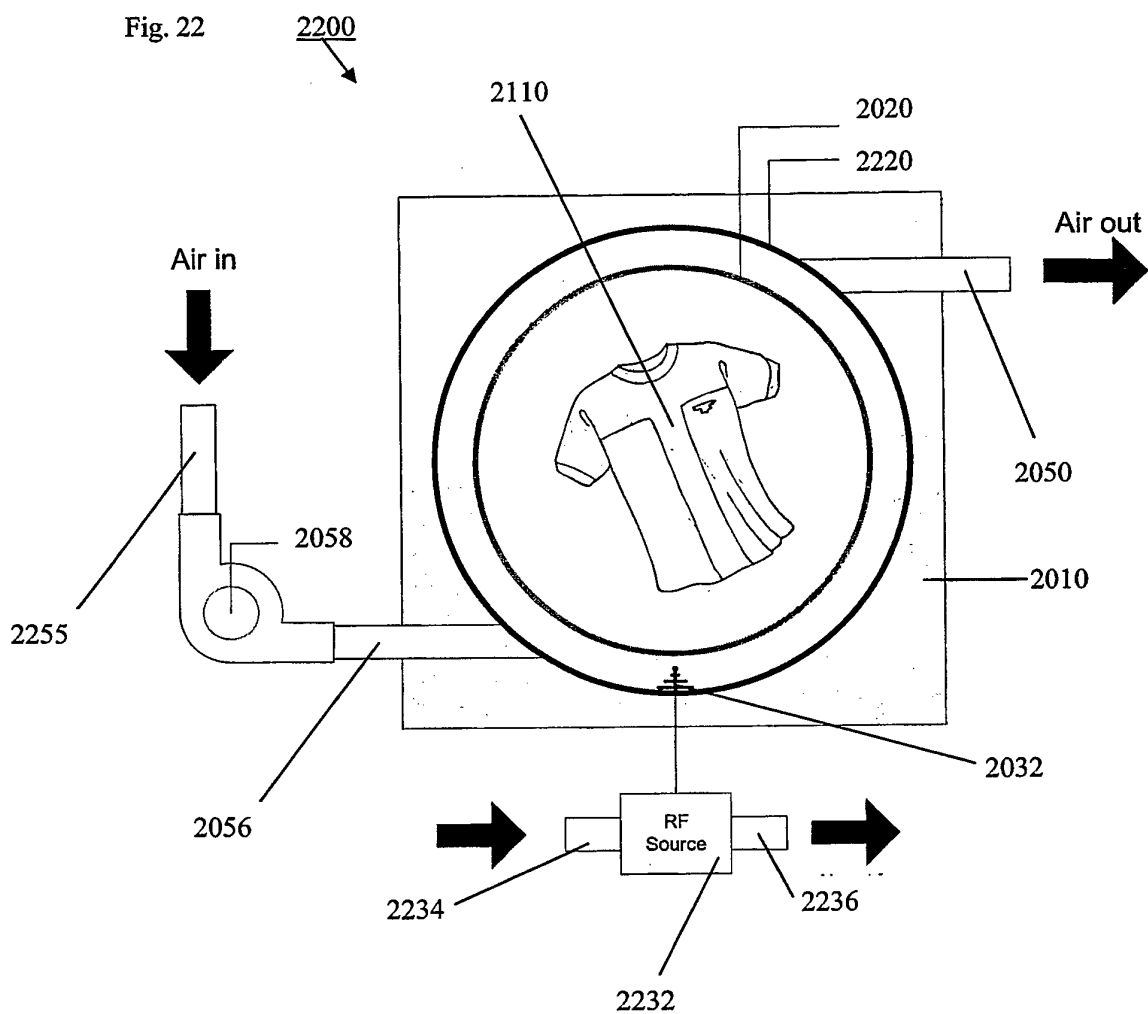
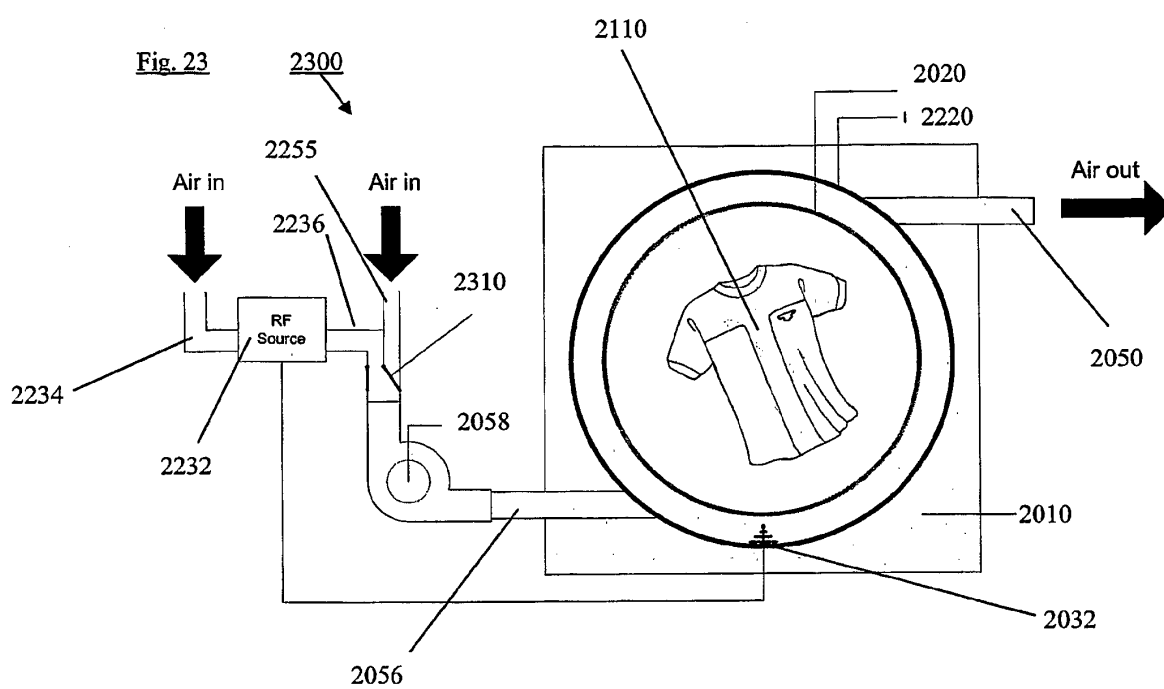


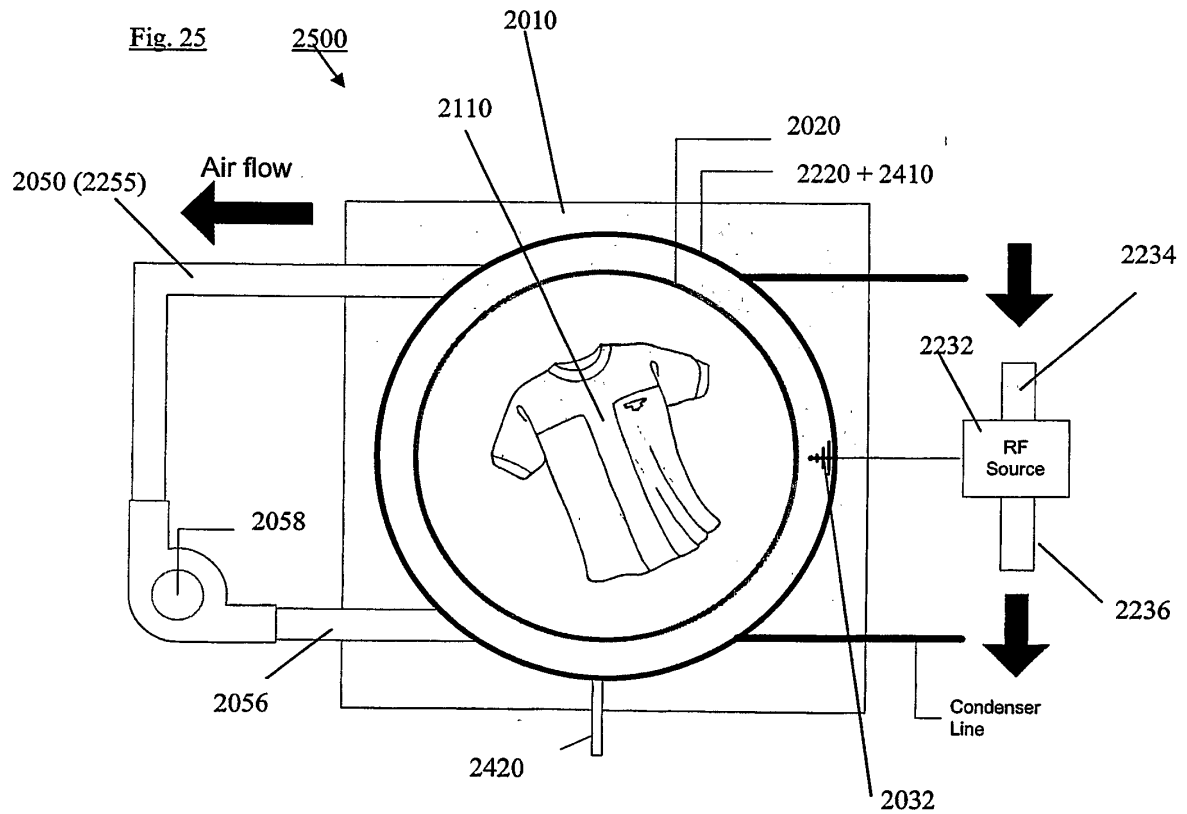
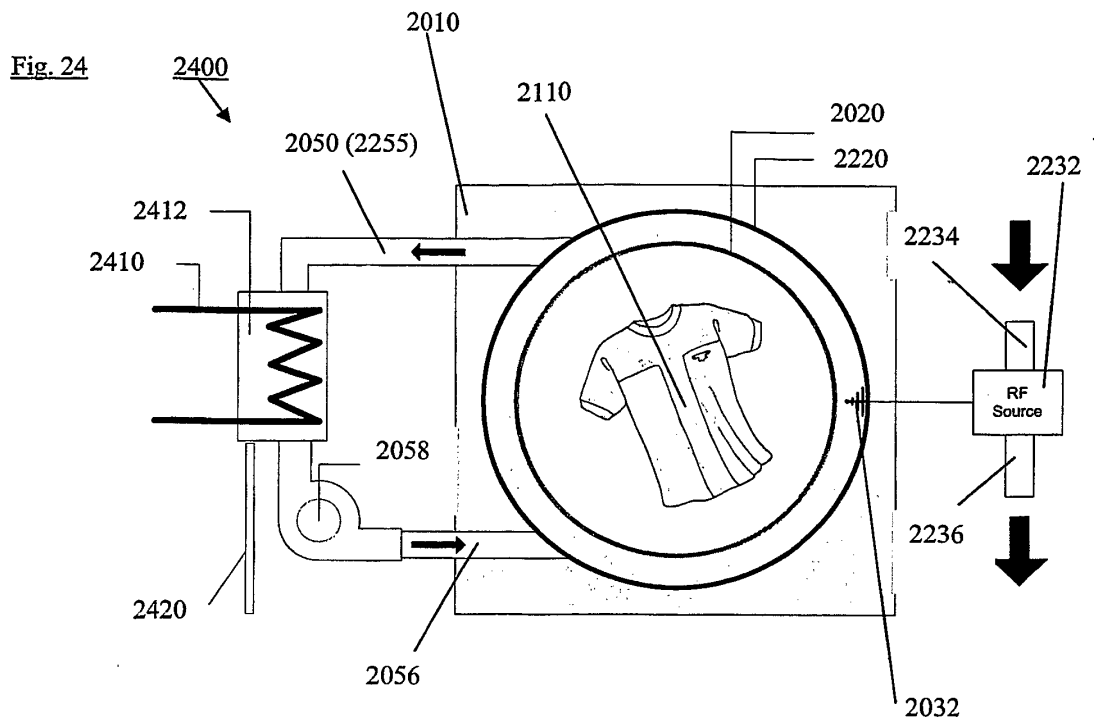
Fig. 21b

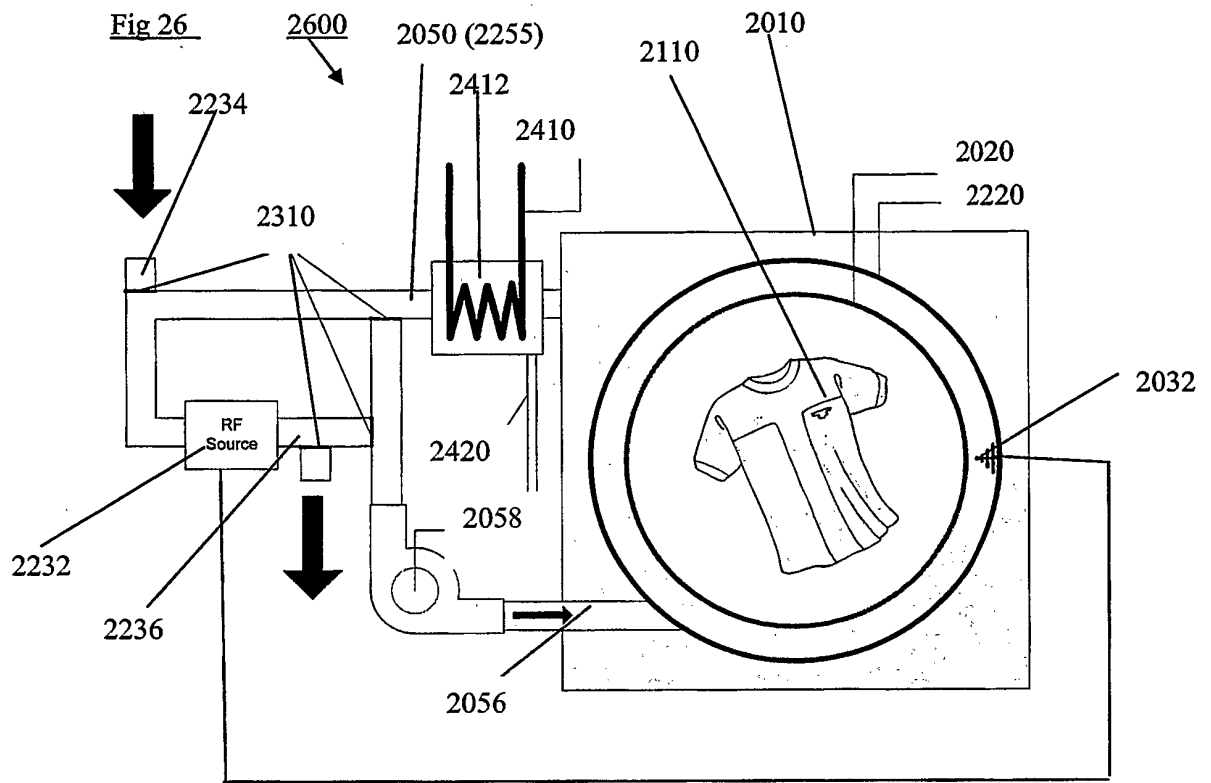


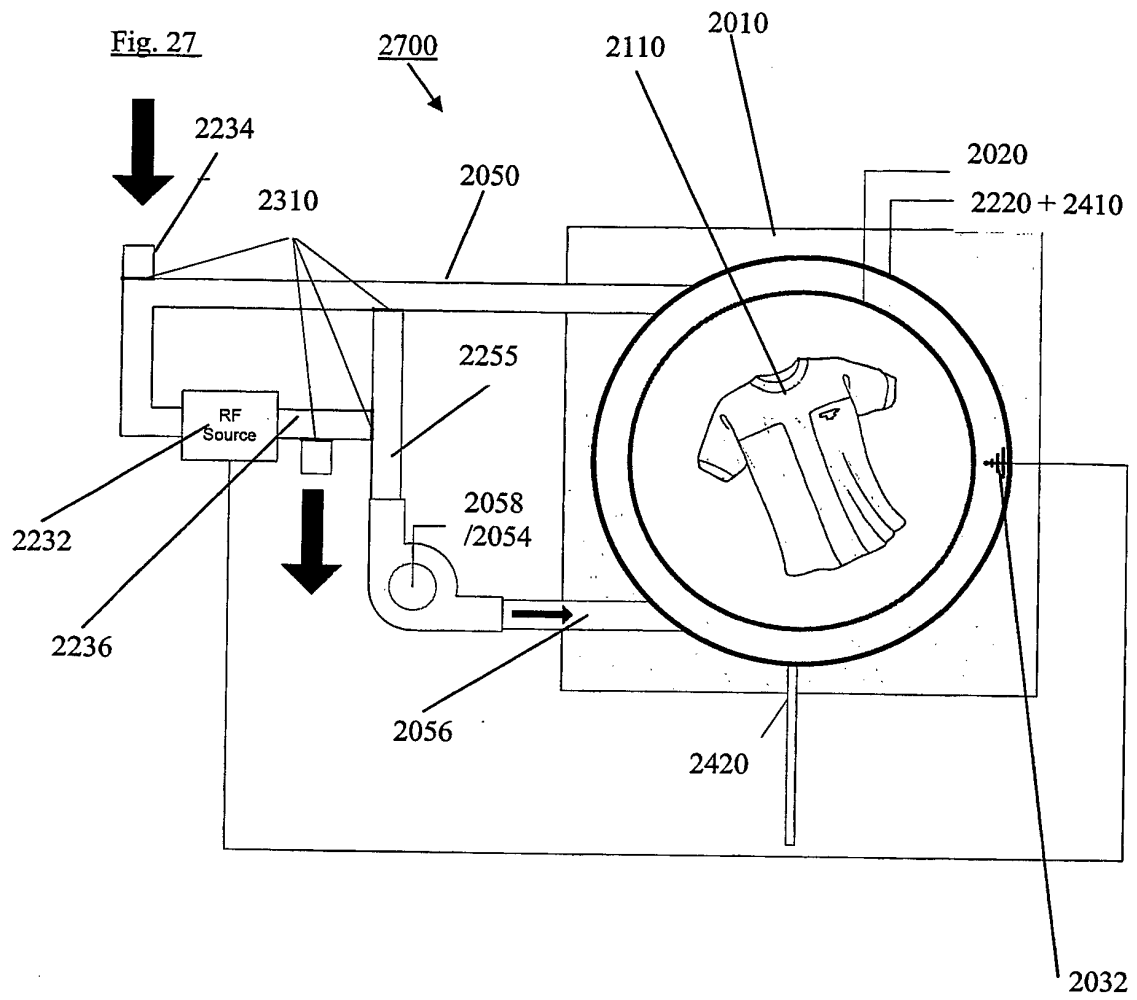












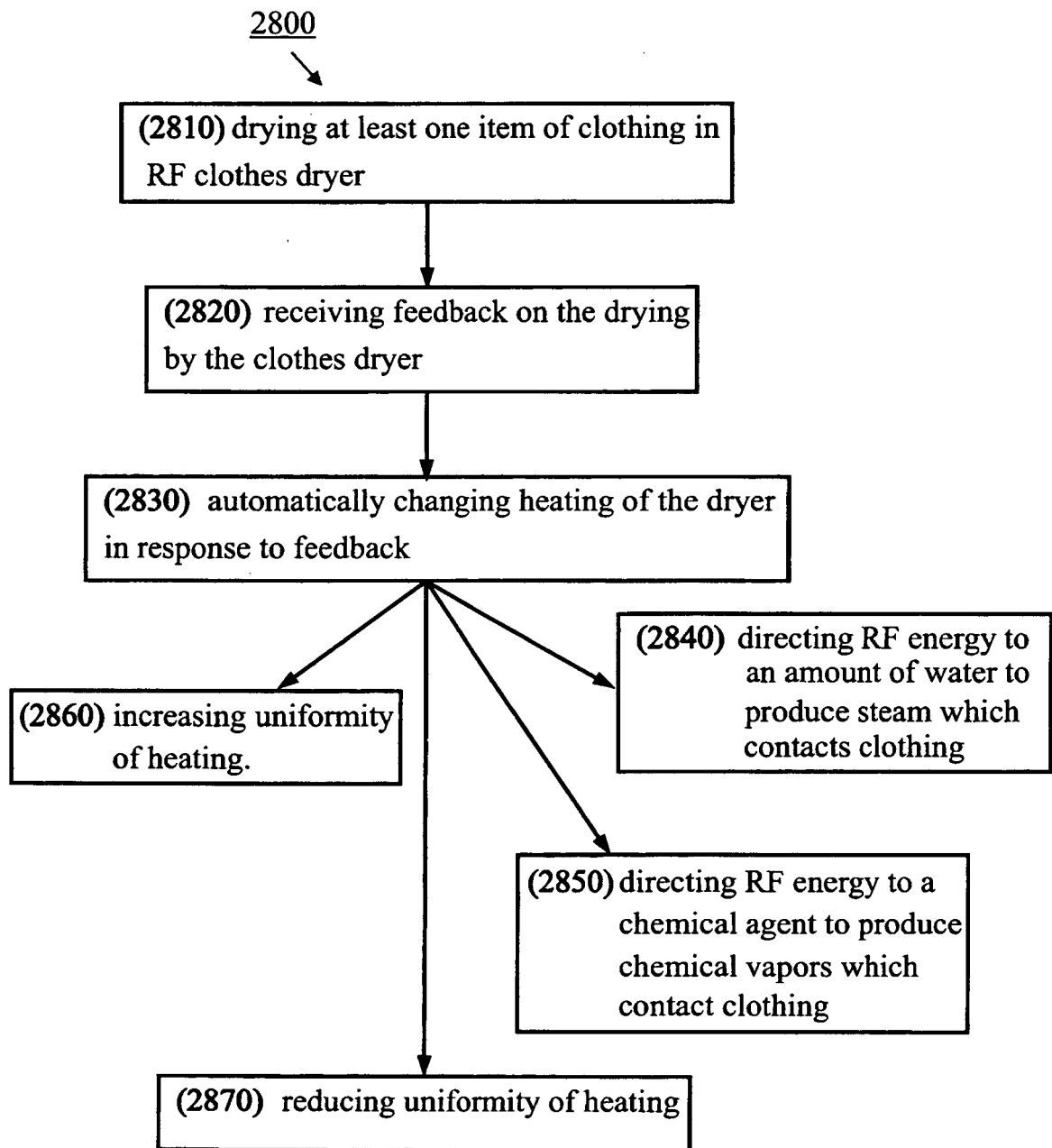


Fig. 28

Fig. 29

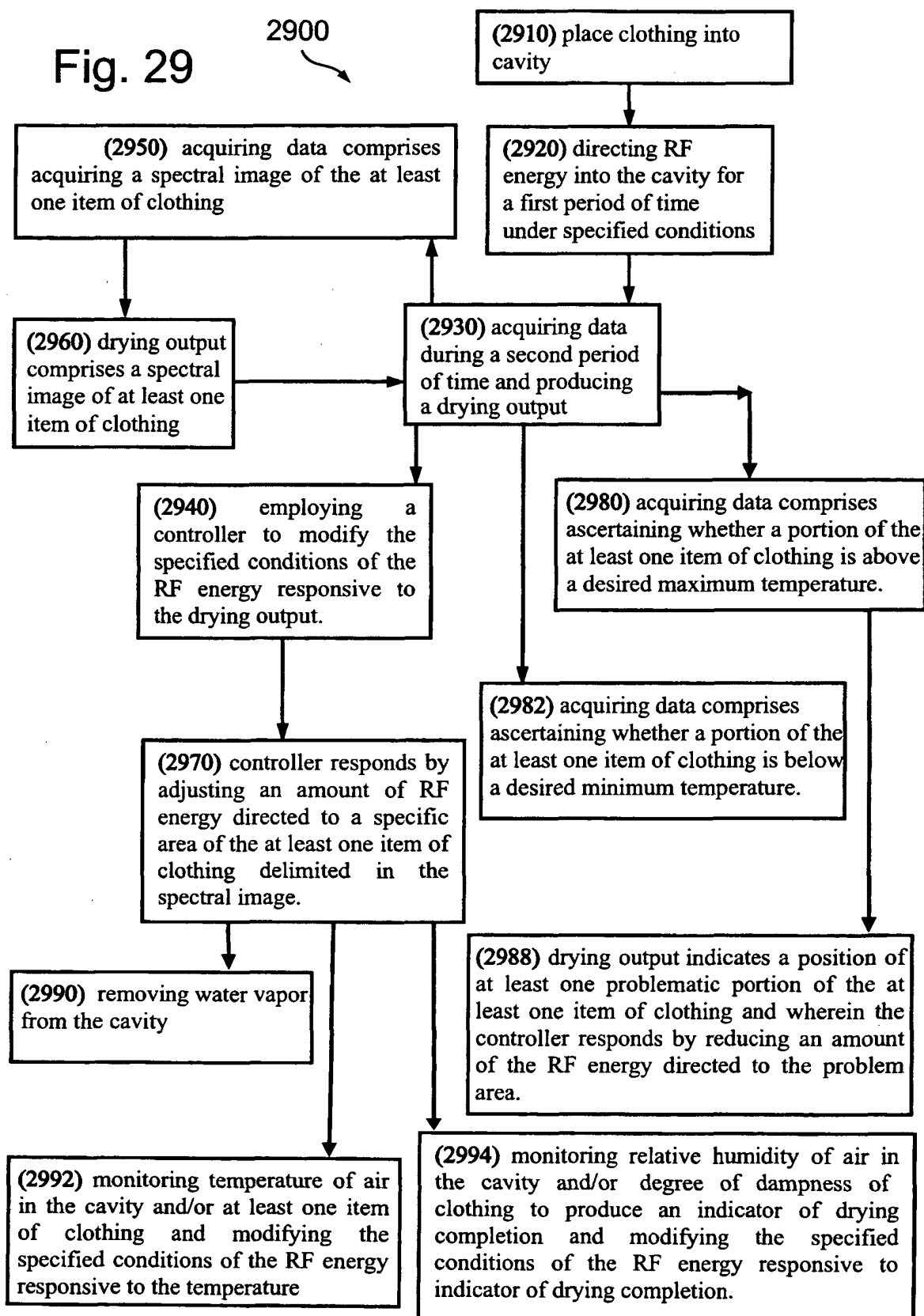


Fig. 30

3000

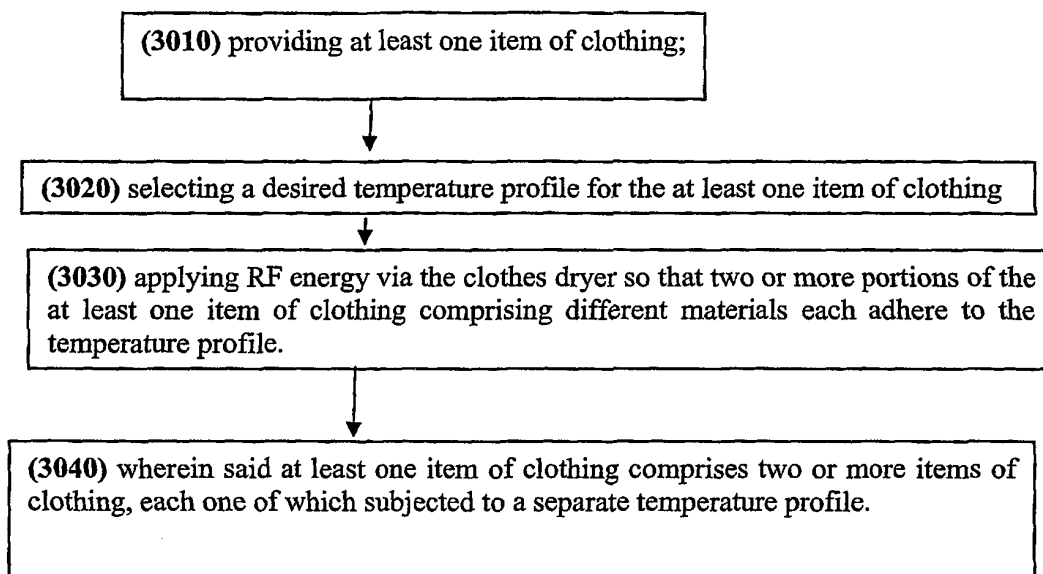


Fig. 31

3100

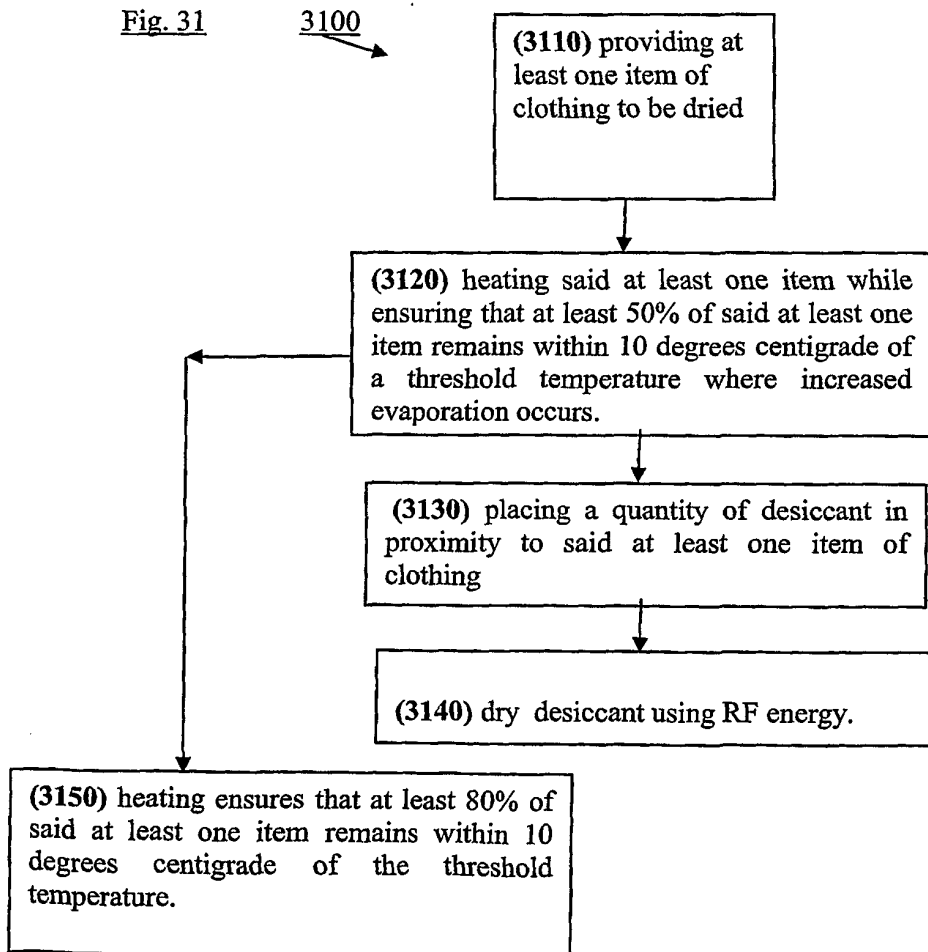
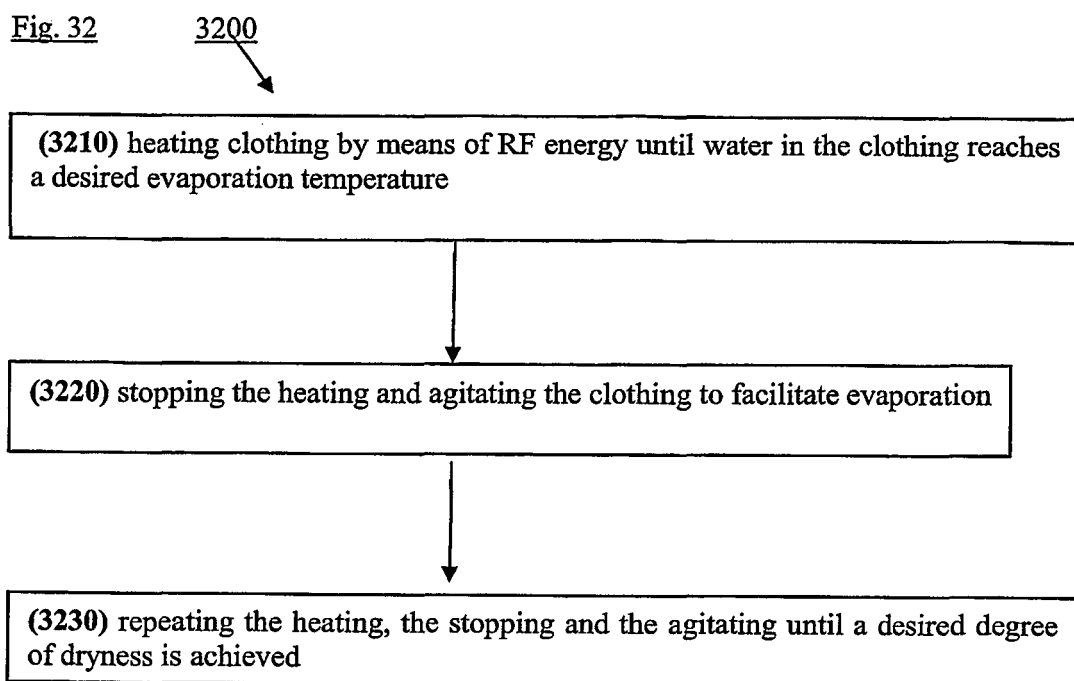


Fig. 32

3200





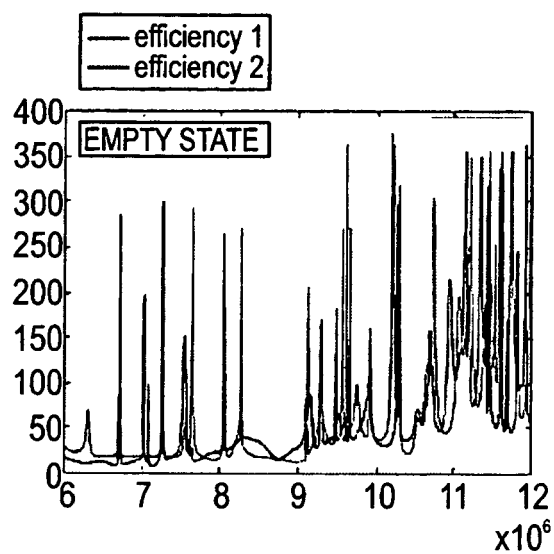


Fig. 33a

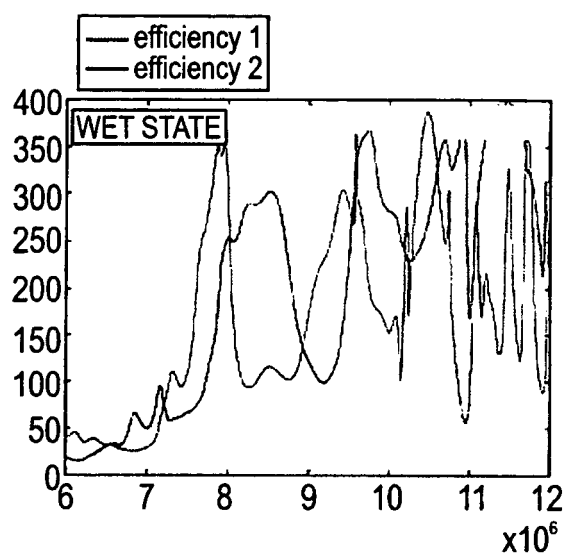


Fig. 33b

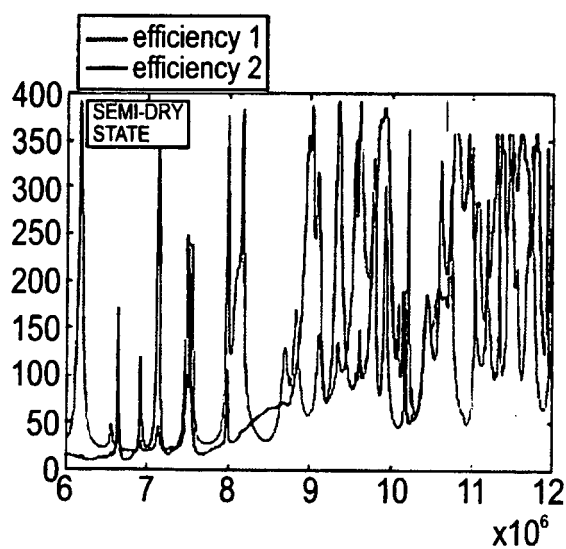


Fig. 33c

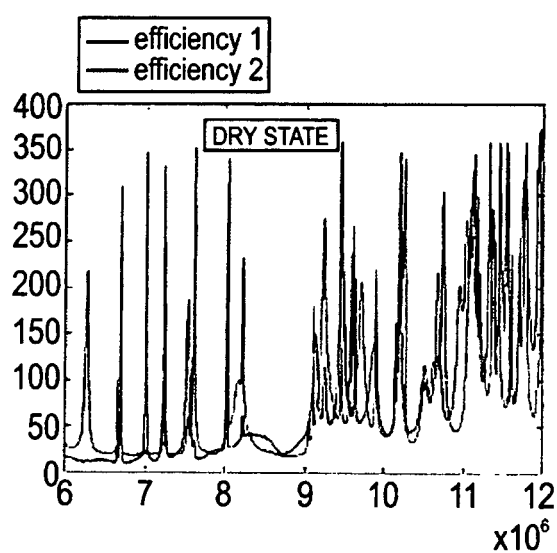


Fig. 33d

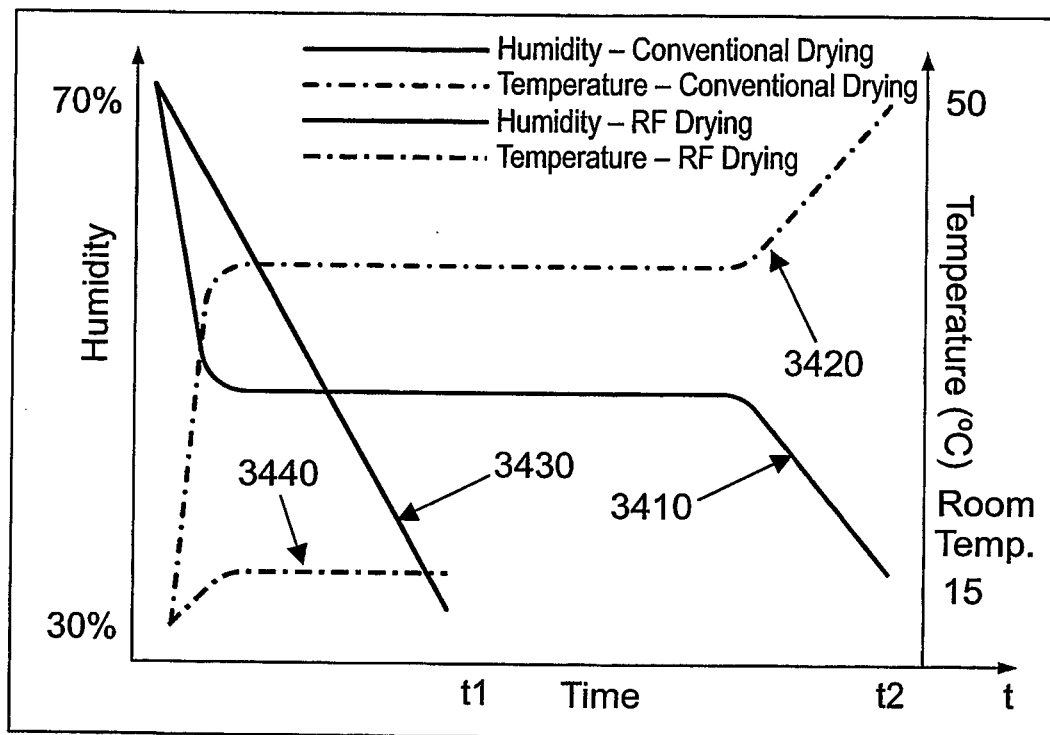


Fig. 34

## REFERENCES CITED IN THE DESCRIPTION

*This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.*

### Patent documents cited in the description

- US 5321897 A [0004]
- US 60924555 B [0133]
- US 5873254 A [0153]
- WO 2006016372 A [0153]
- WO 2003056919 A [0153]

### Non-patent literature cited in the description

- Multiband Characteristics of Two Fractal Antennas. **XU LIANG ; MICHAEL YAN WAN CHIA.** MW and Optical Tech. Letters. John Wiley, 20 November 1999, vol. 23, 242-245 [0023]
- **G.J. WALKER ; J.R. JAMES.** Fractal Volume Antennas. *Electronics Letters*, 06 August 1998, vol. 34 (16), 1536-1537 [0023]