US 20130080098A1

(19) **United States**

(12) **Patent Application Publication**

HADAD et al.

(10) **Pub. No.: US 2013/0080098 A1**

(43) **Pub. Date: Mar. 28, 2013**

(54) **OBJECT PROCESSING STATE SENSING USING RF RADIATION**

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(21) Appl. No.: **13/599,472**

(22) Filed: **Aug. 30, 2012**

Related U.S. Application Data

(60) Provisional application No. 61/529,361, filed on Aug. 31, 2011, provisional application No. 61/612,961, filed on Mar. 19, 2012.

Publication Classification

(51) **Int. Cl.**

G01N 27/00 (2006.01)

G06F 15/00 (2006.01)

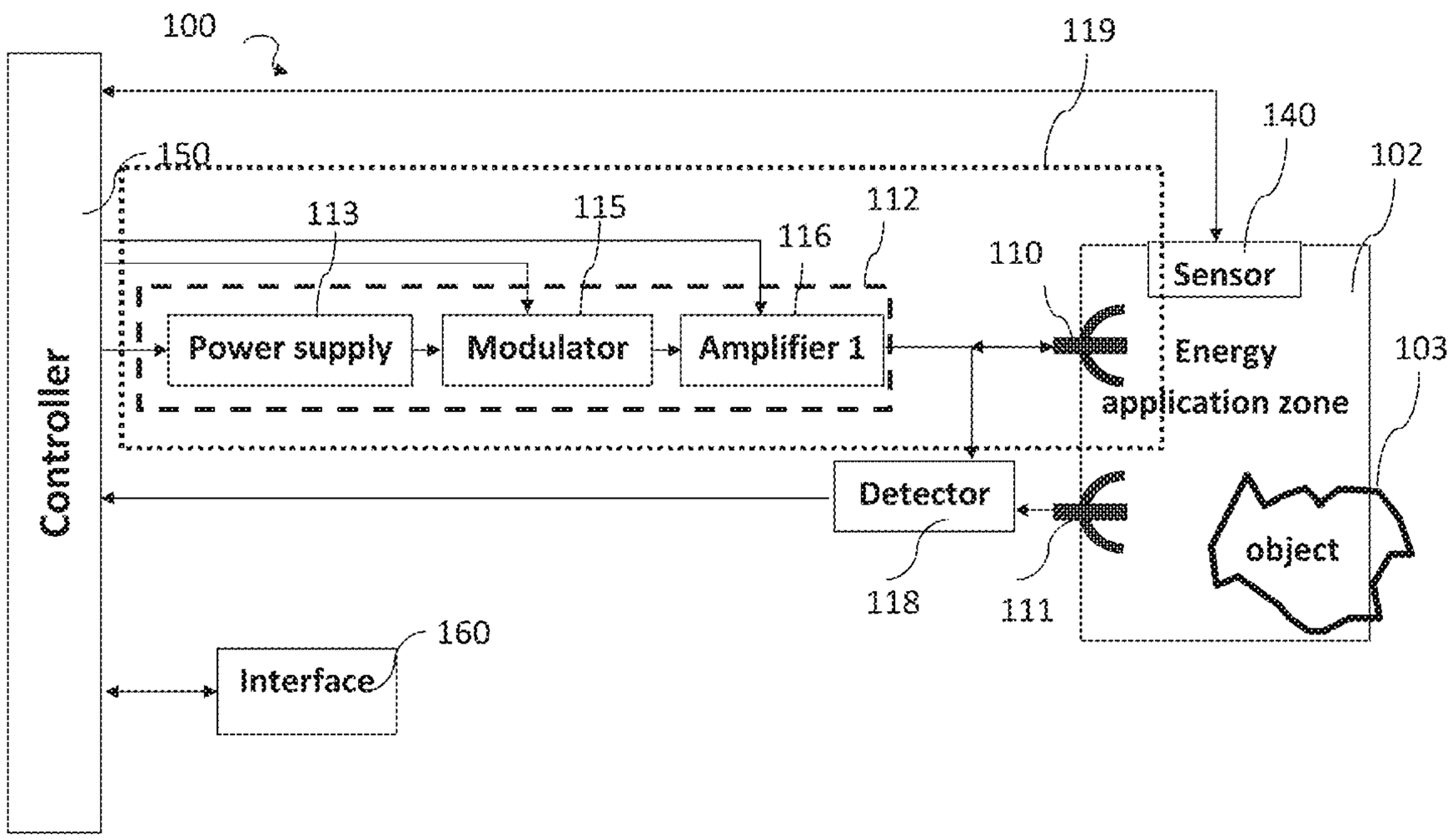
(52) **U.S. Cl.**

CPC ***G01N 27/00*** (2013.01); ***G06F 15/00*** (2013.01)

USPC **702/66**

(57) **ABSTRACT**

An apparatus for determining a correlation of a processing state of an object with RF feedback received from an energy application zone during processing of the object in the energy application zone may include at least one detector configured to detect the RF feedback from the energy application zone. The apparatus may also include at least one controller configured to receive from the at least one detector the RF feedback; receive an indication of one or more processing states of the object (e.g., as indicated by at least one processing state indicator); and determine a correlation between the received RF feedback and the one or more processing states.



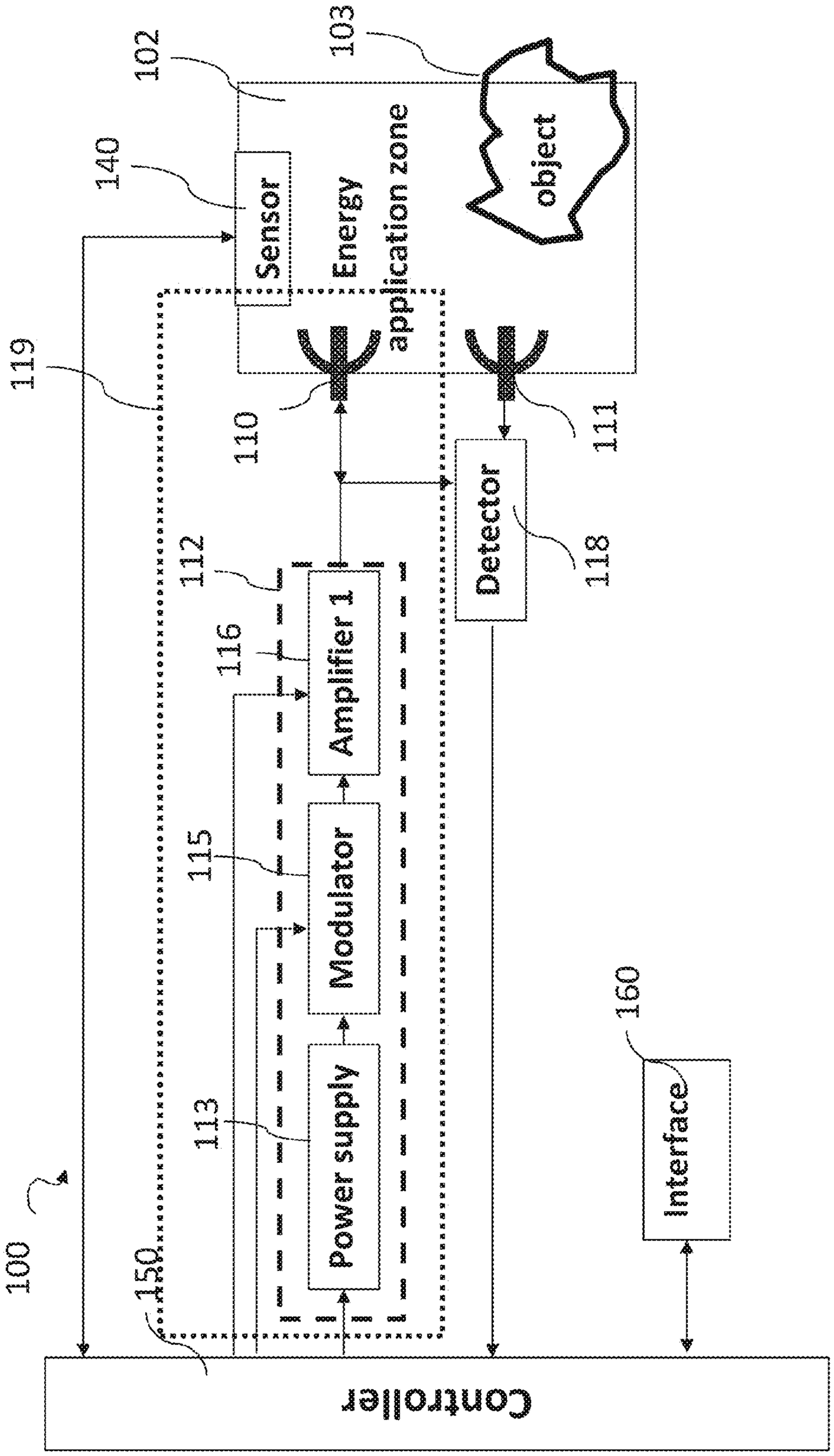

100
119
102
103
140
Sensor
Energy
application zone
object
110
111
112
116
115
113
150
Amplifier 1
Modulator
Power supply
Detector
118
160
Interface
Controller

FIG. 1A

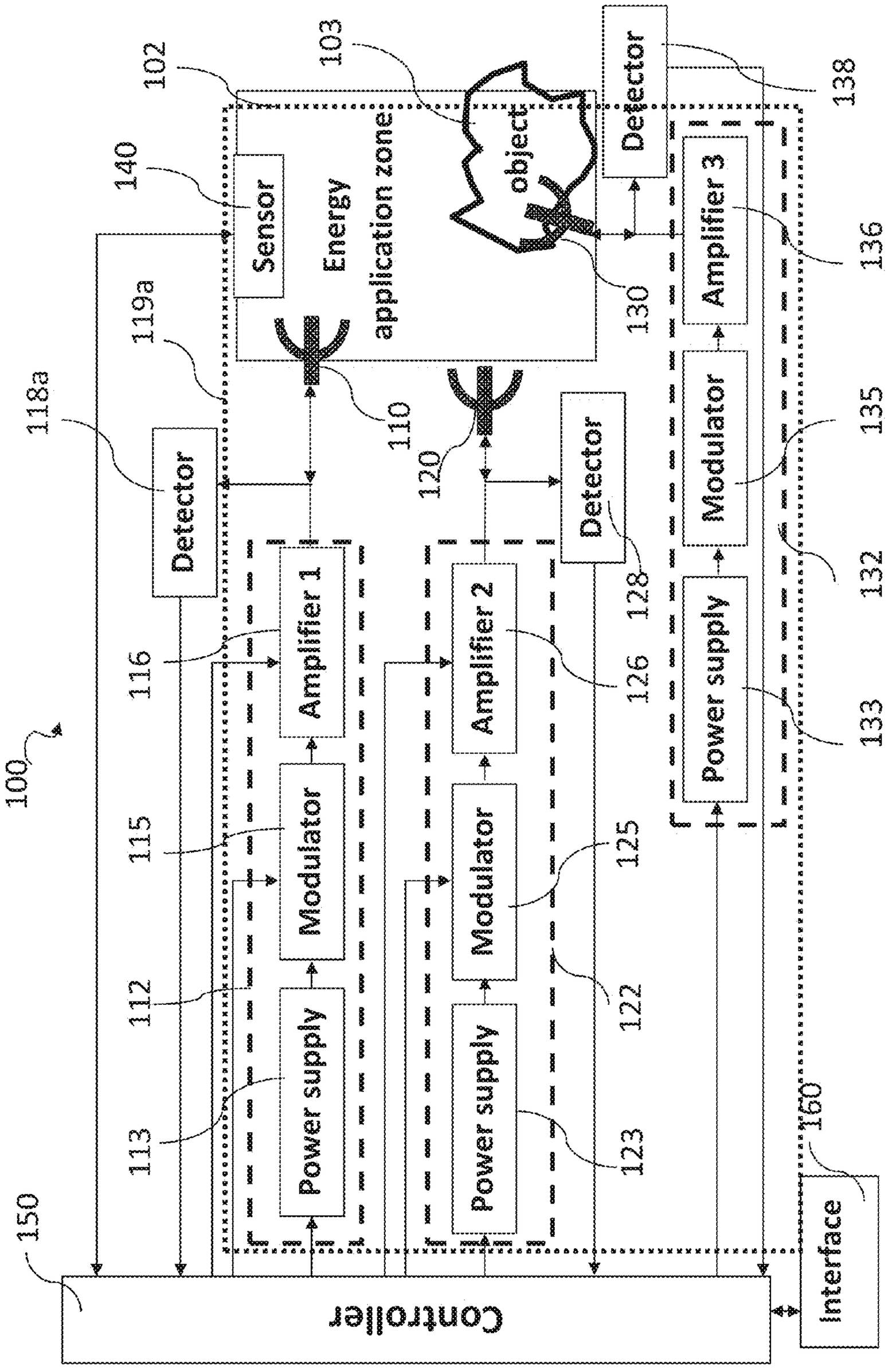

100
102
103
138
140
Sensor
Energy application zone
object
Detector
Amplifier 3
136
119a
130
118a
119
110
120
Detector
Modulator
135
116
Amplifier 1
Amplifier 2
126
128
Power supply
132
115
Modulator
Modulator
125
112
122
113
Power supply
Power supply
123
133
160
150
Controler
Interface

FIG. 1B

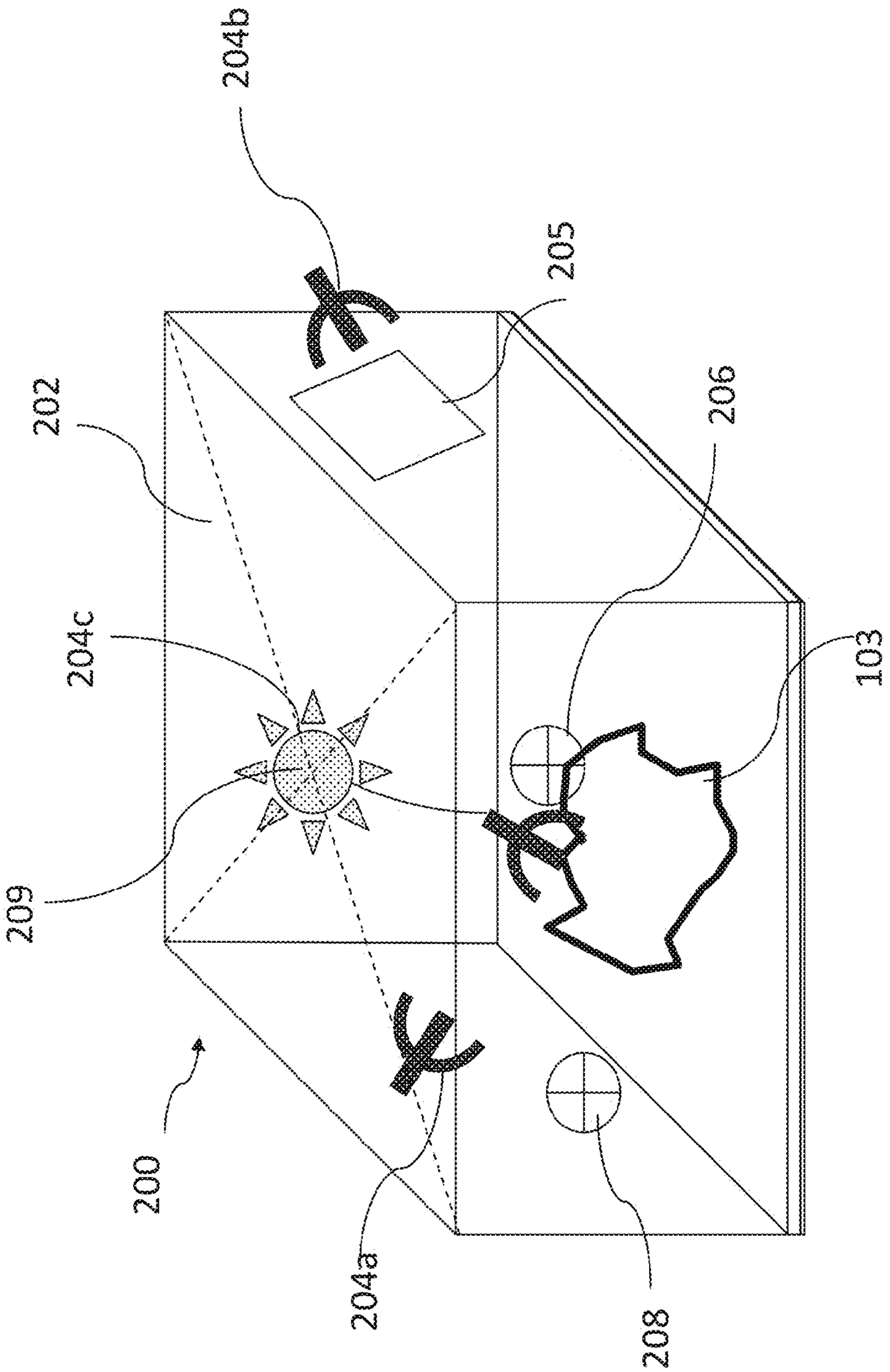


FIG. 2A

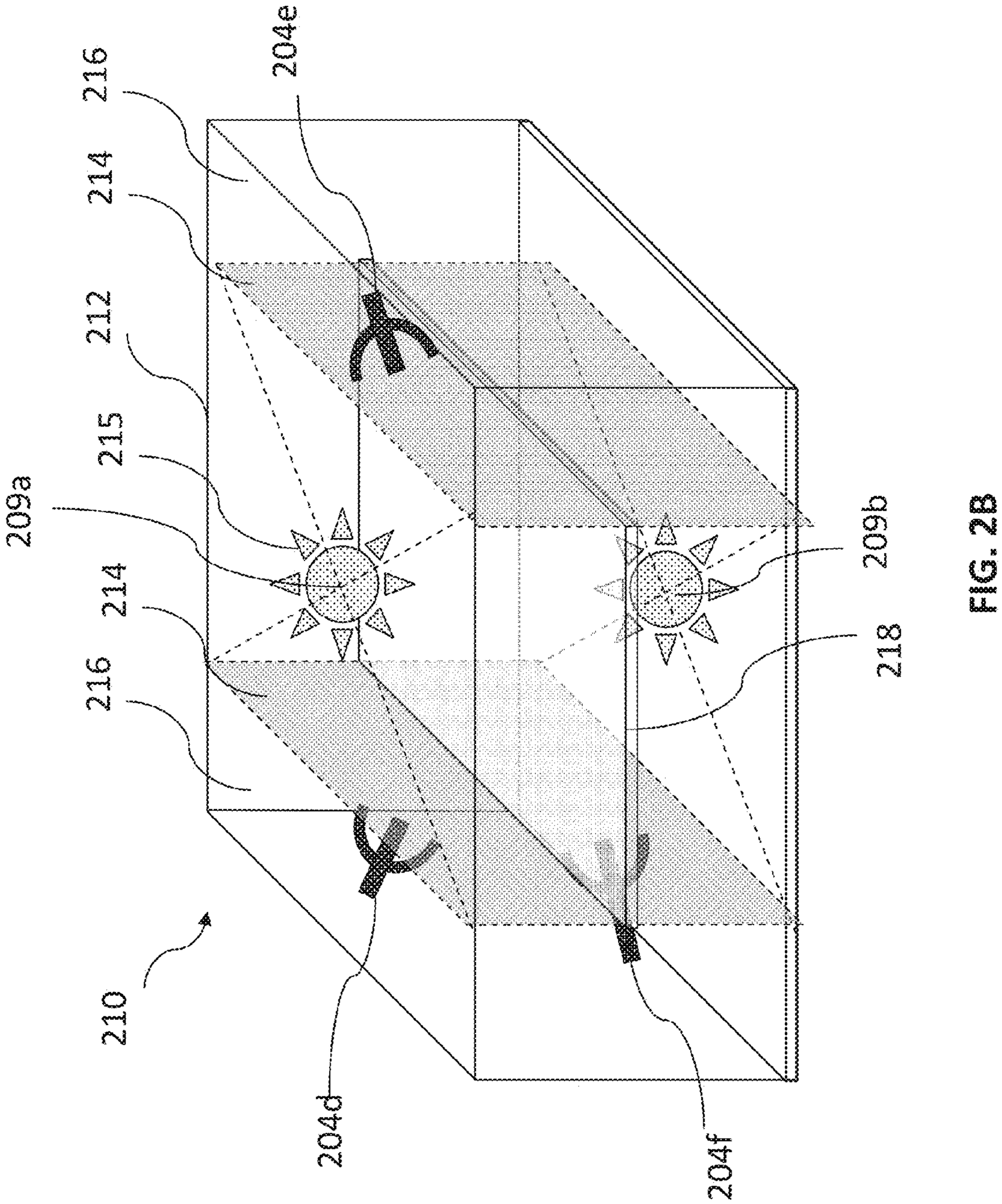


FIG. 2B

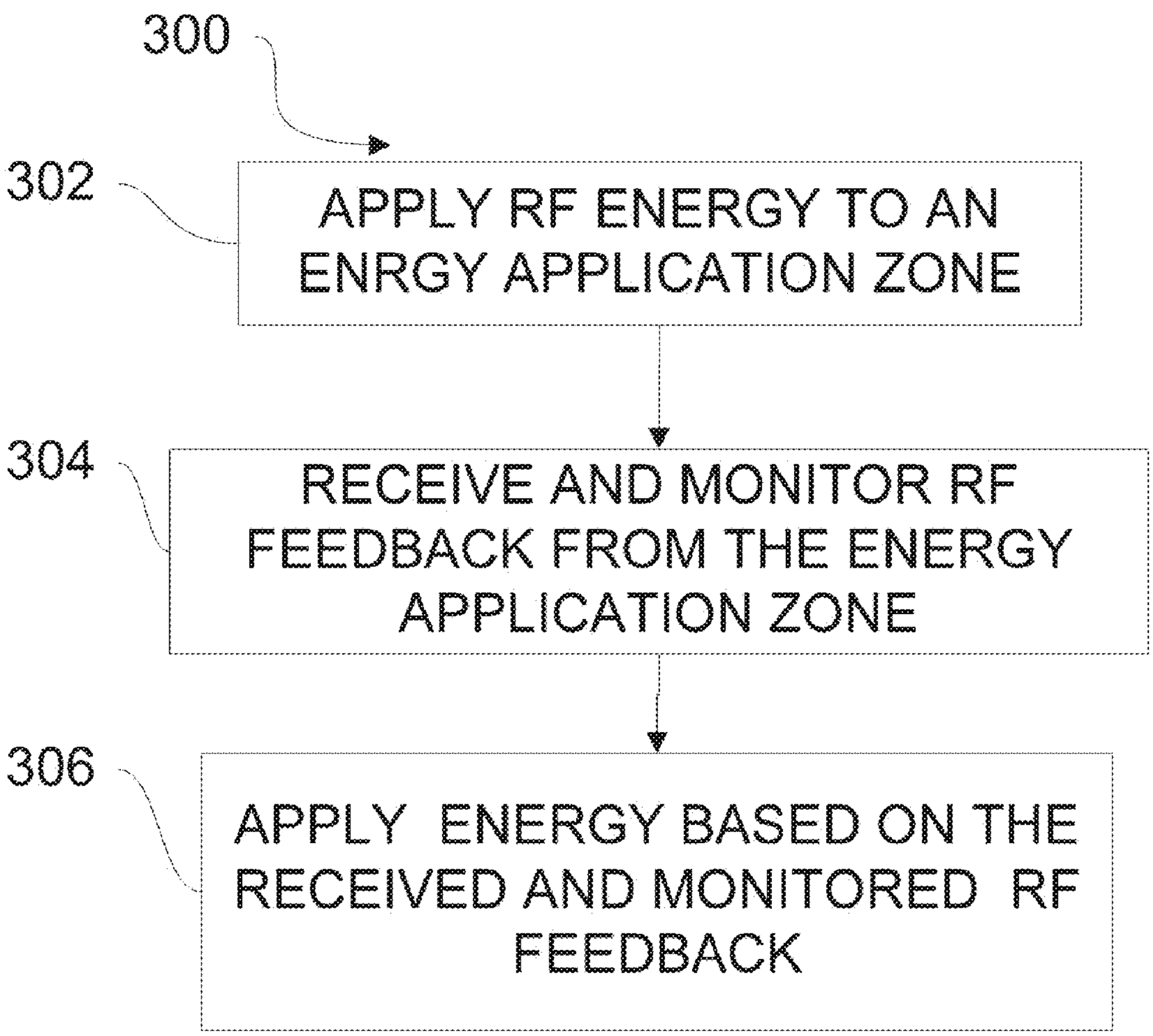

300
302
APPLY RF ENERGY TO AN ENRGY APPLICATION ZONE
304
RECEIVE AND MONITOR RF FEEDBACK FROM THE ENERGY APPLICATION ZONE
306
APPLY ENERGY BASED ON THE RECEIVED AND MONITORED RF FEEDBACK

FIG 3A

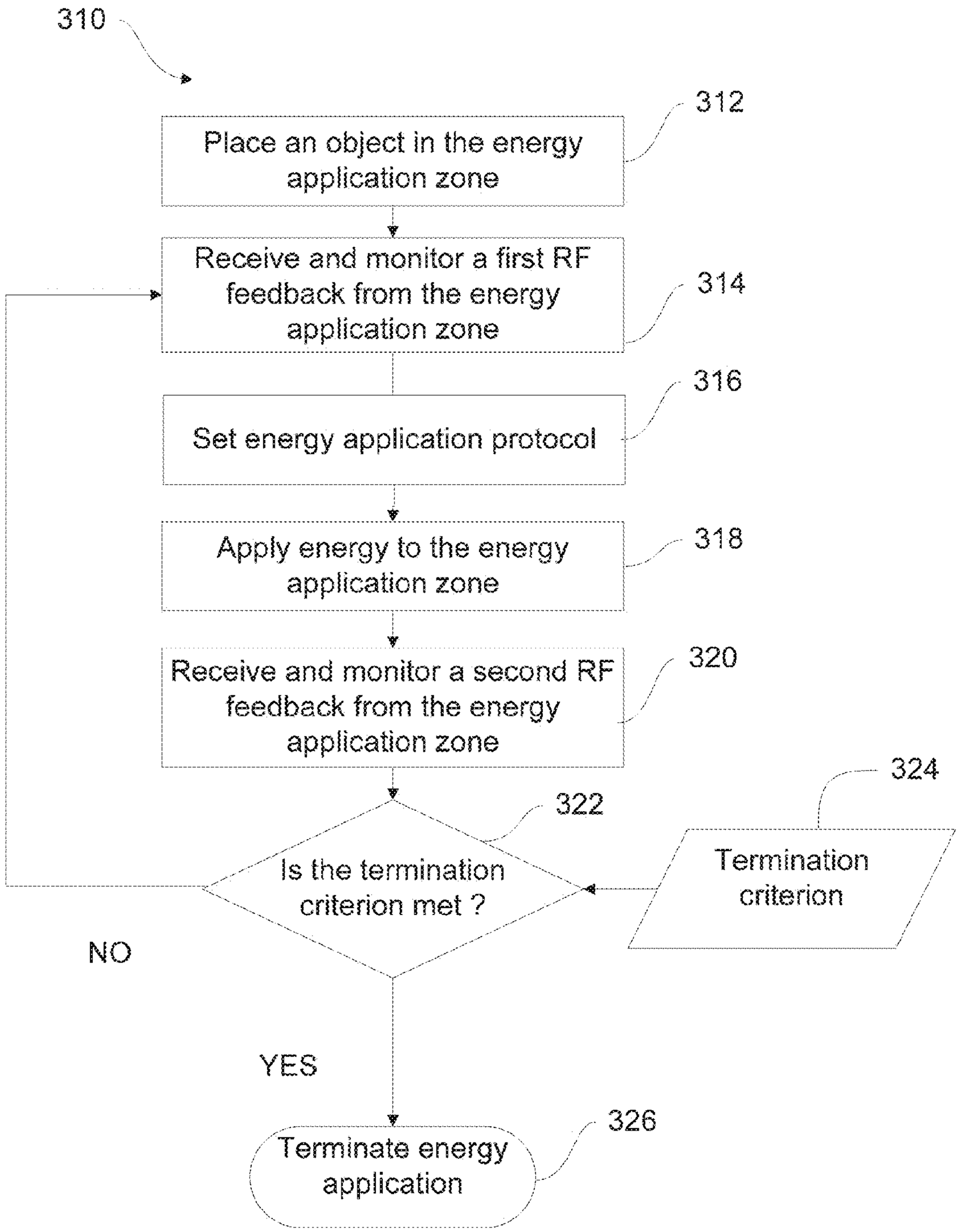

310
Place an object in the energy application zone
312
Receive and monitor a first RF feedback from the energy application zone
314
Set energy application protocol
316
Apply energy to the energy application zone
318
Receive and monitor a second RF feedback from the energy application zone
320
Is the termination criterion met ?
322
Termination criterion
324
NO
YES
Terminate energy application
326

FIG 3B

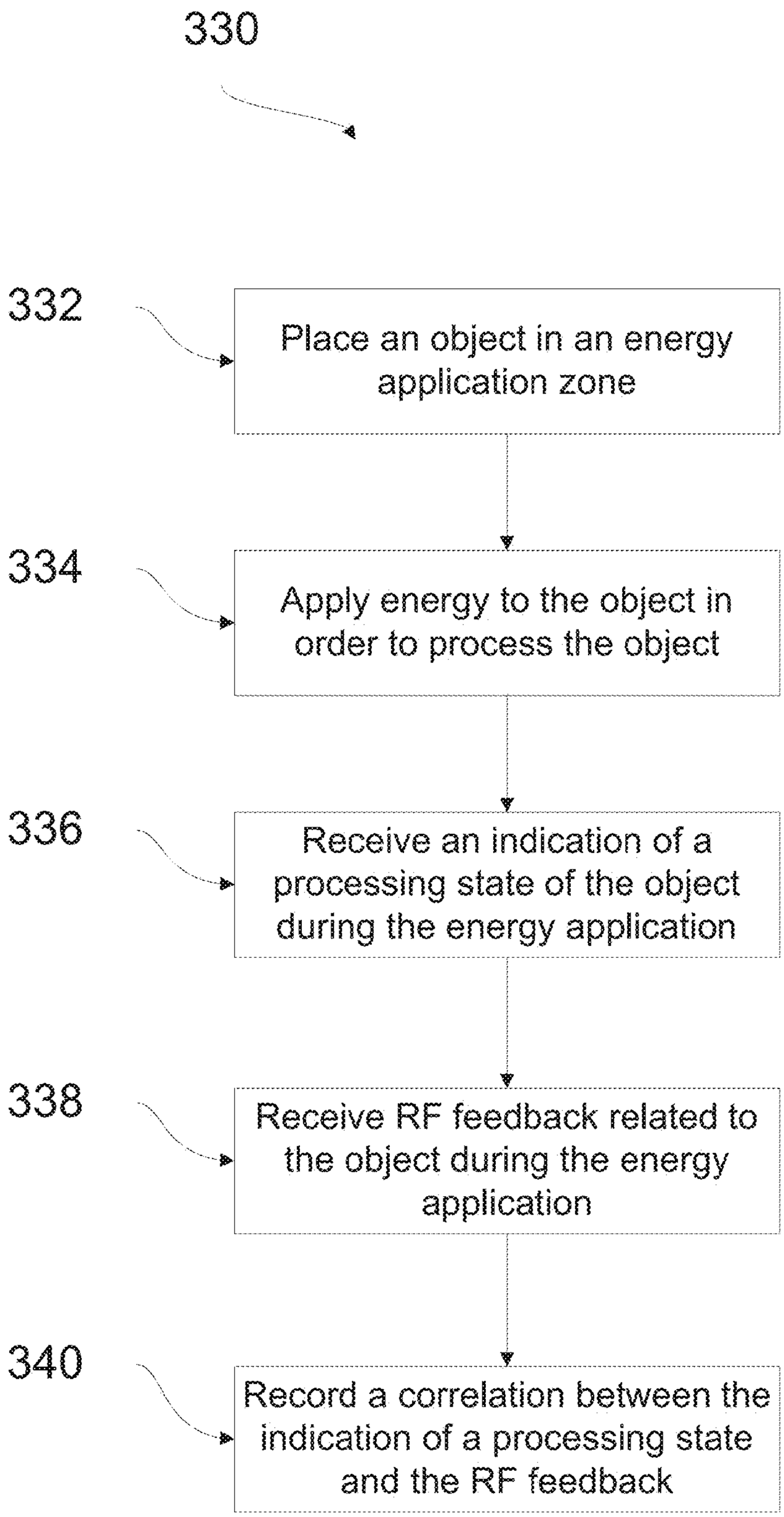

330
332
Place an object in an energy application zone
334
Apply energy to the object in order to process the object
336
Receive an indication of a processing state of the object during the energy application
338
Receive RF feedback related to the object during the energy application
340
Record a correlation between the indication of a processing state and the RF feedback

FIG. 3C

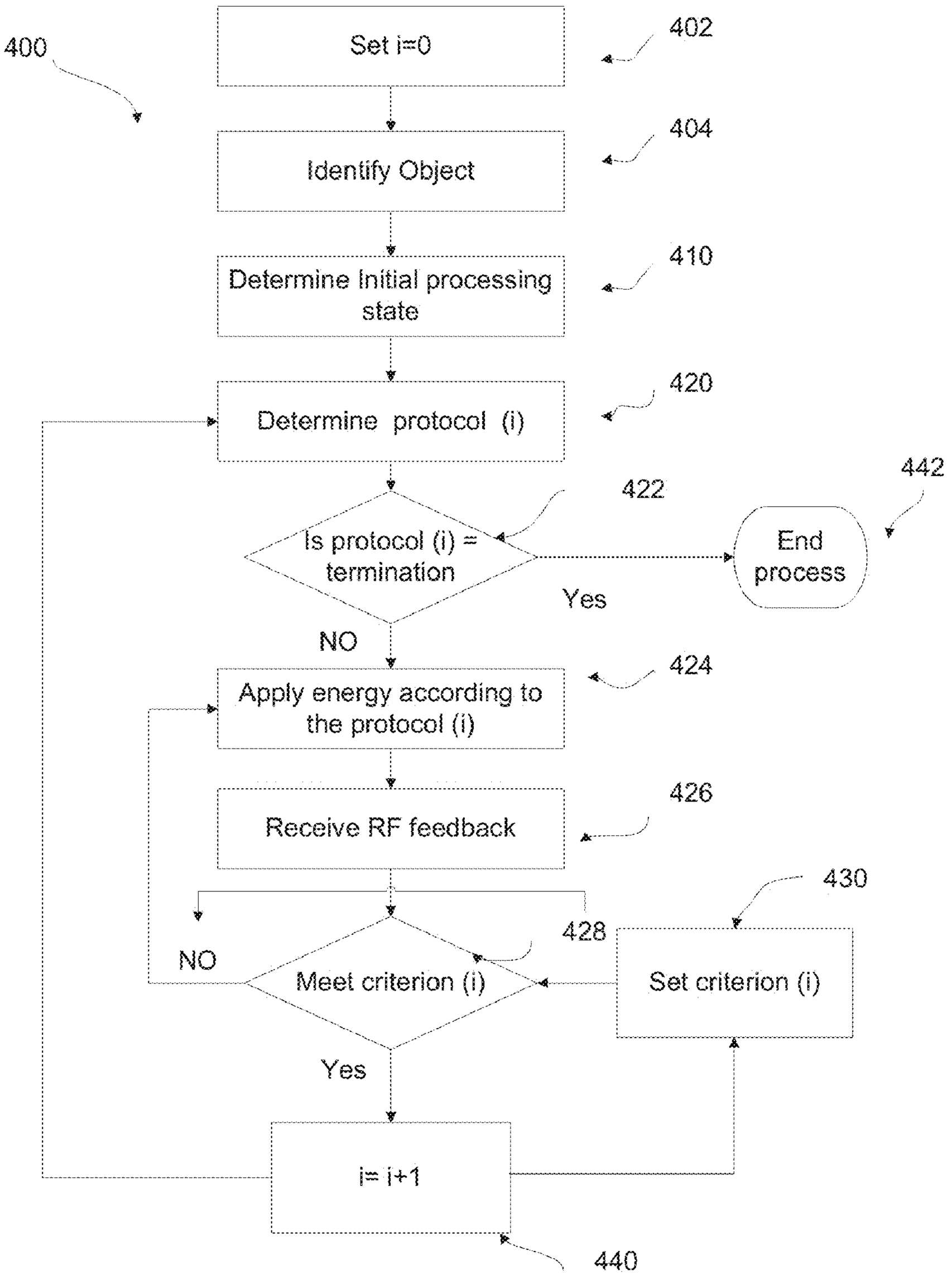

400
Set i=0
402
Identify Object
404
Determine Initial processing state
410
Determine protocol (i)
420
Is protocol (i) = termination
422
End process
442
Yes
NO
Apply energy according to the protocol (i)
424
Receive RF feedback
426
Meet criterion (i)
428
NO
Set criterion (i)
430
Yes
i= i+1
440

FIG. 4

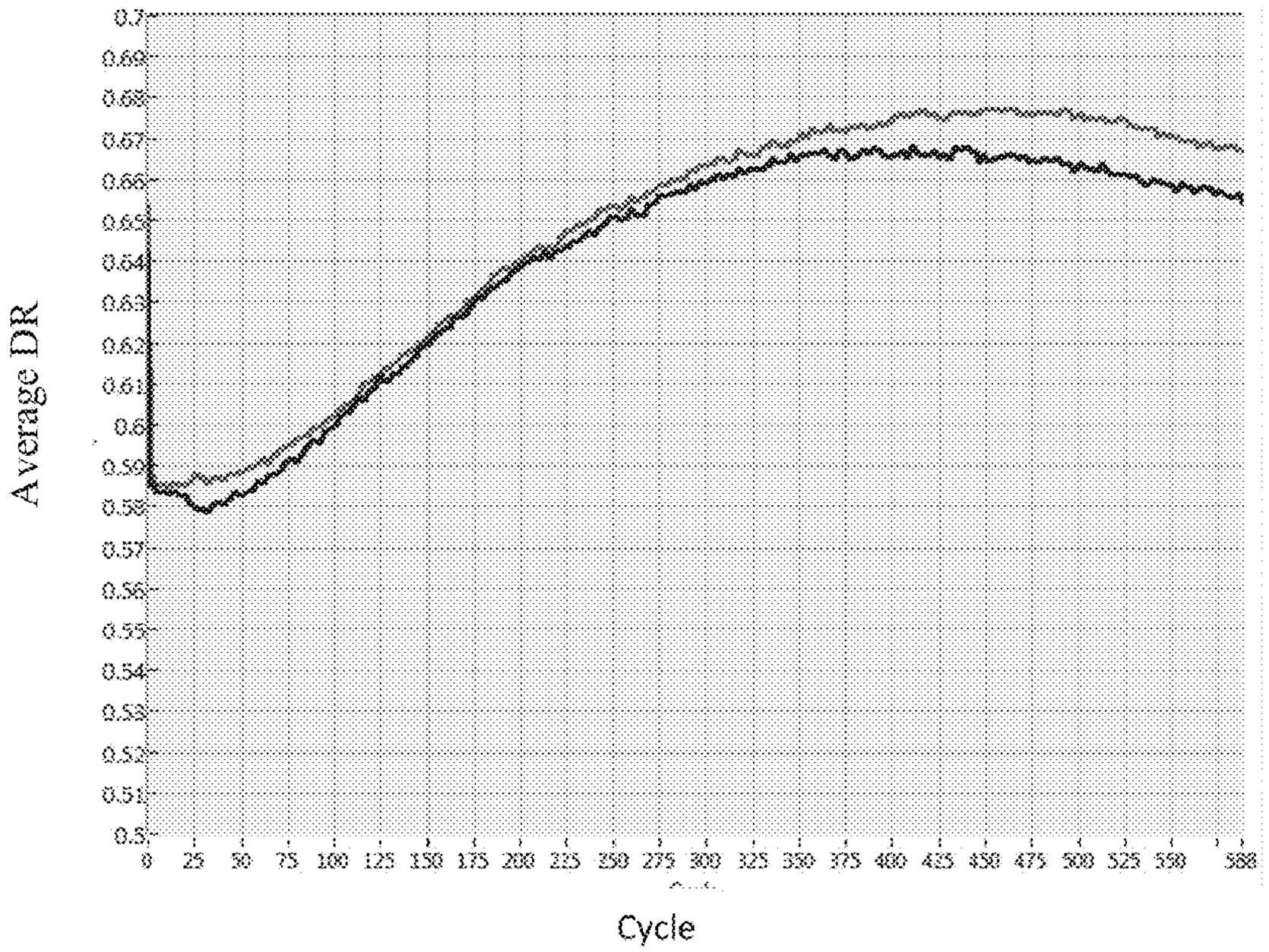

Average DR
0.7
0.69
0.68
0.67
0.66
0.65
0.64
0.63
0.62
0.61
0.6
0.59
0.58
0.57
0.56
0.55
0.54
0.53
0.52
0.51
0.5
0 25 50 75 100 125 150 175 200 225 250 275 300 325 350 375 400 425 450 475 500 525 550 588
Cycle

FIG. 5

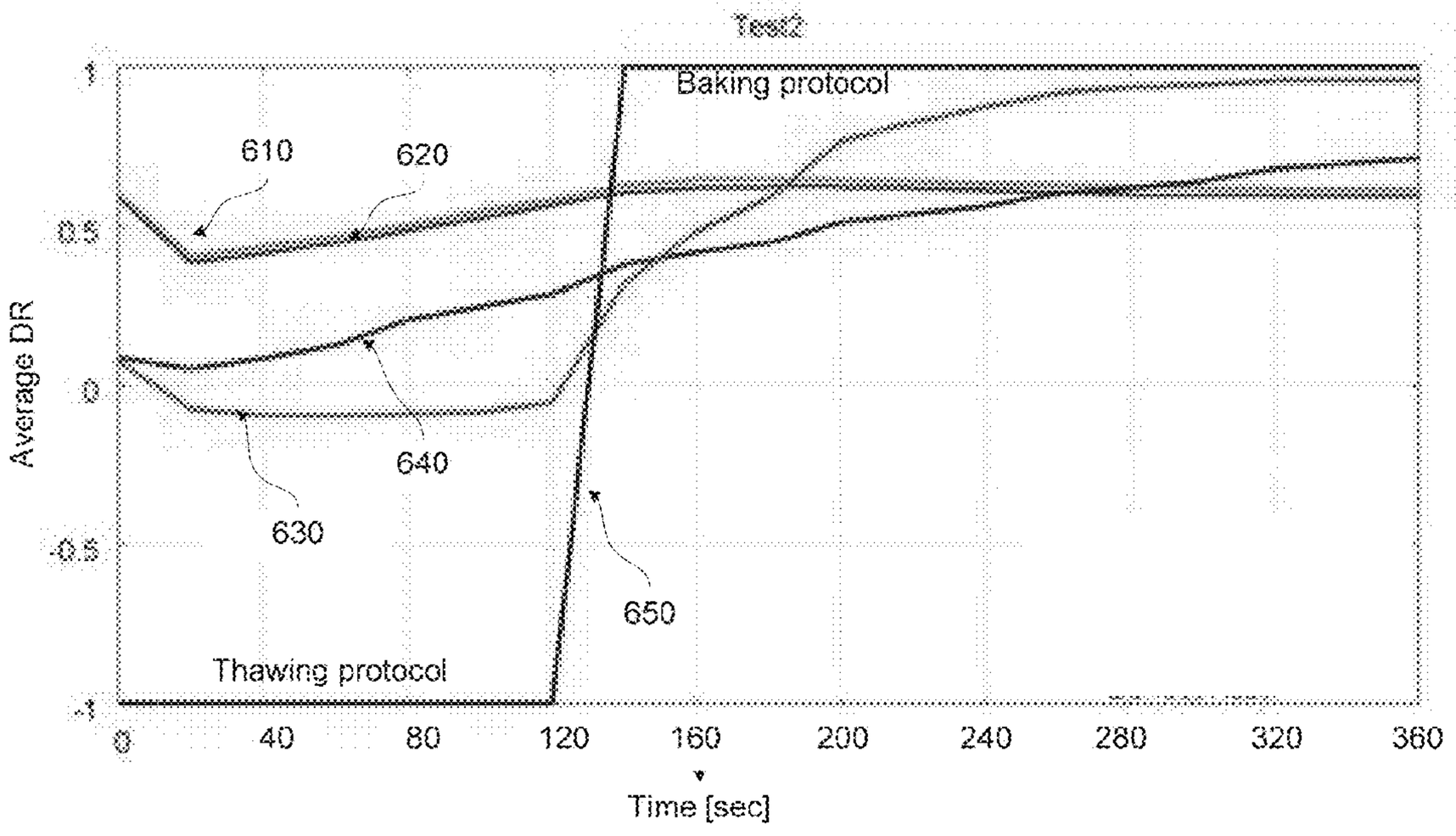

Test2
Baking protocol
610
620
640
630
650
Thawing protocol
Average DR
1
0.5
0
-0.5
-1
0
40
80
120
160
200
240
280
320
360
Time [sec]

FIG. 6A

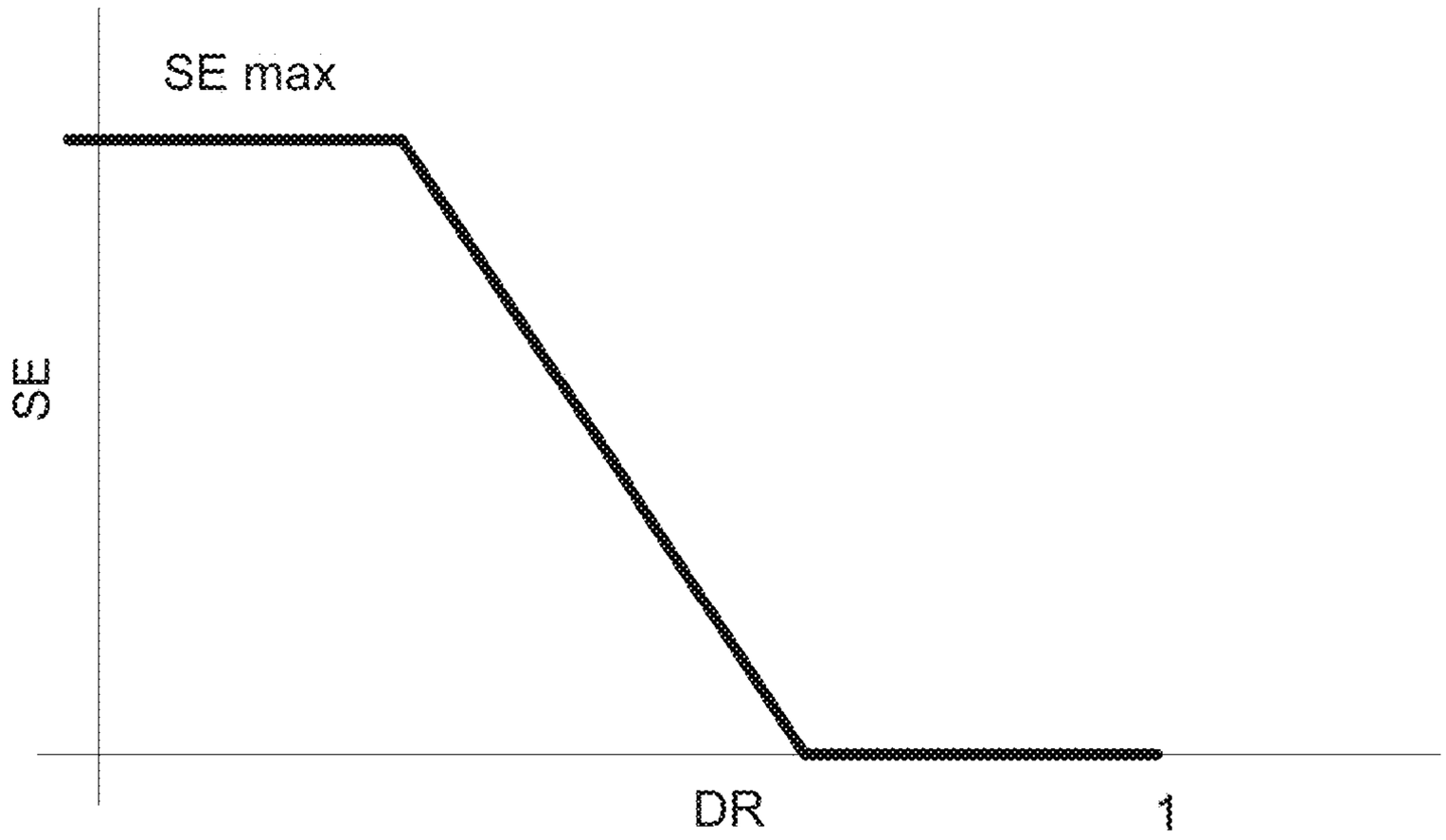


FIG. 6B

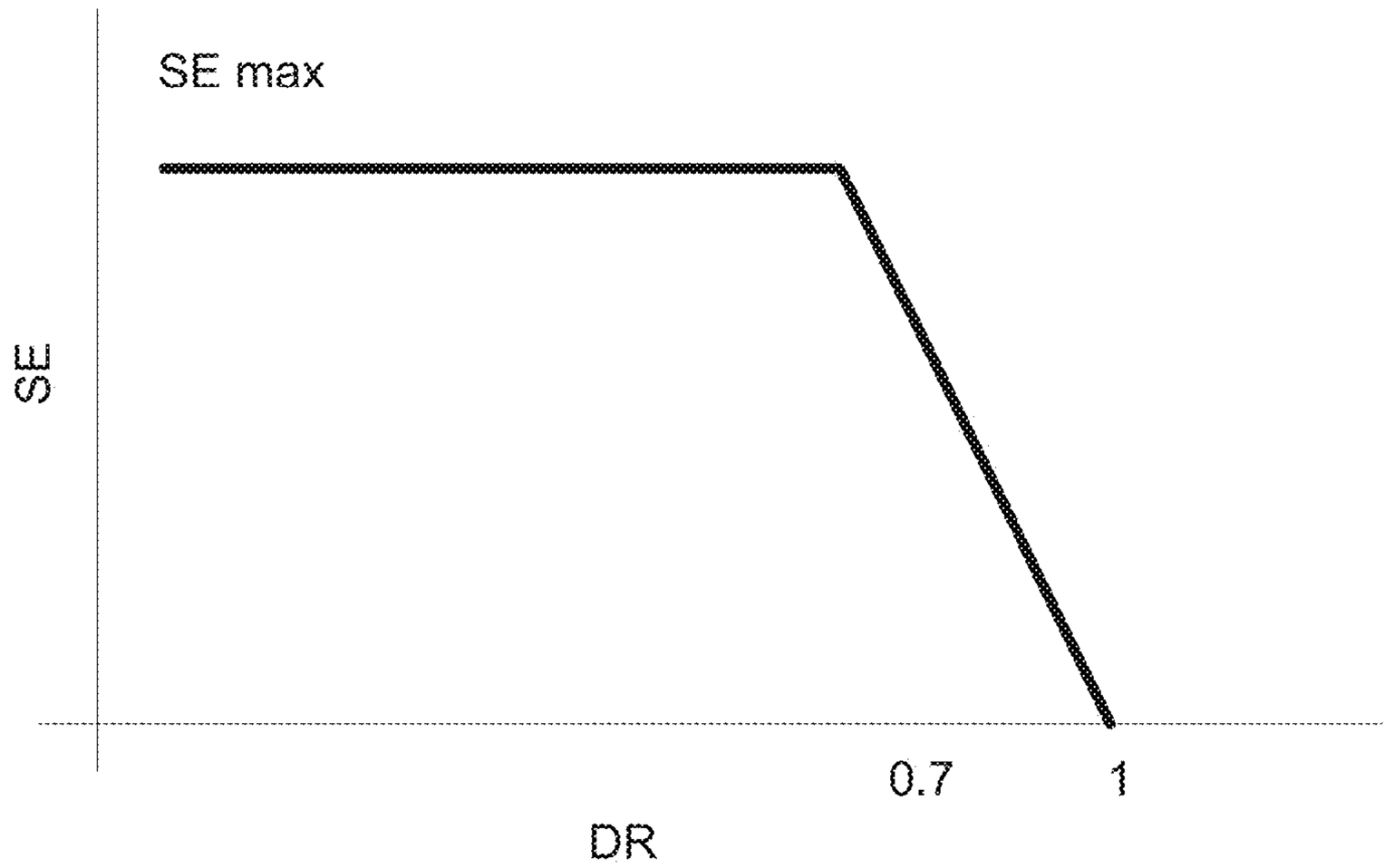


FIG. 6C

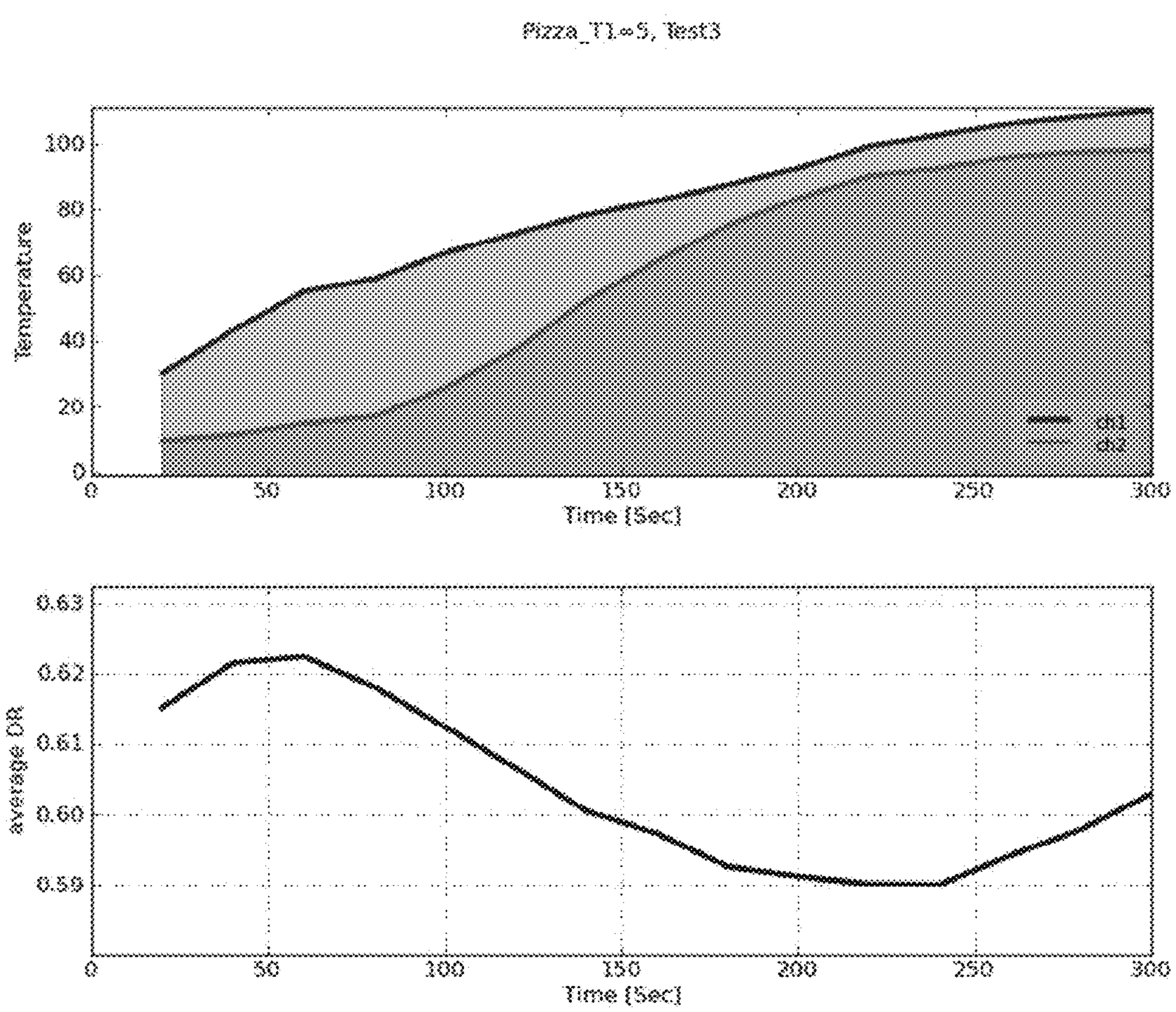

Pizza_T1=5, Test3
Temperature
Time [Sec]
0
20
40
60
80
100
0
50
100
150
200
250
300
average DR
0.59
0.60
0.61
0.62
0.63

FIG. 7

Protocol (0)
Criterion (0)
Protocol (1)
Criterion (1)
.
.
.
Protocol (N)
Criterion (N)
Termination protocol

FIG. 8A

1. Initial processing state- frozen
2. Thawing Protocol
3. Criterion (1) (average DR at a thawed state
4. cooking protocol
5. Criterion (2) change in the derivative of the average DR
6. Terminate energy

FIG. 8B

OBJECT PROCESSING STATE SENSING USING RF RADIATION

[0001] This application claims the benefit of priority to U.S. Provisional Patent Application No. 61/529,361, filed on Aug. 31, 2011, and also claims the benefit of priority to U.S. Provisional Patent Application No. 61/612,961, filed on Mar. 19, 2012, both of which are incorporated herein in their entirety.

TECHNICAL FIELD

[0002] This is application relates to a device and method for applying electromagnetic energy. More particularly, but not exclusively, disclosed embodiments may relate to a device and method for applying electromagnetic energy in the radio frequency range to determine or detect a processing state of an object being processed.

BACKGROUND

[0003] Electromagnetic (EM) waves have been used in various applications to supply energy to objects. In the case of radio frequency (RF) radiation for example, RF energy may be supplied using a magnetron, which is typically tuned to a single frequency for supplying RF energy only in that frequency. One example of a commonly used device for supplying RF energy is a microwave oven. Typical microwave ovens supply RF energy at or about a single frequency of 2.45 GHz. Other apparatus have been used to process objects. For example, conventional ovens may be used to cook, heat, and dry objects. Other processing apparatus may be employed in fields of chemical production, products manufacturing, materials fabrication, etc. In each of these fields or apparatus, a need may exist to monitor the progress of a process or processes.

SUMMARY OF A FEW EXEMPLARY ASPECTS OF THE DISCLOSURE

[0004] Some exemplary aspects of the invention may be directed to methods and apparatuses for applying RF energy to detect and sense one or more processing states of an object placed in an energy application zone to be processed (e.g., to be heated). The object may be processed by applying various types of energy, for example convection heating, infrared (IR) radiating (heating), etc. In addition to applying convection and/or IR heating, RF energy may also be applied to process the object simultaneously with or instead of the IR and/or convection heating. Optionally, the RF energy may be applied before and/or after the IR and/or convection heating. Changes that may occur in the object during processing may be referred to as a processing state of the object. Some examples of processing states of an object may include: a physical property of the object (e.g., temperature, pressure, flow rate, phase(s) etc.), chemical property of the object (e.g., pH, chemical composition, etc) and if the object is a food item—the processing state of an object may include: cooking and/or doneness state of the object (e.g., thawed, proofed, fully baked/cooked etc.). Changes in the object during processing may affect the dielectric behavior and response of the object to RF energy application. One or more RF feedbacks received from the energy application zone, optionally in response to an RF energy application, may be correlated to one or more processing states of the object. The RF feedback may be monitored during the processing of the object in order to detect the one or more processing states of the object.

[0005] In some embodiments, an apparatus for applying RF energy to detect one or more processing states of an object may be provided as an add-on device which may be installed in a processing apparatus (e.g., it may be installed in cooking oven, for example: conventional MW oven, a cooking oven operated by convection, or any other device for applying heat to an object, and may indicate a cooking state of objects). It may be installed on the manufacturing site of the processing apparatus or may be installed at a later stage (e.g., after purchasing). In some embodiments an add-on device for detecting one or more processing states of an object may be provided with one or more radiating elements. Alternatively or additionally, the device may be connected to one or more radiating elements or sensors installed in the processing apparatus and may use the elements or sensors for receiving RF feedback.

[0006] Some additional embodiments may include an apparatus and method for applying RF energy to detect a cooking state of a food item placed in an energy application zone, during cooking of the food item. RF energy may be applied to the food item during cooking. Cooking the food item may be performed in a cooking apparatuses, such as: a cooking oven, a stove, an oven using an IR lamp for heating, a frying pan, an RF oven (e.g., a microwave oven) or an apparatus comprising two or more of the cooking apparatuses thereof. RF feedback may be received (e.g., by a controller) from the energy application zone. The RF feedback may by correlated with one or more processing states of the food item, for example, the temperature (e.g., is the item frozen or thawed, baked), degree of doneness, water constant, cooking state (proofed, cooked, baked, etc.). The RF feedback may be monitored during the cooking process to detect the processing state of the food item, optionally based on the correlation. In some embodiments, a computed RF feedback (to be discussed below) may be monitored during the cooking process to detect the processing state of the food item, optionally based on a correlation between the computed RF feedback and the processing state of the food item. In some embodiments, the controller may compute the computed RF feedback from the received RF feedback.

[0007] Some exemplary embodiments may include an apparatus and method for applying RF energy to detect a processing state of an object placed in an energy application zone, during processing of the object. RF energy may be applied at a plurality of excitation setups (e.g., frequencies, phases, amplitudes—as discussed below) to the object during processing. RF feedback or a computed RF feedback correlated with one or more processing states of the object may be received. The RF feedback or the computed RF feedback may be monitored during the processing of the object to detect the processing state of the object, optionally based on the correlation.

[0008] In some embodiments, the RF feedback may include a computed RF feedback. The computed RF feedback may be computed using mathematical manipulation of a raw RF feedback received from the energy application zone. A method and apparatus for applying RF energy to detect a processing state of an object placed in an energy application zone may include applying RF energy to the object during processing. In response to the RF energy application, raw RF feedback may be received (e.g., by a controller), optionally from a detector configured to receive RF signals. A computed

RF feedback may be computed based on at least two values associated with raw RF feedback parameters (e.g., S-parameters, DR values at one or more frequencies, etc.). The computed RF feedback may be correlated with one or more processing states of the object. The computed RF feedback may be monitored during the processing to detect the one or more processing states of the object.

[0009] Some exemplary embodiments of the invention disclosing a method and apparatus for determining a correlation between a processing state of an object and RF feedback. Determining the correlation may be done during processing of the object. An indication of one or more processing states of the object may be received during processing of the object. The indication may be received from at least one sensor and/or inspected by a user and received from a user interface. RF energy may be applied to an energy application zone and RF feedback may be received from the energy application zone (in response to the RF energy application) during the processing of the object. A correlation between the RF feedback and the one or more processing states of the object may be determined (by a controller).

[0010] Some other exemplary methods and apparatus may include applying RF energy to detect a processing state of an object placed in an energy application zone, during processing of the object. RF energy may be applied to the object during processing, optionally using an RF energy application unit comprising at least one radiating element, configured to apply energy to the object in order to generate RF feedback. A computed RF feedback, correlated with one or more processing states of the object may be received, by at least one controller. The controller may further be configured to monitor the computed RF feedback during the processing to detect the one or more processing states of the object. Optionally the computed RF feedback may comprise one or more results of mathematical manipulation on two or more directly measurable values of the RF feedback.

[0011] In some embodiments the method (executed by the controller) may further include receiving a correlation between the computed RF feedback and the processing state of the object. The correlation may be used to detect the one or more processing states of the object. The correlation between the computed RF feedback and the processing state of the object may be received from a memory associated with a controller. The controller may be further configured to cause the application of RF energy to the object during processing. Additionally or alternatively the correlation between the computed RF feedback and the processing state of the object may be received from a machine readable element associated with the object and may further be used to determine the one or more processing states of the object.

[0012] In some embodiments processing the object may include applying heat to the object, from a heat source. The controller may cause and/or control the heat application. Applying heat may include heating the object using convection heating source. Alternatively or additionally heat may be applied via IR heating. In some embodiments RF energy may be applied from an RF source to also to heat the object, optionally in addition to other heating source(s) (e.g., IR, convection, et.). The controller may be configured to cause application of RF energy at a plurality of excitation setups. The controller may control the application of the RF energy to heat the object at a first power level and control the application of the RF energy to receive the computed RF feedback is at a second power level, such that the first power level is higher than the second power level. Optionally RF energy is applied to heat the object at a first average amount of energy per excitation setup and to receive the computed RF feedback at a second average amount of energy per excitation setup, such that the first average amount of energy per excitation setup is higher than the second average amount of energy per excitation setup.

[0013] In some embodiments the processing state of the object may be associated with a phase of the object and/or associated with a phase of the object and/or a physical property of the object and/or a chemical property of the object. In cases where the object is a food item the one or more processing states include cooking states, for example, degree of doneness.

[0014] In some embodiments the controller may further control the processing of the object based on the one or more detected processing states of the object. The controller may further terminate the processing of the object when the one or more processing states reach a target value.

[0015] In some embodiments the computed RF feedback may be received from at least one detector configured to detect the computed RF feedback. Additionally or alternatively the at least one detector may be configured to detect RF feedback, and the computed RF feedback may be calculated based on one or more values of the RF feedback by the at least one controller. In some embodiments the detector may be associated with the radiating element. The computed RF feedback may include an indication of EM energy absorbability of the object. The controller may calculate the computed RF feedback from one or more values of an RF feedback. Optionally the received computed RF feedback may include mathematical manipulation of at least two of reflected energy, coupled energy, incident energy, S parameters or input impedance.

[0016] Some embodiments of the invention may include a display and wherein the at least one controller is configured to display a representation of the one or more processing states on the display. The display may comprise a visual display configured to display a visual representation of the one or more processing states. Additionally or alternatively the display may comprise an audio component configured to provide an audio representation of the one or more processing states.

[0017] In some embodiments the apparatus may further comprise an interface configured to receive information. The information received may include an indication of the processing state of the object. Additionally or alternatively the information may include at least one energy application protocol. In some embodiments the information may be recorded on a machine readable element and the interface may be configured to read the information from the machine readable element.

[0018] Some other aspects of the invention may be related to a machine readable element, comprising a data storage portion including one or more stored values of computed RF feedback each indicative of a processing state of the object. Optionally the one or more stored values may include values indicative of EM energy absorbability indicator of the object.

[0019] Some exemplary embodiments of the invention may include a method for processing an object placed in an energy application zone. The method may comprise applying RF energy to receive computed RF feedback; monitoring the computed RF feedback during the processing, wherein the computed RF feedback is correlated with one or more pro-

cessing states of the object; and terminating the processing of the object when the computed RF feedback reaches a target value. Processing the object may include applying heat (e.g., via convection heating or IR heating) to heat the object.

[0020] Some aspects of the invention may be related to a machine readable element including data indicative of instructions for at least one controller to control processing, in an energy application zone, of an object associated with the machine readable element, the instructions may be configured to cause the at least one controller to: apply energy to the energy application zone according to a first protocol and during a first time period before RF feedback received from the energy application zone meets a criterion; and apply energy to the energy application zone according to a second protocol and during a second time period after RF feedback received from the energy application zone meets the criterion.

[0021] In some embodiments applying energy may include applying RF energy via at least one radiating element. Additionally or alternatively applying energy may include applying IR energy and/or applying convection heating.

[0022] In some embodiments the RF feedback received from the energy application zone may provide an indication of EM energy absorbability of the object.

[0023] In some embodiments the data indicative of instructions may include the criterion; optionally the criterion may include a threshold value for the RF feedback. Additionally or alternatively the data indicative of instructions may include at least one of the first protocol and the second protocol. In some embodiments data may include an identity of the object and optionally the instructions may further be configured to cause the at least one controller to select the first protocol according to the identity of the object. Alternatively the instructions may be configured to cause the at least one controller to select the first protocol according to the received RF feedback.

[0024] In some embodiments the instructions may further be configured to cause the at least one controller to select the first protocol according to an initial processing state of the object. Optionally the instructions may be configured to cause the at least one controller to determine the initial processing state of the object based on RF feedback received from the energy application zone.

[0025] In some embodiments the second protocol includes terminating the EM energy application. Optionally the at least one of the first and second protocols may include selecting one or more excitation setups from a plurality of excitation setups, and applying RF energy at the selected one or more excitation setups and/or parameters for applying RF energy. In some embodiments the at least one of the first and second protocols is a default protocol and wherein the data indicative of instructions may comprise an instruction to use the default protocol.

[0026] In some embodiments the RF feedback is correlated to a processing state of the object that changes during EM energy application. Optionally the processing state of the object that changes during EM energy application is indicated by one or more of: temperature, moisture, humidity, pressure, chemical composition, volume, weight, color, doneness level, density, taste or crispiness.

[0027] Some additional aspects of the invention may involve a method and an apparatus for controlling energy application for processing an object in an energy application zone. A controller may cause energy application to the energy application zone according to a first protocol during a first time period before an RF feedback received from the energy application zone may meet a criterion and then cause energy application according to a second protocol during a second time period after an RF feedback received from the energy application zone in the presence of the object meets the criterion. Optionally the criterion may include a threshold value for the RF feedback.

[0028] In some embodiments data indicative of instructions for processing the object may be read, from a machine readable element associated with the object, and the controller may further control the energy application according to the instructions. In some embodiments the instructions may include at least one of the first protocol and the second protocol. The at least one of the first and second protocols may include selecting at least one excitation setup from a plurality of excitation setups, and applying RF energy at the selected at least one excitation setup. Additionally or alternatively the at least one of the first and second protocols may include parameters for applying RF energy at a plurality of excitation setups. In some embodiments the at least one of the first and second protocol may be a default protocol and wherein the data indicative of instructions may comprise an instruction to use the default protocol.

[0029] In some embodiments the criterion may be read from the machine readable element.

[0030] Some embodiments may further include associating the data read from the machine readable elements with information stored in a memory. Optionally the memory may be accessible via a communication network.

[0031] In some embodiments the RF feedback comprises a value indicative of EM energy absorbable by the object.

[0032] In some embodiments energy application may include applying RF energy. Additionally or alternatively applying energy may include at least one of: applying IR energy or applying convection heating.

[0033] In some embodiments an initial processing state of the object may be determined based on RF feedback received from the energy application zone. Additionally the first protocol may be selected based on the determined initial processing state of the object. Alternatively the initial processing state of the object may be determined based on data read from the machine readable element.

[0034] In some embodiments the second protocol may include terminating the energy application.

[0035] Some embodiments may include identifying the object. Optionally the first protocol may be selected according to the identity of the object.

[0036] In some embodiments a processing state of the object, which changes during EM energy application, may be correlated to the RF feedback. The processing state of the object that changes during EM energy application may be indicated by one or more of: temperature, moisture, humidity, pressure, chemical composition, volume, weight, color, doneness level, density, taste or crispiness.

[0037] Some other embodiments of the invention may be related to a machine readable element to be associated with an object to be processed in an energy application zone, wherein the machine readable element may comprise data indicative of a criterion for changing RF energy application, via at least one radiating element, from a first protocol to a second protocol. Optionally criterion may be met when a value associated with RF feedback received from the energy application zone exceeds a threshold.

[0038] The drawings and detailed description which follow contain numerous alternative examples consistent with the

invention. A summary of every feature disclosed is beyond the object of this summary section. For a more detailed description of exemplary aspects of the invention, reference should be made to the drawings, detailed description, and claims, which are incorporated into this summary by reference.

BRIEF DESCRIPTION OF THE DRAWINGS

[0039] FIGS. **1**A and **1**B include diagrammatic representations of exemplary apparatuses for applying RF energy to an object, in accordance with some exemplary embodiments of the present invention;

[0040] FIGS. **2**A-**2**B include diagrammatic representations of cavities, in accordance with some exemplary embodiments of the present invention;

[0041] FIGS. **3**A and **3**B include flowcharts of two methods for controlling energy application to an energy application zone based on RF feedback, in accordance with some embodiments of the invention;

[0042] FIG. **3**C includes a flowchart of a method for correlating and recording a processing state of an object with RF feedback, in accordance with some embodiments of the invention;

[0043] FIG. **4** includes a flowchart of a method for controlling energy application to process an object based on a criterion, in accordance with some embodiments of the invention;

[0044] FIG. **5** includes a graphical representation of results obtained in a cooking experiment for correlating RF feedback (average DR) with cooking states of a vanilla cake according to some embodiments of the invention;

[0045] FIG. **6**A presents results from pizza thawing and baking experiments, in accordance with some embodiments of the invention;

[0046] FIG. **6**B represents a thawing protocol used in a thawing experiment in accordance with some embodiments of the invention;

[0047] FIG. **6**C represents a baking protocol used in a baking experiment in accordance with some embodiments of the invention;

[0048] FIG. **7** presents results from pizza baking experiments in accordance with some embodiments of the invention; and

[0049] FIGS. **8**A and **8**B are representations of recordable elements in accordance with some embodiments of the invention.

DETAILED DESCRIPTION

[0050] Reference will now be made in detail to exemplary embodiments of the invention, examples of which are illustrated in the accompanying drawings. When appropriate, the same reference numbers are used throughout the drawings to refer to the same or like parts.

[0051] In one respect, the disclosed embodiments may involve apparatuses and methods for applying EM energy. The term EM energy, as used herein, includes energy deliverable by EM radiation in all or portions of the EM spectrum, including but not limited to, radio frequency (RF), infrared (IR), near infrared, visible light, ultraviolet, etc. In one particular example, applied EM energy may include RF energy with a wavelength in free space of 100 km to 1 mm, which corresponds to a frequency of 3 KHz to 300 GHz, respectively. In some other examples, the applied EM energy may fall within frequency bands between 500 MHz to 1500 MHz or between 700 MHz to 1200 MHz or between 800 MHz to 1 GHz. Applying energy in the RF portion of the EM spectrum is referred herein as applying RF energy. Microwave and ultra high frequency (UHF) energy, for example, are both within the RF range. In some other examples, the applied EM energy may fall only within one or more industrial, scientific and medical (ISM) frequency bands, for example, between 433.05 and 434.79 MHz, between 902 and 928 MHz, between 2400 and 2500 MHz, and/or between 5725 and 5875 MHz. Even though examples herein are described in connection with the application of RF energy, these descriptions are provided to illustrate a few exemplary principles of the invention, and are not intended to limit the invention to any particular portion of the EM spectrum.

[0052] Some embodiments of the invention may be related to apparatuses and methods for processing object(s), optionally by applying heat to the object, from a heat source. Heat may be applied to thaw a frozen object, to cook or bake a food item, to accelerate a chemical reaction, to dry objects (e.g., clothes), to sinter parts (e.g., powder parts), to cure polymers, etc. The heat may be applied by a convection heat source, including, for example, a heating element, such as a filament. Additionally or alternatively, the heat may be applied from an IR source, for example, an IR lamp. Optionally, the heat may be applied from an RF source configured to supply RF energy, for example a magnetron or a solid-state power amplifier. In some embodiments, two or more types of heat sources may be used to process the object. Two or more types of heat sources may be applied simultaneously or sequentially, or both. For example, RF energy and convection heating may be applied simultaneously for part or all of the time energy is applied to process the object. In some embodiments, the different energy sources may be applied alternately or consecutively. The application is not limited to any particular heat source or sources.

[0053] In some embodiments, RF energy may be applied to sense (i.e., detect, monitor, etc.) one or more processing states of an object before, during and/or after processing of the object. In some embodiments, the processing state may be sensed (detected) by monitoring RF feedback. The RF feedback may be received in response to the RF energy application. RF energy application apparatuses for sensing one or more processing states of an object are diagrammatically presented in FIGS. **1**A and **1**B. In some embodiments, RF energy may be applied to object **103** before the processing, to detect and determine the initial state of object **103**. RF energy may be applied to object **103** during processing, for example, in order to monitor changes in the object that occur due to the processing (e.g., heating) of the object. Some examples of such changes may include a phase change (e.g., thawing of a frozen object), pH change due to a progress of a reaction in a reactant solution, polymerizing of polymers due to curing, denaturation of proteins (e.g., in cooking of egg-based dishes and pastries and cooking of meat), various cooking states (e.g., baking of dough), etc. Those changes may be associated with one or more processing states of the object. The RF energy may also be applied near or at the end of the processing, for example, in order to determine if the process should be terminated.

[0054] In some embodiments, RF energy may be applied (e.g., in apparatus **100**) to correlate between a processing state of object **103** (e.g., indicated by at least one processing state indicator) with RF feedback received from an energy application zone during processing of the object. A processing

state indicator may include any mechanism that is configured to convey to the controller information regarding the processing state of the object. For example, the processing state indicator may comprise or be one or more sensors configured to sense one or more conditions, attributes, etc. indicative of the processing state of the object, e.g., a temperature sensor, a humidity sensor etc. Additionally or alternatively, the processing state indicator may comprise or be a user interface configured to receive from a user an indication of the processing state of the object and convey this indication to the controller.

[0055] The indication of the processing state may be sensed by one or more sensors provided in the energy application zone or may be provided by a user through an interface. An indication of a processing state may include any measurements of a physical or chemical properties of the object either quantitatively (e.g., temperature, pressure etc.) or non-quantitatively (e.g., color, degree of doneness, taste, cooking state, etc.) of an object before, during or after processing of the object. The indication of the processing state may be measured (sensed) by a sensor (e.g., sensor **140**) or may be determined through inspection by a user. Apparatus **100** may further include a first user interface (e.g., interface **160**) configured to receive from a user an indication of the processing state of the object. Some examples of quantitatively variable indicative of the processing state of the object may include: temperature, humidity, pressure, flow rate, pH, chemical composition, density, weight, volume, etc. Some examples of non-quantitatively measurable variable indicative of the processing state may include: color, taste, cooking state, doneness level etc. As used herein, cooking state may refer to any possible state of an object, either desired or undesired, that may occur relative to a food item during any form of cooking/processing (e.g., roasting, baking, boiling, steaming, grilling, slow cooking, thawing, browning, dough proofing etc.) of the food item. Some examples for cooking states may include: the end of baking of dough, the beginning and end of softening stage in slow cooking of meat or cooking of starchy vegetables, end of proofing of yeast dough, end of browning of various baking products, degree of doneness of various meats, or degree of any other type of cooking process, etc.

[0056] Sensing (i.e., detecting, monitoring, etc) one or more processing states of an object may be performed by applying RF energy to an energy application zone, e.g., zone **102** in order to receive RF feedback from the object. The RF feedback may be correlated with the one or more processing states of the object. Method **330** for correlating RF feedback and one or more processing states of the object is described in reference to FIG. **3**C. The correlation may be recorded, for example, on a memory associated with apparatus **100** (e.g., a memory associated with controller **150**) or on a machine readable element (e.g., a barcode).

[0057] As used herein, RF feedback may include any received RF signal or any value calculated based on one or more received RF signals, which may be indicative of the dielectric response of the cavity and/or the object to EM fields excited in the cavity. RF feedback may be excitation setup-dependent and may include, for example, values that vary over different excitation setups. RF feedback may include raw RF feedback and computed RF feedback. The raw RF feedback may include directly measurable parameters, for example, input and output power levels, field intensities, network parameters, e.g., scattering (S) parameters of the cavity, admittance (Y) parameters, reflection and transmission coefficients, impedances, etc. The computed RF feedback may include a result of any mathematical manipulation on two or more directly measurable parameters or values, for example, sums, multiplicative products, ratios, and/or differences between directly measurable parameters, dissipation ratio values (DR) (as discussed below), averages (e.g., time-average and/or excitation setup-average), of directly measurable parameters or of computed parameters; derivatives (e.g., time derivatives and/or excitation setup derivatives) of directly measurable parameters or of computed parameters, etc. The concept of excitation setups is broadly discussed below.

[0058] In some embodiments, RF feedback may be responsive to RF energy (i.e., EM energy in the RF range) application. RF energy may be applied to an energy application zone at least partially occupied by an object. The RF energy applied to receive the RF feedback may be at relatively low energy amounts, e.g., at a low power level. As used herein, low energy amounts may refer to amounts of energy that result in little or no processing of an object or that are otherwise too low to provide a desired degree of a processing. For example, in some embodiments, a low energy amount may be insufficient to cause a change (or a change of a certain degree) in at least one detectable processing state of the object. In some embodiments, applying RF energy to process (e.g., heat) the object may be at a first average amount of energy per excitation setup and applying RF energy to receive the RF feedback may be at a second average amount of energy per excitation setup, and the first average amount of energy per excitation set is higher than the second average amount of energy per excitation setup.

[0059] The RF feedback may include signal(s) received in response to the RF energy application by detectors (e.g., detectors **118**, **118***a*, **128**, **138**) or sensors (e.g., sensor **140**) placed in or around the energy application zone. The signal(s) may include any or all directly measurable parameters associated with the RF energy application. Energy may be supplied to at least one radiating element (e.g., element **110** illustrated in FIGS. **1**A and **1**B), and energy may be reflected back from the energy application zone to the emitting radiating element in response to the application of the RF energy. Additionally or alternatively, energy may be coupled to other radiating elements (e.g., element **111** illustrated in FIG. **1**A and elements **120** and **130** illustrated in FIG. **1**B). Various examples of RF feedback that may be received in response to RF energy application are discussed below.

[0060] In some embodiments, the processing of the object (e.g., by applying energy to the object) may be controlled based on the received RF feedback and/or the detected processing state. For example, the amount of energy (e.g., the temperature of a conventional cooking oven or the power level in a microwave oven) or the duration of the energy application (e.g., the length of time of the energy application) may be determined based on the received RF feedback (e.g., computed RF feedback). In an exemplary embodiment, computed RF feedback may be monitored during the application of heat in a conventional oven (e.g., during baking). The computed RF feedback may be monitored during heating of the food item at a first temperature (e.g., 180° C.) until the computed RF feedback indicate(s) that the food item has been cooked to a certain degree, after which, the heat application may be terminated.

[0061] In some embodiments, a protocol in which energy is applied to process the object may be determined based of an

RF feedback (e.g., computed RF feedback). As use herein, a protocol may include one or more of the parameters that controls the energy application, for example, the temperature and the duration of heating in a convection heating (for example: heating at temperature T_1 for S_1 seconds followed by heating at temperature T_2 for S_2 seconds etc.), the power and the time IR heating. When RF energy is applied to process the object—the protocol may include: setting RF energy levels (e.g., power levels and/or time durations) and/or selecting one or more excitation setups from a plurality of excitation setups, and applying RF energy at the selected excitation setups, one or more rules for energy application as a function of the RF feedback etc. Energy may be applied to process an object using a first protocol (e.g., temperature and time may be set to cook a food item). RF feedback may be monitored during the energy application until one or more RF feedback value reaches a threshold value (i.e., a first criterion) indicative of a first processing state of the object (e.g., the food item is cooked). After the RF feedback value reaches the threshold value, a second protocol may be applied by elevating the temperature (e.g., to 220° C.) for a short period of time in order to brown the food item. The processing (e.g., heating) may be terminated (i.e., a third protocol) when the monitored RF feedback indicates that the one or more states (e.g., a second state) of processing have reached a target value or a second criterion (e.g., a desired temperature, or a desired degree of doneness, or a target pH, etc.) was met. Exemplary methods **300** and **310** for controlling energy application to an object based on RF feedback are disclosed in FIGS. **3**A and **3**B and exemplary method **400** for controlling RF energy application based on a criterion is disclosed in FIG. **4**.

[0062] In certain embodiments, RF energy may be applied (e.g., to sense at least one processing state of an object) in an energy application zone. For example, RF energy may be applied to the energy application zone, such as energy application zone **102**, illustrated in FIGS. **1**A and **1**B. As indicated above, other energy types (e.g., convection and/or IR) may be applied to the zone in order to process the object. Energy application zone **102** may include any cavity, void, location, region, or area where energy may be applied to process the object. In some embodiments, RF energy may be applied to sense and/or detect a processing state of the object. The zone may be hollow, or may be filled or partially filled with liquids, solids, gases, or combinations thereof. By way of example only, energy application zone **102** may include an interior of an enclosure, interior of a partial enclosure, open space, solid, or partial solid that allows existence, propagation, and/or resonance of EM waves. Zone **102** may include a conveyor belt or a rotating plate. In some embodiments, zone **102** may include or be a cavity (for example: exemplary cavity **200** as illustrated in FIG. **2**A).

[0063] In certain embodiments, EM energy may be applied to sense and detect a processing state of an object, e.g., object **103** in FIG. **1**A, placed in the energy application zone, e.g., energy application zone **102**. An object may be considered in the energy application zone if at least a portion of the object is located in the zone or if some portion of the object receives applied EM radiation. The type of object to which EM energy may be applied for processing is not limited to a particular form of the object. An object may include a liquid, semi-liquid, solid, semi-solid, or gas, depending upon the particular process with which the disclosed embodiment is utilized. The object may also include composites or mixtures of matter in differing phases. Thus, by way of non-limiting example, the term object may encompass such matter as food to be defrosted or cooked; clothes or other wet material to be dried; frozen organs to be thawed; chemicals to be reacted; fuel or other combustible material to be combusted; hydrated material to be dehydrated, gases to be expanded; liquids to be heated, boiled or vaporized, or any other material for which there is a desire to apply, even nominally, energy (e.g, EM energy).

[0064] In some embodiments, a portion of RF energy applied to energy application zone **102** may be absorbed (dissipated) by object **103**. In some embodiments, another portion of the EM energy applied to energy application zone **102** may be absorbed by various elements (e.g., food residue, particle residue, additional objects, structures associated with zone **102**) or any other EM energy-absorbing materials found in zone **102** or associated with energy application zone **102**. Energy application zone **102** may also include loss constituents that may not, themselves, absorb an appreciable amount of EM energy, but otherwise account for EM energy losses. Such loss constituents may include, for example, cracks, seams, joints, door(s), interface between cavity body and a door, or any other loss mechanisms associated with energy application zone **102**. Thus, in some embodiments, energy dissipated in the zone may include energy dissipated in at least a portion of object **103** along with any EM energy-absorbing constituents in the energy application zone as well as any EM energy loss constituents associated with the zone.

[0065] Exemplary energy application zone **102** may include locations where energy is applied: an oven (e.g., a cooking oven), chamber, tank, dryer, thawer, dehydrator, reactor, engine, chemical or biological processing apparatus, pipe (e.g., fuel pipe), furnace, incinerator, material shaping or forming apparatus, conveyor, combustion zone, filter, cooler, freezer, etc. In some embodiments, the energy application zone may be part of a vending machine, in which objects are processed once purchased.

[0066] FIGS. **1**A and **1**B include diagrammatic representations of an apparatus **100** for applying RF energy to an object (e.g., to detect one or more processing states of the object) placed in zone **102**, for example during processing of the object. RF energy may include EM energy applied at frequencies in the RF range. Apparatus **100** may include at least one radiating element **110** configured to apply RF energy to energy application zone **102**. Radiating element **110** may include any element, system, array of elements, etc. designed or configured to transmit (emit) RF energy. For example, radiating element **110** may include: any antenna, an array of antennas, an RF feed, a waveguide, a slow wave antenna, a patch antenna, inverted F antenna, etc. in any combination or numbers thereof. In the presently disclosed embodiments, more than one antenna and/or a plurality of radiating elements (e.g., antennas) may be provided (e.g., radiating elements **110** and **111** illustrated in FIG. **1**A or radiating elements **110**, **120** and **130** illustrated in FIG. **1**B). Energy application zone **102** may include an enclosure with defining surfaces. The radiating elements may be located on one or more of the surfaces that define zone **102** (e.g., cavity walls). For example, radiating elements **110** and **130** may be located on two different (e.g., opposing) surfaces of energy application zone **102**. In some embodiments, one or more of the radiating elements may be located inside zone **102** (e.g., element **130**) or partially located inside zone **102** (e.g., elements **110** and **111**). Additionally or alternatively, a radiating element may be located outside the energy application zone

(e.g., element **120**). One or more of the radiating elements (e.g., element **130**) may be near, in contact with, in the vicinity of or even embedded in object **103** (e.g., when the object includes a liquid, or a filter, for example—radiating element **204***c* illustrated in FIG. **2**A). The orientation, type, dimensions and/or configuration of each radiating element may be distinct or the same, based on a specific application, e.g., based on a desired target effect. Each radiating element may be positioned, adjusted, and/or oriented to emit EM waves along a same direction, or various different directions. Furthermore, the location, orientation, and configuration of each radiating element may be predetermined before applying energy to the object. Alternatively or additionally, the location, orientation, and/or configuration of each radiating element may be dynamically adjusted, for example, by using a controller (e.g., controller **150**), during operation of the apparatus and/or between rounds/cycles of energy application. Radiating elements of any structure or configuration may be used with the disclosed embodiments.

[0067] As shown in FIG. **1**A, apparatus **100** may include at least one radiating element **110** for emitting RF energy to energy application zone **102** and at least one radiating element **111** may be configured to receive EM energy from energy application zone **102**. A radiating element may function as an emitter, a receiver, or both, depending on a particular application or configuration. When a radiating element acts as a receiver of RF energy from an energy application zone (e.g., received reflected and/or coupled EM waves), the radiating element receives RF energy from the energy application zone or from other radiating elements. In some embodiments, radiating element **110** may function as emitter and receiver.

[0068] Some aspects of the present invention may involve detecting, measuring, monitoring or sensing: RF energy emitted from the radiating element to energy application zone **102**, RF energy supplied to the emitting radiating element, or RF energy received by the radiating element(s) (e.g., elements **110** and **111**) from the energy application zone, to detect one or more processing states of the object. A detector configured to measure and/or detects and/or calculate various RF feedback of the emitted and/or received (e.g., reflected or coupled) RF energy may be associated with at least one radiating element. In some embodiments, the detector may include a directional coupler associated or connected to a radiating element. The detector may detect and/or measure RF feedback (e.g., raw RF feedback) related to the RF energy emitted and/or received. The raw RF feedback may be associated with one or more processing states of the object. The raw RF feedback may include all detectable parameters of the RF emission, for example: power, frequency, energy, current, voltage, phases between emissions, etc. For example, detector **118**, illustrated in FIG. **1**A, may be associated with radiating element **110** and **111**. Detector **118** may be configured to measure or detect one or more parameters related to element **111**, for example, responsive to the RF energy emission from element **110**. In some embodiments, detector **118** may be configured to detect the parameters of the RF energy received from zone **102** (e.g., reflected back) to element **110** as a result of the RF energy emission from element **110**. Detector **118** may also include suitable types of circuits or devices that measure the voltage and current at the ports of radiating elements **110** and **111**. In some embodiments, detector **118** may include a directional coupler, configured to allow signals to flow from the RF source (e.g., source **112**) to the radiating elements when the radiating elements function as emitters, and to allow signals to flow from the radiating elements to the detector when the radiating elements function as receivers. Detector **118** may further include a controller configured to perform mathematical manipulation of the raw RF feedback to receive (obtain) a computed RF feedback. Alternatively or additionally, the computed RF feedback may be calculated by controller **150** and the detector may send the raw RF feedback to controller **150** for further manipulation.

[0069] In some embodiments, detector **118** may be associated with two elements (e.g., elements **110** and **111**). In some embodiments, each element may be associated with a detector. For example, elements **110**, **120** and **130** may be associated with detectors **118***a*, **128** and **138** illustrated in FIG. **1**B. Detectors **118***a*, **128** and **138** may be configured to detect RF energy parameters of both the emitted and the received RF energy from zone **102**. For example, RF energy may be emitted from element **110** to zone **102**. As a result, a portion of the RF energy may be absorbed by or dissipated in object **103**, and another portion may be reflected back or coupled from zone **102** and received by elements **110**, **120** and **130**.

[0070] Consistent with some disclosed embodiments, RF energy may be supplied to one or more emitting radiating elements from RF source **112**. Energy supplied to the emitting radiating element (e.g., element **110**) from RF source **112** may be referred to as supplied energy and denoted as SE.

[0071] Some of the supplied RF energy may be absorbed by the object (e.g., object **103**). This portion of energy may be referred to as absorbed energy or dissipated energy and denoted as AE.

[0072] A portion of the supplied RF energy may be reflected back to the emitting element (e.g., element **110**). This portion of energy may be referred to as reflected energy and denoted as RE. The reflected energy may be reflected at the interface between the radiating element and the energy application zone. Alternatively or additionally, the reflected energy may include energy that is reflected from the energy application zone (e.g., due to impedance mismatch), for example, from the object or from a wall defining the zone, etc.

[0073] Other portions of the supplied energy may be coupled to other radiating elements or sensors in the energy application zone (for example, receiving radiating elements—e.g., element **111**, another emitting radiating element (e.g., **120** and **130**), a sensor (e.g., sensor **140**)) and may be referred to as coupled energy and denoted as CE.

[0074] In some embodiments, the supplied RF energy (SE) may include energy that is reflected (RE) back to the emitting radiating element, absorbed (AE) in the object, and coupled (CE) to one or more of other radiating element(s). Equation (1) may represent a relationship between quantities SE, RE, AE, and CE, as follows:

$$SE=RE+AE+CE \tag{1}$$

[0075] The difference between the amount of energy supplied to a radiating element and the amount of energy reflected back to that radiating element may be referred to as delivered energy and may be denoted as DE. One or more detectors (e.g., detector **118**, **118***a*, **128** and **138**) may be configured to detect and measure the supplied, reflected, and coupled energy values, and a controller (e.g., controller **150**) may be configured to determine the delivered and/or absorbed

amounts of energy, for example, based on equation (1). This may result in the following equations:

$$AE=SE-(RE+CE) \quad (2a)$$

$$DE=SE-RE \quad (2b)$$

$$DE=AE+CE \quad (2c)$$

[0076] Apparatus **100** may further include a source for supplying RF energy to the radiating element(s). For example, source **112** may supply RF energy to emitting element **110**, source **122** may supply RF energy to emitting element **120**, and source **132** may supply RF energy to emitting element **130**.

[0077] In accordance with some embodiments of the invention, an apparatus or method may involve the use of at least one source configured to supply RF energy to the energy application zone. A source may include any component(s) that may be suitable for generating and supplying RF energy. For example, source **112** may include an RF power supply (e.g., power supply **113**). In yet another example, the source may include more than one power supply (e.g., **113**, **123** and **133**). Each of the power supplies may be configured to generate EM waves that carry EM energy. For example, power supply **113** (or **123** or **133**) may include a magnetron configured to generate high power microwaves at a predetermined wavelength or frequency. Alternatively or additionally, power supply **113** (or **123** or **133**) may include a semiconductor oscillator, e.g., a voltage controlled oscillator, configured to generate AC waveforms (e.g., AC voltage or current) with a controllable frequency. The frequency may be controlled to be constant or to vary. AC waveforms may include sinusoidal waves, square waves, pulsed waves, triangular waves, or another type of waveforms with alternating polarities. Alternatively or additionally, a source of RF energy may include any other power supplies, e.g., EM field generator, EM flux generator, or any mechanism for generating vibrating electrons. The source may include a solid state amplifier.

[0078] Consistent with some embodiments, RF energy may be supplied to the energy application zone in the form of propagating RF waves at predetermined wavelengths or frequencies (also known as RF radiation). As used herein, propagating RF waves may include resonating waves, traveling waves, evanescent waves, and waves that travel through a medium in any other manner. RF radiation carries energy that may be imparted to (or dissipated into) matter with which it interacts.

[0079] In some embodiments, the source (e.g., source **112**, **122** or **132**) may further include at least one modulator (e.g., modulator **115**, **125** or **135**) and/or at least one amplifier (e.g., amplifier **116**, **126** or **136**). The modulator may include a phase modulator, a frequency modulator, an amplitude modulator, an oscillator or any other modulator configured to modulate at least one aspect of the RF energy supplied to the radiating element. The amplifier may include any apparatus configured to change (e.g., amplify) the amplitude of the RF waves supplied by the power supply. It is to be noted that the source (e.g., source **112**, **122** or **132**) may include only one component or more than one component or any combination of components according to the requirements of particular embodiment. The power supply, the modulator, and/or the amplifier may each be controlled by a controller (e.g., controller **150**), as will be discussed in greater detail below.

[0080] Apparatus **100** may further include at least one sensor, such as sensor **140**. Sensor **140** may be installed in or around energy application zone **102**. In some embodiments, sensor **140** may constitute an exemplary processing state indicator. Sensor **140** may be configured to detect and/or measure RF feedback in accordance with some embodiments of the invention. For example, sensor **140** may be configured to monitor the intensity of EM field excited in the energy application zone. Additionally or alternatively, sensor **140** may be configured to detect and/or measure other signals or feedback indicative of one or more processing states of the object or the energy application zone. For example, sensor **140** may include a thermometer configured to measure a temperature associated with the object and/or the energy application zone (e.g., a thermocouple or an IR sensor). Sensor **140** may include a humidity sensor, a pressure sensor (e.g., a barometer), a pH sensor configured to measure the pH value of a solution (e.g., when the object comprises liquids), a flow meter, etc. Sensor **140** may be configured to measure the weight of at least a portion of the object (e.g., a scale). Sensor **140** may be configured to measure any detectable and measurable property (e.g., an indicator for the processing state) of the object or the energy application zone. Sensor **140** may be configured to send feedback signals to controller **150**. In some embodiments, two or more sensor **140** may be provided. The two or more sensors **140** may include one or more different types or the same types of sensors (e.g., a temperature sensor, fiber optics for detecting temperature, a weight sensor, etc. may be provided). Some aspects of the invention may involve correlating, e.g., by controller **150**, the signal(s) detected at sensor **140** that are indicative of the processing state of object **103**, with RF feedback sensed, monitored or detected by detectors **118**, **118***a*, **128** and/or **138**, in parallel or in addition to the signal(s) received from sensor **140**.

[0081] In some embodiments, apparatus **100** may include a controller (e.g., controller **150**). Controller **150** may be coincident with or may be part of processor. As used herein, the term "processor" may include an electric circuit that performs a logic operation on input or inputs. For example, such a processor may include one or more integrated circuits, microchips, microcontrollers, microprocessors, all or part of a central processing unit (CPU), graphics processing unit (GPU), digital signal processors (DSP), field-programmable gate array (FPGA) or other circuit suitable for executing instructions or performing logic operations.

[0082] The instructions executed by the controller (e.g., one or more scripts or energy protocols) may, for example, be pre-loaded into a memory unit integrated with or embedded into the controller or may be stored in a separate memory unit, such as a RAM, a ROM, a hard disk, an optical disk, a magnetic medium, a flash memory, other permanent, fixed, or volatile memory, or any other mechanism capable of storing instructions for the controller. The separate memory unit may or may not be a part of the controller. The controller may be customized for a particular use, or can be configured for general-purpose use and can perform different functions by executing different software.

[0083] If more than one controller or processor is employed, all may be of similar construction, or they may be of differing constructions electrically connected or disconnected from each other. They may be separate circuits or integrated in a single circuit. When more than one controller or processor is used, they may be configured to operate independently or collaboratively. They may be coupled electrically, magnetically, optically, acoustically, mechanically or by other means permitting them to interact.

[0084] An apparatus according to some embodiments of the invention may include one or more RF energy application units, for example units **119**, and **119***a*, illustrated in FIGS. **1**A and **1**B. An energy application unit (e.g., unit **119***a*) may include one or more radiating elements, e.g., elements **110**, **120** and **130**, and an RF energy source supplying RF energy to the radiating element(s). In some embodiments, RF energy application unit **119***a* may include two or more synchronized RF energy sources, e.g., sources **112**, **122** and **132**, which may be controlled by, for example—by controller **150**, to supply to the radiating elements signals having a common frequency, at a controlled phase difference, at a controlled amplitude difference, etc. In some embodiments, unit **119***a* may include two or more non-synchronized RF energy sources. In some embodiments, the effect of applying energy from one or more of the RF energy application units in series or during non-overlapping or partially overlapping time periods may result in substantially the same as the effect as applying energy from one or more or all of the RF energy application units simultaneously. Embodiments consistent with the present invention may include one or more energy application units.

[0085] An RF energy application unit according to some embodiments may apply energy at two or more different excitation setups. Applying energy at different excitation setups may result in excitation of different field patterns in energy application zone **102**. The excitation setups (ES) may differ from one another by one or more values of parameters that may affect the field pattern and may be controlled by controller **150**. Such a parameter is referred to herein as a controllable field affecting parameter (c-FAP). In some embodiments, a value may be selected for each c-FAP, and the excitation setup may be defined by the selected values. Varying a selected value of even one c-FAP may vary the excitation setup, which, in turn, may vary the field pattern excited in the energy application zone.

[0086] In some cases, varying values of c-FAPs may result in significant variations in the generated field patterns. In other instances, however, varying values of c-FAPs may produce little or no change in the generated field patterns (e.g., if the variation between the two values of the c-FAP is small).

[0087] To obtain a mental image of an excitation setup and how it may be set, one may imagine an RF energy application unit according to some embodiments of the invention to be controlled from a switchboard. The switchboard may include a set of knobs, dials, switches, or other value-selectors, each for determining the value of (or selecting a value for) one c-FAP. Switching from one excitation setup to another may be accomplished by manipulating one (or more) of the value-selectors to select a different value. The position of all the value selectors collectively (e.g., the positions of all the knobs, dials and switches collectively) may define a single excitation setup. While this mental image may be helpful, in practice, an RF energy application unit may be controlled by a controller, which may set the values of the available c-FAPs by using micro-switches, transistors, electronic circuitries, and other value selectors, which may look differently than knobs and dials.

[0088] Applying energy at a particular excitation setup may excite an EM field in energy application zone **102**. For brevity, this EM field may be referred to as an excitation. Thus, each excitation setup may correspond to an excitation, and a reference to supply, reception, absorption, leaking, etc. of an excitation setup may refer to supply, reception, absorption, leaking, etc. of the corresponding excitation. Thus, for example, a statement that a given excitation or excitation setup is absorbed in the object may mean that an EM field excited by the energy application unit (e.g., unit **119**) at the given excitation setup results in energy absorbed in the object.

[0089] Different apparatuses may be able to control different field affecting parameters. For example, in some embodiments, controller **150** may control the frequency of an EM wave applied by energy application unit **119** to energy application zone **102**. In such embodiments, the frequency may be available as a controllable field affecting parameter (c-FAP). In one example, controller **150** may control the frequency to have any of two or more values, e.g. 800 MHz, 800.5 MHz, etc. By controlling the frequency and changing from one frequency value to another, the excitation setup may be changed, which, in turn, may change the field pattern excited in the energy application zone.

[0090] In another example, an energy application unit (e.g., unit **119***a*) may include two radiating elements (e.g., elements **110**, **120** and **130**) that emit radiation at a controllable phase difference. The phase difference may be controlled, by controller **150**, to have two or more values, e.g., 0°, 90°, 180°, or 270°. The phase difference between EM fields emitted by the two radiating elements may be available to the apparatus comprising the energy application unit as a c-FAP.

[0091] In another example, a difference between intensities at which two radiating elements emit EM fields of the same frequency may be controlled, and thus may be available as a c-FAP.

[0092] In another example, an energy application zone (e.g., zone **102**) may include one or more conductive elements (e.g., rods), each of which may be controlled, e.g., by controller **150**, to be either in a parasitic state or in a connected state. The value of the state of each rod (i.e. parasitic or connected) may affect the EM field pattern excited in the energy application zone. In apparatuses having such rods, the state of each rod may constitute a c-FAP.

[0093] In another example, an energy application zone may include a magnetizable element (e.g., at a wall of the energy application zone) and an electromagnet near the magnetizable element. The magnetizable element and the electromagnet may be arranged such that a field pattern excited in the energy application zone may be affected by current flowing in the electromagnet. In some embodiments, controller **150** may be configured to control the value of the current in the electromagnet (e.g., 1 mA, 20 mA, 500 mA, etc.). The value of the current may be available as a c-FAP.

[0094] In another example, energy application unit **119***a*, illustrated in FIG. **1**B may include a plurality of radiating elements **110**, **120** and **130**, and each may be turned on or off. In such embodiments, the status of each radiating element (i.e., on or off) may be available as a c-FAP. Additionally, or alternatively, the total number of radiating elements turned on may constitute a c-FAP.

[0095] Other examples of parameters that may serve as controllable field affecting parameters in some embodiments may include the position of a radiating element, orientation of a radiating element, cavity dimensions, or any other controllable parameter, the value of which may affect the field pattern excited in the energy application zone upon RF energy application to the zone.

[0096] Excitation setups (ES) of apparatuses configured to control only a single c-FAP may be referred to as one-dimensional excitation setups. An excitation setup of an apparatus that controls multiple c-FAPs may be referred to as multi-

dimensional excitation setup. In general, the number of c-FAPs available to an apparatus determines a dimension of the excitation setups available to the apparatus. The collection of all the excitations that may be excited by an apparatus (or the collection of all the excitation setups available to an apparatus) may be referred to as the excitation space of the apparatus. The dimension of an excitation space of an apparatus may be the same as the dimension of each excitation setup available to that apparatus.

[0097] In some embodiments, an RF energy application unit may be controlled by a controller (e.g., controller **150**), configured to control RF energy application based on an RF feedback.

[0098] Thus, in some embodiments, when RF energy is applied to heat the object as well as to sense a processing state of the object, RF energy application may be controlled such that one or more aspects of energy application at a given excitation setup (e.g., amount of energy, power level at which energy is applied, time duration at which energy is applied etc.) may depend on RF feedback received to the same excitation, to a different excitations, or over multiple excitations. At these embodiments, RF energy may be applied in an amount sufficient to process the object, i.e., in an amount sufficient to cause a change in at least one property (e.g., a processing state) of at least a portion of the object (e.g., to raise the temperature of at least a portion of the object). In some embodiments, applying RF energy to process (e.g., heat) the object may proceed at a first power level (e.g., a script) and applying RF energy for purposes of generating (receiving) RF feedback may proceed at a second power level. In some embodiments, the first power level is higher than the second power level. In some embodiments, RF energy applied to heat the object may be at a first average amount of energy per excitation setup and RF energy applied to receive the RF feedback may be at a second average amount of energy per excitation setup, and the first average amount of energy per excitation set is higher than the second average amount of energy per excitation setup.

[0099] The controller may be configured to select a subgroup of excitation setups (or at least one excitation setup), from all the excitation setups available to the apparatus, to apply RF energy to zone **102**. Controller **150** may select a subgroup of excitation setups based on the RF feedback received at each excitation setup or at one or more excitation setups.

[0100] In some embodiments, when RF energy is applied to process the object, the controller may be configured to determine amounts of RF energy to be applied at each excitation setup (e.g., associate RF energy amounts with each of the excitation setups), for example—based on the RF feedback. In certain embodiments, the controller may be configured to determine, from at least a part of the RF feedback, an absorbability indicator, (or in short, AI) at each of a plurality of excitation setups in which energy is applied to the zone. The controller may be configured to associate RF energy amounts with each of the excitation setups available for an apparatus based on the AI value at the respective excitation setup. The rules in which the controller may cause the application of RF energy to the energy application zone based on the RF feedback (e.g., the AI) may be included in one or more scripts for applying RF energy to process an object. For example, a script or a rule may include a decision not to supply RF energy to excitation setups associated with certain AI values, for example, those that may have AI values lower than a minimum threshold and/or higher than a maximum threshold. In other examples, the script or the rule may include, associating the same amount of RF energy with excitation setups associated with different AI values, for example, with values in a certain range. Additionally or alternatively, according to another script, the controller may associate different amounts of RF energy with excitation setups associated with different AI values. In some embodiments, other rules or scripts based on the AI values and/or other RF feedback may be utilized by the controller for determining the amounts of RF energy to be applied for processing the object.

[0101] Applying RF energy to the zone, to either detect a processing state of the object and/or heat the object, may be done by a sweep, and RF feedback may be received and associated with different excitation setups during the sweep. As used herein, a sweep may include, for example, the application, over time, of energy at more than one excitation setup. For example, a sweep may include the sequential application of energy at multiple excitation setups in one or more contiguous excitation setup group; the sequential application of energy at multiple excitation setups in more than one non-contiguous excitation setup group; the sequential application of energy at individual non-contiguous excitation setups; and/or the application of synthesized pulses having a desired excitation setup/power spectral content (e.g., a synthesized pulse in time). The excitation setups groups may be contiguous or non-contiguous. Thus, during an excitation setup sweeping process, one or more controllers may regulate the energy supplied from a source (e.g., source **112**) to one or more radiating elements to sequentially apply RF energy at various excitation setups to zone **102** (e.g., by switching from one c-FAP to the other) and to receive RF feedback from zone **102** associated with each excitation setup.

[0102] During the sweeping process, controller **150** may receive raw RF feedback indicative of the energy reflected and/or coupled at radiating elements **110**, **120** and **130**. Controller **150** may then determine an absorbability indicator (AI) by object **103** (i.e., a computed RF feedback) at each of a plurality of excitation setups based on the received information. Consistent with some disclosed embodiments, an absorbability indicator (AI) may include a dissipation ratio (DR) associated with each of a plurality of excitation setups. As referred to herein, a DR (or absorption efficiency or power efficiency) associated with an emitting radiating element may be defined as a ratio between EM energy absorbed by object **103** and EM energy supplied into the energy application zones by the emitting radiating element. In some embodiments, a DR may be defined as a ratio between EM energy absorbed by object **103** ('AE') and EM energy delivered by the emitting radiating element (DE). Some examples for computed RF feedback (e.g., DR) are given below.

[0103] In some embodiments, a DR associated with an emitting radiating element (e.g., element **110**) may be calculated using Equation (3):

$$DR=AE/SE \tag{3}$$

[0104] wherein SE is the energy supplied by source **112** to emitting radiating element **110** and AE is the energy absorbed, for example in object **103**. Both SE and AE may be calculated by integrating over time of power detected by power detectors (e.g., detectors **118**, **118***a*, **128** or **138**). For t=ti, wherein ti may be any moment in time during which

energy is applied to the energy application zone, equation (4) may have the form:

$$DR=P_A/P_S; \quad (4)$$

[0105] Wherein P_A is the power absorbed and P_S the power supplied from the RF source. P_A may be evaluated using equation (5):

$$P_A=P_S-P_{out}; \quad (5)$$

[0106] wherein P_{out} refers to the power detected by all the detectors (e.g., radiating elements **120** and **130** act as receiving radiating elements), denoted as $P_{detect}(i)$ in the i^{th} detector, in and around the energy application zone, when P_S was supplied to radiating element **110**, from RF source **112** at a certain excitation setup, see equation (6):

$$P_{out}=\tau P_{detect}(i) \quad (6)$$

[0107] If the only available detectors are the ones associated with the radiating elements (e.g., detectors **128** and **138** associated with radiating elements **120** and **130** respectfully), DR may be calculated using three detected power parameters P_S, P_R and P_C and equation (6) may have the form of equation (7):

$$DR=(P_S-P_R-P_C)/P_S \quad (7)$$

[0108] where P_S represents the RF power supplied to emitting radiating element **110**, P_R represents the EM energy and/or power reflected/returned to the emitting radiating element **110**, and P_C represents the EM energy coupled to the other radiating elements (e.g., **120** and **130**) function as receiving elements. DR may be a value between 0 and 1, and thus may be represented by a percentage number.

[0109] For example, consistent with an embodiment which is designed for three radiating elements **110**, **120**, and **130**, controller **150** may be configured to determine raw RF feedback parameters, such as the input reflection coefficients S_{11}, S_{22}, and S_{33} and transfer coefficients S_{12}, S_{21}, S_{13}, S_{31}, S_{23}, and S_{32} based on measured power and/or energy information during the sweep. Accordingly, the computed RF parameter (DR) corresponding to radiating element **1** may be calculated based on the above raw RF feedback parameters (e.g., the reflection and transmission coefficients (a/k/a S parameters)), according to equation (8):

$$DR_1=1-(IS_{11}I^2+IS_{12}I^2+IS_{13}I^2). \quad (8)$$

[0110] As shown in equation (8), DR may be different at different radiating elements. Thus, in some embodiments, an amount of energy supplied to a particular radiating element may be determined based on the AI associated with that particular radiating element.

[0111] During the EM energy application, additional computed RF feedback may be calculated and monitored based on the DR. In some embodiments, an average DR, for example, averaged over all transmitted excitation setups (ES), may be calculated. For example, an average DR may optionally be calculated for each radiating element, as a function of time, using equation (9):

$$\overline{DR} = \frac{1}{N}\sum_i DR(ES_i) \quad (9)$$

[0112] Wherein $DR(ES_i)$ is the dissipation ratio measured when the RF energy was supplied using the i_{th} excitation setup, and i is an integer between 1 to N wherein, N is the number of excitation setups used to apply energy to the energy application zone in a particular application. The average DR may vary over time. In some embodiments, the computed RF feedback may include ES average of other RF feedback, for example raw RF parameters (e.g., the reflection and transmission coefficients).

[0113] In some embodiments, DR (or a different absorbability indicator) calculated for an excitation setup may be time dependent. RF feedback received at that excitation setup may be monitored at different occasions during the energy application (during processing) and DR (or any other computed RF feedback used for determining amounts of energy to be supplied (e.g., temperatures, power levels, durations of energy application etc.)) may be calculated at each occasion. Thus equations (7) and (8) may take the form:

$$DR(t)=(P_S(t)-P_R(t)-P_C(t))/P_S(t)=1-(IS_{11}(t)I^2+IS_{12}(t)I^2+IS_{13}(t)I^2) \quad (7,8)$$

[0114] Additionally or alternatively the average DR may time dependent. Thus an average over N excitation setups as a function of time is presented in equations (10):

$$\overline{DR(t)} = \frac{1}{N}\sum_i DR(t)(ES_i) \quad (10)$$

[0115] In some embodiments, the average DR may be correlated with one or more processing states of the object (e.g., the temperature of the object, the cooking state of the object, etc.). The average DR may be monitored during cooking (e.g., during baking) and the cooking state of the object may be determined based on the average DR. The correlation may be done, for example, by using a lookup table stored in memory associated with apparatus **100**, comprising threshold values of the computed RF feedback (e.g., the average DR) and comparing the average DR received from the energy application zone during processing.

[0116] In some embodiments, the correlation between average DR and a processing state of the object may be recorded in a memory (e.g. in a lookup table, or any other suitable format). For example, as the object is being processed, a processing state of the object may be determined based on RF feedback received from the object, based on input from a user, based on automated monitoring devices (IR sensors, thermometers, cameras, or any other type of sensor or detector configured to monitor at least one property or characteristic of the object being processed), or based on any other input from a monitoring source. The processing state of the object may then be correlated with an average DR determined for the object at various (e.g., periodic) times during processing. This correlated information may be stored.

[0117] In some embodiments, correlated average DR and processing state information stored in a memory may be accessed and used in processing objects. For example, to process a particular object, the controller may access a memory (either remotely located or local to the controller) and identify stored information for the same or similar type of object. The controller may then rely upon the stored information, either fully or partially, to process the particular object. That is, rather than having to monitor the processing state of the object through separate input from sensors or detectors, the controller may determine the processing state of the object by monitoring an average DR obtained from the par-

ticular object during processing, accessing the information stored in memory, and determining a processing state of the object based on the observed average DR and the stored correlation between average DR and processing state of a same or similar type of object.

[0118] In some embodiments, a time average of DR may be calculated while giving different weights to different excitation setups. When plotting each of the DR(t)(ES) versus time, some of the plotted curves may show variation in the value of DR over time (the time derivative of DR(ESi) may be higher than a threshold). In some embodiments, the average DR may be calculated assigning more weight to DR(t)(ES) having larger variations than to DR(t)(ES) having lower variations (the time derivative of DR(ESi) may be lower than a threshold). In some embodiments, DR(t)(ES) having lower variations may be assigned with a zero weight. For example, the weighted average $\overline{DRw}$ may be calculated using equation (11):

$$\overline{DR_w(t)}=\Sigma_i w_i \cdot DR(ES_i)(t) \quad (11)$$

[0119] wherein w_i is the weight given to $DR(ES_i)(t)$.

[0120] In certain embodiments, the average DR may be calculated over time for each excitation setup.

[0121] In some embodiments, a reflection coefficient Γ may be used as an absorbability indicator of the object. This AI may be defined by equation (12):

$$\Gamma = \frac{\sum SE - \sum RE}{\sum SE} \quad (12)$$

[0122] where ΣS E represents the sum of all amounts of energy (or power) supplied to emitting radiating elements, and ΣRE represents the sum of all amounts of energy (or power) received by the emitting radiating elements. The reflection coefficient Γ may be used when more than one emitting radiating element emit RF energy simultaneously.

[0123] In some embodiments, processing of the object may be automatically controlled based on one or more raw or computed RF feedback (e.g., DR and/or average DR). Energy may be applied to process the object using one or more energy application protocols. The protocols may include at least one of: the type of energy to be applied (e.g., convection heating, IR heating or RF heating), the amount of energy to be applied (e.g., the temperature, the power levels, amount of RF energy) and the duration of the application of each type of energy. The different protocols may be predetermined and stored in a memory associated with controller **150**, or on a machine readable element associated with the object. Controller **150** may be configured to select an energy application protocol to be applied to process the object based on RF feedback received from the energy application zone. Additionally or alternatively, the controller may be configured to terminate the energy application and/or switch to another energy application protocol based on the received RF feedback and/or computed RF feedback. For example, the RF feedback may be detected during the application of energy according to a first energy application protocol, and when a value of an RF feedback (e.g., the DR(t), the average DR(t) or time derivatives of the DR(t), and/or the average DR(t)) reaches a target value, the energy application may stop or change in at least one aspect (e.g., to a second energy application protocol). For example, the application of convection heating for baking a loaf of bread may be terminated. Additionally, processing of the object may be controlled based on one or more other feedbacks (e.g., signals received from one or more sensors, e.g., sensor **140**, provided in the energy application zone). Additionally, processing of the object may be controlled by processing instructions provided by a user, e.g., by a graphical user interface (GUI) or instructions read from a machine readable element associated with the object. The instructions may be configured to cause the at least one controller (e.g., controller **150**) to control the energy application to process the object.

[0124] In certain embodiments, when the energy applied to process the object includes RF energy, controller **150** may determine an RF energy application protocol by adjusting the amount of RF energy supplied at each excitation setup based on the RF feedback (e.g., RF feedback parameters). RF feedback may be received from energy application zone **102**, e.g., during sweeping over a plurality of excitation setups. For example, according to some embodiments, controller **150** may be configured to determine the amount of energy to be supplied at each excitation setup based on RF feedback received at the respective excitation setup. An energy application protocol may be selected to include an amount of energy determined based on RF feedback. In some embodiments, an energy application protocol may dictate that amounts of energy applied at some excitation setups may be inversely related to the RF feedback values at these excitation setups (e.g., AI(ES)) calculated for the respective excitation setups. Additionally or alternatively, an energy application protocol may dictate that amounts of energy applied at an excitation setup have an inverse relationship with another RF feedback. RF feedback related values may include any value of RF feedback that may be received during the application of RF energy at a particular excitation setup. Additionally or alternatively, an amount of energy associated with a particular energy application protocol for application at an excitation setup may be determined according to other relationships. For example, a linear relationship between energy applied and feedback-related values may be used to determine an amount of energy to apply. For example, when the AI in a particular excitation setup subgroup (i.e., one or more excitation setups) tends to be relatively high (e.g., above a predetermined threshold or higher than the average AI value over a set of excitation setups that includes the subset, etc.), the amount of energy determined by an energy application protocol to be applied at each excitation setup of that excitation setup subgroup may be relatively low (e.g., lower than the amounts of energy applied at any excitation setup associated with AI values below the predetermined threshold). Additionally or alternatively, when an indicator of absorbable energy in a particular excitation setup subgroup tends to be relatively low (e.g., below a predetermined threshold or below the average AI value over a set of excitation setups that includes the subset, etc.), the applied energy may be relatively high (e.g., higher than the amounts of energy applied at any excitation setup associated with AI values above the predetermined threshold). According to some energy application protocols, there may be a substantially inverse relationship between the amounts of energy applied at different excitation setups and the AI values calculated for the same excitation setups. In some embodiments, if the energy applied according to such protocols at each excitation setup is plotted against the AI value calculated for the excitation setup at which energy is applied, the resulting line may include a decreasing line seg-

ment. In some embodiments, the decreasing line segment may have a constant slope. In other embodiments, the slope of the decreasing line segment may vary. In some embodiments, the slope may vary such that a multiplicative product of the AI value and amount of energy applied remains substantially constant.

[0125] Controller **150** may be configured to hold substantially constant the amount of time at which energy is supplied to radiating elements **110**, **120** and **130** at each excitation setup, while varying the amount of power supplied at each excitation setup as a function of the absorbable energy value. In some embodiments, controller **150** may be configured to cause the energy to be supplied to radiating element at a particular excitation setup or excitation setups at a power level substantially equal to a maximum power level of the device and/or the amplifier at the respective excitation setup (s). Alternatively or additionally, controller **150** may be configured to vary the period of time during which energy is applied at each excitation setup as a function of the absorbable energy value. In some embodiments, both the time duration and power at which each excitation setup is applied are varied as a function of the absorbable energy value.

[0126] Controller **150** may be further configured to control the RF energy application by controlling various aspects of the energy application units (e.g., units **119** and **119***a*) and RF energy source (e.g., sources **112**, **122** and **132**).

[0127] In some embodiments, apparatus **100** may include a phase modulator (not illustrated) that may be controlled to perform a predetermined sequence of time delays on an AC waveform, such that the phase of the AC waveform is increased by a number of degrees (e.g., 10 degrees) for each of a series of time periods. The time delays may be considered c-FAPs in apparatus **100**. In some embodiments, controller **150** may dynamically and/or adaptively regulate modulation based on feedback (e.g., RF feedback—for example, AI) from the energy application zone. In some embodiments, controller **150** may select phases (between pairs of radiating elements) based on the EM feedback (e.g., the absorbable energy value).

[0128] In some embodiments, apparatus **100** may include a frequency modulator (not illustrated). The frequency modulator may include a semiconductor oscillator configured to generate an AC waveform oscillating at a predetermined frequency (i.e., the frequency is a c-FAP in this apparatus). The predetermined frequency may be associated with an input voltage, current, and/or other signal (e.g., analog or digital signals). For example, a voltage controlled oscillator may be configured to generate waveforms at frequencies proportional to the input voltage.

[0129] Controller **150** may be configured to regulate an oscillator (not illustrated) to sequentially generate AC waveforms oscillating at various frequencies within one or more predetermined frequency bands. This sequential process may be referred to as frequency sweeping. In some embodiments, based on the feedback signal provided by detector **118**, controller **150** may be configured to select one or more frequencies from a frequency band, and regulate an oscillator to sequentially generate AC waveforms at these selected frequencies. In some embodiments, the frequencies may be selected based on the EM feedback (e.g., the absorbable energy values).

[0130] In some embodiments, the energy application unit (e.g., unit **119***a* included in FIG. **1**B) may include more than one source of RF energy. For example, more than one oscillator may be used for generating AC waveforms of differing frequencies. The separately generated AC waveforms may be amplified by one or more amplifiers. Accordingly, at any given time, radiating elements may be caused to simultaneously emit RF waves at, for example, two or more differing frequencies (i.e., two different c-FAPs) to zone **102**.

[0131] In some embodiments, a splitter (not illustrated) may be provided in apparatus **100** to split an AC signal e.g., a signal generated by an oscillator) into two AC signals (e.g., split signals). Controller **150** may be configured to regulate a phase shifter to sequentially cause various time delays such that the phase difference between two split signals may vary over time. This sequential process may be referred to as phase sweeping.

[0132] In some embodiments, apparatus **100** may include at least one interface **160** (for example, as illustrated in FIG. **1**A or FIG. **1**B). Controller **150** may be configured to receive from interface **160** one or more processing instructions and/or other information related to the object. Interface **160** may include any user interface, e.g., a GUI, a touch screen, a key pad, a screen associated with a mouse, etc. A first interface may be configured to receive from a user an indication of a processing state of the object. For example, the user may indicate to the controller via the first interface that a food item has being cooked to a desired degree of doneness or reached a desired level of browning. In some embodiments, a second user interface **160** may be configured to display to a user a representation indicative of the processing state associated with the object (i.e., an image associated with the RF feedback). For example: one or more signals of sensor **140**—e.g., the temperature of the object while processing may be displayed as graphs. In some embodiments, a single interface (e.g., one display) may be used both to display to a user one or more signals of sensor(s) and to receive inputs from the user. In some embodiments, user interface **160** may be configured to display to a user one or more RF feedback and/or computed RF feedback while processing the object. Additionally or alternatively, a third interface **160** may include a device capable of reading and receiving information (e.g., protocol (s)) from a machine readable element, for example a barcode reader, an RFID reader, etc. Controller **150** may be configured to receive the energy application protocol solely based on the information received from interface **160** or in combination with the RF feedback. In some embodiments, the first and/or second and/or the third user interfaces are the same. Additionally or alternatively, controller **150** may be configured to determine the energy application protocol solely based on user instruction received from interface **160**, e.g., a user may instruct processing information through a GUI. For example, the controller may receive from the interface (e.g., from a machine readable element or from a user) a target value (i.e., a criterion) of the RF feedback (e.g., a time derivative of the average DR value) and the controller may monitor the RF feedback during the processing and terminate the processing of the object when the RF feedback reaches the target value (i.e., the criterion).

[0133] In some embodiments, the user interface may include a display (not illustrated) and the controller may be further configured to display to a user the monitored RF feedback and/or a representation indicative of the processing state associated with the object. The user may then decide based on the displayed RF feedback or processing state, how to control the energy application to the object. The display may include any screen configured to display a visual repre-

sentation to a user either graphically or by any other technique. Additionally or alternatively, the display may include an audio system configured to provide an audio representation for the user.

[0134] In some embodiments, the user may create a machine readable element (e.g., a barcode) based on the information provided to the user (e.g., displayed) by interface **160**, for example: based on the RF feedback and/or computed RF feedback, one or more signals of sensor(s) **140**, and or correlation thereof. In some embodiments, the energy application protocol used and/or the RF feedback (e.g., its value (s)) correlated with one or more processing states to obtain a desired result may be recorded by the user and used for creating the machine readable element or used for future processing of the same or similar object (e.g., for automatic cooking)—for example: it may be used to create a special program in the interface for obtaining a specific result when processing the object.

[0135] Reference is now made to FIGS. **2**A-**2**B which illustrate some exemplary cavities in accordance with some embodiments of the invention. In some embodiments, the energy application zone may be at least partially located inside a cavity. Cavities **200** and **210** may be exemplary energy application zones and may be part of apparatus **100**. A cavity may include any void comprising at least one wall made from a material substantially opaque to RF energy. Any of the walls of a cavity may be made from materials opaque to RF energy. For example, an oven may be constructed from cast iron, stainless steel, or aluminum alloys or other metals and alloys suitable for constructing a cavity. Alternatively, the at least one wall may comprise a dielectric material at least partially transparent to RF energy and coated by a coating made from material substantially opaque to RF energy. A material substantially opaque to RF energy may include any material capable of blocking or reflecting RF energy above a predetermined threshold (e.g., above 90%).

[0136] FIG. **2**A includes a diagrammatic representation of a cavity **200** in accordance with some embodiments. Cavity **200** may include cavity body **202**. Cavity body **202** may be configured to hold at least a portion of an object (e.g., object **103**). Cavity body **202** may comprise at least one wall constructed from or coated by, a material substantially opaque to RF energy. Cavity body **202** may have a rectangular shape (as illustrated), cylindrical shape, or may have any other suitable shapes. For example, cavity body **202** may take a shape of a cooking oven for cooking food, a cylindrical tank for processing liquids, an industrial furnace for curing polymers or sintering parts, a pipe comprising flowing fluids and/or gasses, etc. Cavity **200** may further comprise at least one radiating element. For example, cavity **200** may include three (or more) radiating elements **204***a*, **204***b*, and **204***c* as illustrated in FIG. **2**A. Any or all of radiating elements **204***a*, **204***b*, or **204***c* may constitute examples consistent with any of the radiating element described herein. Radiating elements **204***a*, **204***b*, and **204***c* may include any elements configured to emit and/or receive RF energy from the cavity (e.g., to detect a processing state of the object). The radiating elements may be connected to an RF source (e.g., source **112** illustrated in FIG. **1**B), to a detector configured to detect one or more RF feedback (e.g., detector **118***a* in FIG. **1**B) and to a controller (e.g., controller **150** in FIG. **1**B). Radiating elements may be installed in proximity to at least one cavity wall (for example, element **204***a*). A radiating element may be installed outside the cavity (for example, element **204***b*), in proximity to a cavity wall having an RF transparent window **205**. RF transparent window **205** may be constructed from any dielectric material capable of transferring at least a portion of the RF energy emitted from element **204***b* to cavity **200**. A radiating element may be located in proximity to or at least partially inside object **103** (for example, element **204***c*). For example, element **204***c* may be immersed in a solution in a chemical reactor or a beer in a brewery tank, element **204***c* may also be embedded in a filter or a catalytic convertor in order to heat the filter or the convertor. In some embodiments, radiating elements **204***a*, **204***b*, and **204***c* may be part of one or more energy application units (not illustrated)—(e.g., unit **119** or **119***a*).

[0137] In some embodiments, cavity **200** may include at least one sensor, such as sensors **206** and **208**, which may be similar to sensor **140** described above. Sensors **206** and **208** may constitute exemplary processing state indicators. Sensor **206** may be embedded in, immersed in or placed in proximity to object **103**. Sensor **206** may include any sensor configured to measure a property (e.g., an indication of the processing state) of object **103**. The property may include a measurable property, such as temperature, pressure, volume, pH, humidity ratio, density, moisture, etc. Additionally or alternatively, the property may include other characteristics, such as color, taste, doneness, smell, etc. In some embodiments, one or more properties may be monitored (e.g., detected) by sensor **206**. In some embodiments, sensor **206** may be configured to measure RF feedback (e.g., raw RF feedback parameters) detected in cavity **200**. For example, sensor **206** may be configured to measure the intensity of the EM field excited in cavity **200** by the radiating element(s). In some embodiments, sensor **208** may be installed in proximity to or on at least one wall in cavity **200**. Sensor **208** may include any sensor configured to measure a property (e.g., an attribute, condition, etc. indicative of the processing state) of object **103** or cavity **200**. Similar to sensor **206**, sensor **208** may sense one or more properties associated with object **103** and/or the surrounding environment of the object. In some embodiments, sensors **206** and **208** may be configured to sense the same or similar properties. In some embodiments, sensors **206** and **208** may sense different properties. For example, sensor **206** may sense the temperature of the object, and sensor **208** may sense humidity in cavity **200** in the vicinity of object **103**. Sensors **206** and **208** may be in communication with a controller (e.g., controller **150**). In some embodiments, processing of the object (e.g., energy application) may be controlled in accordance with one or more signals sensed by sensor **206** and/or **208**.

[0138] In some embodiments, cavity **200** may further include at least one energy (heat) source **209**. Source **209** may be configured to apply energy (e.g., heat) to cavity **200** to process object **103**. Source **209** may include any convection heating source, for example: a filament, hot air impingement, gas flame, or any other heating element configured to apply heat to an object by convection means. Additionally or alternatively, source **209** may include IR lamp configured to apply IR radiation to object **103**. In some embodiments, energy may be applied to process the object from two different sources. For example, source **209** may apply heat (convection or IR) and at least one of radiating elements **204***a*, **204***b* and/or **204***c* may apply RF energy to process the object as well and/or to detect a processing state of the object by receiving RF feedback from the object. Source **209** may apply the energy (e.g., heat), and the at least one radiating element may additionally

apply RF energy to process the object, simultaneously, consecutively, or a combination of both. Alternatively, energy for processing the object may be applied solely from source **209**, and the radiating elements may apply RF energy to detect the processing state of the object.

[0139] FIG. **2**B illustrates an exemplary cavity according to some embodiments of the invention. Cavity **210** may include, for example, one or more of the components shown in FIG. **2**A. Cavity **210** may include cavity body **212**. Cavity body **212** may comprise at least one wall constructed from a material substantially opaque to RF energy. Cavity **210** may have any shape or size allowing holding of at least a portion of an object. Cavity **210** may further include at least one radiating element configured to emit and/or receive RF energy from cavity body **212**, optionally more than one radiating element (e.g., 3 elements **204***d*, **204***e* and **204***f*) may be installed in cavity **210**. Each of elements **204***d*, **204***e* and **204***f* may be connected to a detector (e.g., detector **118***a* illustrated in FIG. **1**B) and may be in communication with a controller (e.g., controller **150**) configured to receive signals related to RF feedback from the detectors connected to elements **204***d*, **204***e* and **204***f*. Radiating elements **204***d*, **204***e*, and **204***f* may be part of one or more energy application units (not illustrated)—(e.g., unit **119** or **119***a*). The RF feedback (e.g., computed RF feedback) received from elements **204***d*, **204***e* and **204***f*, may be indicative of a processing state of the object. Elements **204***d*, **204***e* and **204***f* may be located on or in proximity to cavity body **212** walls. Each element may be located on a different wall. Additionally or alternatively, more than one radiating element may be located on the same wall. The invention is not limited to any particular radiating elements configuration. Elements **204***d*, **204***e* and **204***f* may be any radiating elements according to the embodiments of the invention (e.g., elements **110**, **111** etc.). Elements **204***d*, **204***e* and **204***f* may be located in volume **216** between cavity body **212** walls and at least one partition **214**. Optionally, more than one partition **214** (e.g., 2 partitions illustrated in FIG. **2**B) may be installed in cavity **210**. Partitions **214** may be constructed from a material at least partially transparent to RF energy. Additionally or alternatively, at least one partition **214** may include at least one window consisting of a material at least partially transparent to RF. Some examples of materials transparent to RF energy may include: various glasses, polymers and some ceramics and their composites. Partitions **214** may separate inner volume **215** and one or more of radiating elements **204***d*, **204***e* and **204***f*. Elements **204***d*, **204***e* and **204***f* may be installed in at least one outer volume **216**. Inner volume **215** may be configured to hold at least a portion of an object (e.g., object **103**) and partitions **214** may be configured to separate the object from the radiating elements. In some embodiments, the energy application zone may be located at least partially within inner volume **215**. For example, if the object is a meat or chicken to be cooked, partitions **214** may protect elements **204***d*, **204***e* and **204***f* from water and oil vapors extracted from the meat or the chicken during cooking. In yet another example, the object may include a chemical solution to be reacted, and inner volume **215** may be a chemical reactor. Thus, partitions **214** may protect elements **204***d*, **204***e* and **204***f* from a corrosive attack by the chemical solution.

[0140] In some embodiments, cavity **210** may further include tray **218**. Tray **218** may be located in volume **215**, separating volume **215** into two parts each capable of holding different object(s). Tray **218** may be at least partially transparent to RF energy, allowing at least a portion of the energy applied from the two upper radiating elements **204***d* and **204***e* to enter the lower part of cavity **210** and vice versa with respect to the lower radiating element **204***f*. Tray **218** may comprise a heat resistant polymer, for example Silicone, Teflon, etc. Tray **218** may comprise glass (e.g., tempered soda-lime glass also known as Pyrex) or ceramic material. Tray **218** may be substantially opaque to RF energy, blocking much or all of the RF energy emitted from elements **204***d* and **204***e* from enter the lower part of cavity **210**, and vice versa. Tray **218** may comprise any metallic material, including, for example, various stainless steels, cast iron, aluminum based alloys, cupper based alloys etc.

[0141] In some embodiments, cavity **210** may further include one or more energy (heat) sources **209***a* and **209***b*, similar to source **209** illustrated and disclosed in respect to FIG. **2**A. Source **209***b* may be located to apply energy (e.g., heat) to the lower portion of volume **215**, and source **209***a* may be located to apply energy (e.g., heat) to the upper portion of volume **215**. In some embodiments, energy may be applied to process object(s) placed in either or both portions of volume **215**, from sources **209***a* and **209***b*, and RF energy may be applied from radiating element **204***d*, **204***e* and **204***f* (e.g., to process (heat) the object and/or to detect processing state(s) of the object).

[0142] Method **300** for controlling energy application to an energy application zone based on RF feedback in accordance with some embodiments of the invention is presented in the flowchart in FIG. **3**A. Method **300** may include applying RF energy to an energy application zone, to detect a processing state of an object placed in an energy application zone, during processing of the object. Method **300** may be performed by controller **150**, using apparatuses **100**. RF energy may be applied to the energy application zone (e.g., zone **102** and cavities **200** and **210**), in step **302**, via one or more radiating elements. The RF energy may be applied, during the processing of the object, in order to detect RF feedback (e.g., computed RF feedback). RF energy may be applied at one or more excitation setups. The RF energy may be applied for example every 1 second, 3 seconds, 5 seconds or 10 seconds, or other periods of time. The object may be processed by applying energy (e.g., in convection or IR). In some embodiments, low amounts of RF energy may initially be applied at one or more excitation setups. Low RF amounts of energy may be defined as amounts of energy applied to the energy application zone that result in little or no processing of an object (e.g., object **103**) placed in the zone. For example, the low amounts of energy may not be sufficient to: cook a food item, thaw frozen object, cause or accelerate chemical reaction, etc. Low amounts of energy may be applied by for example, by applying low RF power from the RF source (e.g., source **112**) or by applying high power for very short period of time. Alternatively, RF energy application in step **302** may be conducted at energy levels sufficient to process an object placed in the energy application zone by a certain degree. The RF energy application in step **302** may be conducted by sweeping over a plurality of excitation setups available in apparatus **100** (e.g., at a plurality of frequencies), for example, by transmission over time of energy at more than one excitation setup. A controller (e.g., controller **150**) may control the RF energy application by sweeping over a plurality of excitation setups and assigning a constant (e.g., low) amount of energy to be applied at each excitation setup.

[0143] The controller may then receive or detect, and optionally monitor, RF feedback from the energy application zone, in step **304**. The RF feedback may be detected (received) in response to the RF energy application. The RF feedback may include a result of the RF energy applied in step **302**. The RF feedback may be received from one or more sensors and/or detectors configured to measure raw RF feedback in the energy application zone optionally at each of the applied excitation setup. The received raw RF feedback may be processed to determine a computed RF feedback—for example by conducting mathematical manipulation of raw RF feedback parameters or values received from the energy application zone, for example: the computed RF feedback may include: a DR, an average DR, a time derivative of any of the signals, etc. The computed RF feedback may be correlated with one or more processing states of the object. Method **330** for recording (e.g., on a memory associated with controller **150** or on a machine readable element) a correlation between an RF feedback value (or a computed RF feedback) and a processing state of an object is disclosed in FIG. **3**C. The correlation recording may be done during heating of an exemplar of the object (e.g., object **103**) being heated. The exemplar object may comprise at least some of the characteristics of the heated object. Thus when an RF feedback and an indication of a processing state of an object is correlated and recorded during heating experiments of the exemplar object, the recorded correlation may be used to control energy application to the object (e.g., object **103**).

[0144] In some embodiments, the computed RF feedback may be monitored to detect a processing state of the object, for example by comparing the recoded correlation (e.g., stored as a look up table) and the received computed RF feedback (e.g., one or more values of the computed RF feedback). The controller (e.g., controller **150**) may monitor at least one computed RF feedback parameter (e.g., DR, average DR, time derivative of Γ, etc.) before, during or after processing (e.g., heating) of the object. The controller may compare the at least one monitored computed RF feedback parameter (e.g., its value) with a correlated computed RF feedback (value) recorded and stored for example in a lookup table. The correlation received may be used to determine the one or more processing states of the object. The correlation may be recorded and stored on a memory associated with the controller or on a machine readable element associated with the object and the controller may be configured to receive the correlation between the RF feedback and the processing state of the object from the memory and/or the machine readable element. The correlated computed RF feedback (e.g., one or more values) may be collected during processing of another object that may be representative to the object processed.

[0145] The raw RF feedback may be sensed or detected every 1 second, 3 seconds, 5 seconds or 10 seconds, or at any other desired time period. Various RF feedbacks may be received by the controller during the application of RF energy at various excitation setups, for example, during sweeping over a plurality of excitation setups. The controller may be configured to associate some or all of the RF feedback (e.g., its values) with a corresponding excitation setup. In some embodiments, when detected before processing begins—the computed RF feedback received in step **304** may be indicative of the initial state of the object. An exemplary initial state of the object may comprise a frozen object, a deeply frozen (e.g., below a threshold temperature) object, an object at room temperature or in general the initial temperature of the object before processing, different defrosting states, volume of an object, number of pieces or items associated with the object or objects, the position of each item in a package, etc.

[0146] In some embodiments, the RF feedback (e.g., the computed RF feedback) may be correlated with one or more processing states of the object. The correlation may be determined in accordance with method **330**. In some embodiments, the controller may detect one or more processing states of the object based on the monitored RF feedback (e.g., the computed RF feedback). The controller may display or otherwise provide the detected processing state(s) to the user (e.g., via interface **160**). In some embodiments, the user may provide instructions configured to cause the at least one processor to process the object based on the provided processing state(s).

[0147] In step **306**, the controller may control the processing of the object by applying energy based on the received and optionally monitored RF feedback. For example, the controller may cause application of energy when the computed RF feedback values received from the energy application zone include values lower or higher than a threshold. Additionally or alternatively, when the object is processed by RF energy, the controller may adjust the RF energy amounts applied at each excitation setup as a function of the computed RF feedback at that excitation setup. In some embodiments, the controller may terminate the process when the computed RF feedback (its value) reached or is below a predetermined threshold.

[0148] In some embodiments, the process may repeat and RF energy may be applied to detect the processing state of the object during and/or after the energy application. Steps **302** and **304** may be repeated and the processing may be re-adjust in step **306** based on the computed RF feedback received in step **304**. In some embodiments, steps **302** and **304** may be performed several times while processing the object—e.g., every 3 or 5 seconds.

[0149] In some embodiments, an energy application protocol may be set based on the RF feedback (e.g., a computed RF feedback) received from the energy application zone. Method **310** presented in the flowchart in FIG. **3**B may comprise placing an object (e.g., object **103**) in an energy application zone (e.g., zone **102**), in step **312**. Method **310** may be performed by controller **150**, using apparatuses **100**. RF energy may be applied to the energy application zone to detect a processing state of the object by receiving and monitoring a first RF feedback (e.g., computed RF feedback) for example, by controller **150**, in step **314**. The RF feedback received in step **314** may be indicative of the initial state of the object. In some embodiments, the detected initial state may be displayed to the user (e.g., through an interface). The RF energy may be applied at a plurality of excitation setups, for example, by sweeping over at least a portion of available excitation setups, and the RF feedback may be received and associated with each of the applied excitation setups, as disclosed above with respect to steps **302** and **304** in method **300**. The received RF feedback (e.g., one or more values or trend—for example: when the value changes from increasing to decreasing over time) may be correlated with one or more processing states of the object as discussed above.

[0150] Based on the received first RF feedback, a controller (e.g., controller **150**) may set or determine an energy application protocol, in step **316**. In some embodiments, the user may set (select) the energy application protocol in response to the displayed initial state (e.g., the user may select a protocol

from a plurality displayed protocols). The interface may send the energy application protocol to controller. An energy application protocol may include one or more rules at which energy may be applied to the energy application zone. The rules may include setting the amount of energy to be applied (e.g., temperature, power levels energy application durations) or the type of energy (e.g., RF energy, IR energy or convection heating) based on the received RF feedback. For example, when the RF feedback correlated with a processing state that indicates that yeast dough is fully proofed and ready to be baked, the controller may set a rule for an oven to apply 180° for 30 minutes. If the object is to be processed also by RF energy, the rules may control the selection of the excitation setups, from the plurality of excitation setups, at which RF energy may be applied. Additionally or alternatively, the rules may determine the amount of energy to be applied at each excitation setup, for example, by setting the amounts of power and/or time supplied to each radiating element (e.g., element **110**, **120** and **130**) from the RF energy source (e.g., source **112**, **122** and **132**). The energy application protocol may be set based on one or more RF feedbacks.

[0151] Energy may be applied to the energy application zone to process the object according to the energy application protocol set in step **316**, in step **318**. The energy may be applied via one or more heat sources (e.g., source **209**, **209***a* and **209***b*). For example, source **209** may include a filament in a cooking oven, where the oven may include a thermostat and may be configured to heat the oven to 180° C. for 30 minutes. Additionally or alternatively, RF energy may be applied to process the object via radiating elements connected to one or more RF sources. The energy source and/or RF source may be controlled by the controller to apply the energy according to the set protocol. After or during the energy application, a second RF feedback (e.g., a computed RF feedback) may be received and optionally monitored (while processing the object) from the energy application zone to detect processing state(s) of the object after or during the energy application (step **320**). In some embodiments, the processing state(s) may be displayed to the user (e.g., through an interface) during the processing. Optionally, the second type of RF feedback may be similar to the first type of RF feedback. Alternatively, the second type of RF feedback may be different from the first type of RF feedback. For example, the first computed RF feedback received in step **314** indicating that the yeast dough was fully proofed may include the DR, and the second computed RF feedback indicating that the yeast dough is fully baked may include a time derivative of the average DR. The values of the second RF feedback may be compared to a value available to the controller, e.g., a termination criterion, in step **322**. The termination criterion may include at least one RF feedback value (e.g., a computed RF feedback value) correlated with a processing state of the object, e.g., the final desired state of the object. The termination criterion may be recorded and stored in: a memory associated with the controller, on a data indicative of instruction included in a machine readable element (e.g., a barcode tag or an RFID tag) or sent to the controller from a remote location connected to the controller (e.g., the Internet), in step **324**. For example, the termination criterion may include a single value of the average DR, a set of values of DR(ESi), a set of values of S_{11}(ESi), a single value of DR at a particular excitation setup (ES), the time derivative of the power reflected from the zone, the time derivative of the DR(ESi) etc. If a value associated with the second RF feedback is substantially equal to the termination criterion, e.g., when the dough is completely baked, (step **322**-YES), the energy may be terminated in step **326** and the processing of the object placed in the energy application zone may be ended. If the second RF feedback value is not equal to the termination criterion (step **322**-NO), the process may return to step **314** and repeats until the termination criterion is met. In some embodiments, more than one termination criterion may be used in the RF energy application and the controller may cause application of the energy until all criteria are met, at least two criteria are met, etc.

[0152] In some embodiments, other criteria may be stored and compared during the RF energy application. For example, different criteria may be used to switch between various energy application protocols. A first protocol, for example, may apply 40° C. to proof a yeast dough, may be set according to RF feedback, set as a default or predetermined prior the RF energy application. The first protocol may be terminated when a first criterion, for example the criteria that the dough is fully proofed, may be met. The first protocol may be followed by a second EM application protocol (e.g., bake the dough at 180° C. for 30 minutes) and a second criterion (e.g., dough is baked), until a termination criterion may be applied. This concept is discussed broadly in reference to method **400**.

[0153] Method **330** for correlating and optionally recording a processing state of an object, indicated by at least one processing state indicator, with an RF feedback received during the processing of the object is presented in the flowchart in FIG. **3**C, in accordance with some embodiments of the invention. Method **330** may be performed by controller **150**, using apparatuses **100**. An apparatus for recording a correlation of a processing state of an object, indicated or received by at least one processing state indicator, with RF feedback (e.g., one or more values or RF feedback or computed RF feedback) received from an energy application zone during processing of the object in the energy application zone may include one or more components discussed in reference to FIGS. **1**A-**1**B and **2**A-**2**B and may employ method **330**. The apparatus may further be configured to create a machine readable element to be associated with an object. Method **330** may be performed on a test object, and the recorded correlation may be used to process similar or identical object. Method **330** may be performed in order to create a machine readable element or a processing program (e.g., cooking program) to be associated with objects similar or identical to the test object. An object to be processed may be placed in an energy application zone (e.g., zones **102** and cavities **200** and **210**), in step **332**. In some embodiments, the user may provide additional information regarding the test object—e.g., its type (for example: a cake, a steak etc.), size, position of the object in the cavity (e.g., a tray level in multi-level ovens). Alternatively or additionally, the additional information may be read from a machine readable element associated with the test object. Energy may be applied to the object to process the object, in step **334**. For example, sources **209**, **209***a* and/or **209***b* may apply convection heating to bake a cake placed in a cooking oven. In some embodiments, energy may be applied in accordance with instructions provided by the user (e.g., the user may indicate a desired amount of energy to be absorbed in the object (KJ) or may provide a desired temperature of a convection heating). An indication of a processing state (e.g., a chemical or physical property or a cooking state) of the object may be received during (i.e., before, during and after) the energy application, in step **336**. The indication of the process-

ing state of the object may be received from various processing state indicators, for example, sensors configured to sense a variable indicative of the processing state of the object placed in or around the energy application zone, e.g., sensors **140**, **206** and **208**. In some embodiments, the processing state sensed by the sensors (processing state indicators) may be displayed to a user. Additionally or alternatively, the indication of the processing state of the object may be received from a user and the processing state indicator may comprise a first user interface configured to receive from a user an indication of the processing state of the object (e.g., the degree of doneness, a desired color, etc.,). Controller **150** may record the indication of the processing state of the object. For example, the controller may record a temperature signal from a thermometer indicating the temperature inside a steak (e.g., when the steak's temperature has reached 50° C. and the steak reached a medium doneness level). In yet another example, the controller may record a weight, e.g., received from a scale, of berries placed in a drying cabinet to be dried. In some circumstances, the weight may indicate that the berries have lost a certain amount of water.

[0154] During the energy application and the processing (e.g., cooking, drying, baking etc.), RF feedback may be received from at least one detector configured to detect the RF feedback from the energy application zone (step **338**). RF energy may be applied, optionally, by sweeping over a plurality of excitation setups (e.g., a plurality of frequencies) to the energy application zone. The RF energy may be emitted from the radiating elements (e.g., elements **110**, **120**, **130**, **204***a*-**204***f*) and reflected back or coupled to the radiating elements. As a result of the RF energy application, an RF feedback may be received from the energy application zone and recorded (e.g, one or more values) by controller **150**, during the processing of the object. For example, controller **150** may record the values of the DR at each excitation setup and/or the average DR over all excitation setups as a function of time. In some embodiments, the values of DR may be monitored during the some or all of the processing of the object. In some embodiments, the RF feedback received by the detector(s) and/or the computed RF feedback may be displayed to a user.

[0155] In some embodiments, the user may evaluate the process (e.g., the user may evaluate the processing state and compare this to a desired processing state). Optionally, when the desired results are not obtained—an additional test object may be processed with a different instructions—e.g., different energy protocols etc. In some embodiments, the user may indicate (e.g., via interface) that a desired results was obtained. Alternatively, an indication whether the desired result was obtained may be indicated by one or more sensors (processing state indicators) provided in the apparatus. In such case, the program (e.g., the one or more energy protocols) that was used for processing the object may be recorded on a machine readable element (for example: as illustrated in FIGS. **8**A-**8**B). In some embodiments, the program may be displayed to a user for approval before recording it (e.g., on a machine readable element).

[0156] The RF feedback (e.g., one or more values or trends) may be correlated with the indication of object processing state (e.g., one or more signals received by processing state indicator) and the correlation may be recorded, in step **340**. The controller may correlate the recorded indication of the processing state and the RF feedback as the feedback is obtained (at the same time, at different times, or at some later time). The recorded correlation(s) may be used to detect one or more processing states of the object and may set a criterion/criteria for controlling the energy application to process object(s) similar to the test object. For example, the temperature measurements of the object may be correlated to average DR values and the average DR correlated to a desired target temperature may be set as a criterion and may be recorded in a data storage portion included in machine readable element. In some embodiments, one or more of the RF feedback (e.g., values) may be correlated to at least one processing state of the object and may be recorded and stored in data indicative of instructions included in a machine readable element, and/or on a memory associated with the controller and/or in a remote location connected to the controller. In some embodiments, a machine readable element may be associated with an identification number (e/g/. tag ID) and the recorded data may be stored on a remote location such that the identification number may be associated with that data.

[0157] FIG. **4** is a flowchart of a method **400** for controlling energy application based on a criterion, for example the criterion disclosed in step **340** of method **330**, according to some embodiments of the invention. A controller (e.g., controller **150**) may be configured to carry out method **400** utilizing any suitable system (e.g., apparatus **100**). Method **400** may include switching between two or more energy protocols based on a detected criterion. The criterion may be associated with a processing state of the object or an associated RF feedback (e.g., computed RF feedback). The controller may determine an initial processing stage by setting i to zero (i=0), at step **402**. Optionally, at the initial processing stage (i=0), the controller may identify the object to be processed based on identity information received from an interface, at step **404**. An interface (e.g., interface **160**) may include a system configured to read data recorded on a machine readable element, for example, a tag reader (e.g., a barcode reader or an RFID reader), and the identity of the object may be coded or recorded on the tag (e.g., a machine readable element such as a barcode, etc.). Additionally or alternatively, the identity of the object may be received from a user using any user interface **160** (e.g., GUI, touchpad, keypad, touch-screen etc.) configured to receive instruction(s) from a user and forward the instruction(s) to a controller. In some embodiments, the initial processing state of the object may be determined, in step **410**. For example, the controller may determine the initial processing state of the object based on the identity of the object. The controller may correlate between the identity of the object and the initial processing state of the object. For example, the identity of the object may define the chemical composition and reaction mixture concentration in a solution introduced to a chemical reactor. In yet another example, the initial processing state may be recorded on a machine readable element associated with the object, and the controller may be configured to receive a data indicative of the initial processing state of the object (e.g., instructions) from the machine readable element. For example, a code printed on an instant cake powder package may identify the initial conditions of a cake powder mixture after adding the liquids (e.g., milk) and eggs at room temperature and after molding (in the cake mold) and made ready to be introduced to the cooking oven. In some embodiments the instructions recorded on the machine readable lements are further configured to cause the at least one controller (e.g., controller **150**) to determine the initial condition of the object based on RF feedback received from the energy application zone. Alternatively, the initial

processing state of the object (initial conditions) may be determined based on an RF feedback received from the energy application zone holding the object. In some embodiments, the initial conditions of the object may be determined by monitoring RF feedback. Value(s) of RF feedback received from the energy application zone (as a response to RF energy application) at the initial state of the object may be compared to RF feedback values recorded on a media accessible to the controller, for example a machine readable element, a memory associated with the controller, etc. The recorded RF feedback values may be correlated to at least one initial processing state of the object. A first protocol, comprising energy application parameters, may be determined in step **420**. The first protocol may be determined based on the initial processing sate of the object determined in step **410**. For example, if the initial processing state of the object shows that the object is frozen, the determined first energy application protocol may comprise RF energy application parameters that may thaw the object, e.g., 'thawing script', for example using RF energy. Additionally, the initial processing state may indicate the temperature of the frozen object, and the first protocol may comprise energy application parameters for example, temperature and time in a convection oven. If the energy applied to process the object is RF energy—the protocol may include energy level, power level, time duration and/or selecting of one or more excitation setups from a plurality of excitation setups, and applying RF energy at the selected excitation setups, for thawing the object starting at the indicated temperature. Optionally, the first protocol (e.g., protocol (i)) may be determined based on data indicative of instructions recorded on a machine readable element or in a memory accessible to the controller. In some embodiments, the data indicative of instructions recorded on a machine readable element may include instructions configured to cause a controller to select the first protocol according to the initial processing state of the object or RF feedback received from the energy application zone. In some embodiments, one or more protocols may be included in data indicative of instructions recorded on the machine readable elements, and the controller may determine the protocol(i) from data recorded on the readable element. The data may include some or all of the energy application parameters and/or a code associated with some or all of the energy application parameters. The machine readable element or the memory may include processing instructions for processing the object. The instructions may include more than one protocol, and/or data related with the protocol, and/or data related with the initial processing state of the object. In some embodiments, when RF energy is further applied to process the object, the protocol may include a correlation between RF feedback values (e.g., computed RF feedback values) and the RF energy to be applied to the energy application zone. The correlation may be recorded on a readable element (e.g., bar-code), and all the other energy application parameters may be set regardless of the information in the machine readable element. For instance, the processing parameters included in the protocol (i) (e.g., the first protocol) may be set as a default of the processing apparatus, optionally the data indicative of instructions comprises an instruction to use the default protocol. The at least one correlation may be set such that the energy applied to the energy application zone may accelerate a chemical reaction in a chemical reactor. A different correlation may be set (e.g., recorded on a readable element) if the protocol is designed to puff un-puffed dough, taken from a refrigerator at 4° C. Other correlations can be set depending on the requirements of a particular application.

[0158] In step **422**, the protocol is checked to determine whether the protocol is an energy application protocol or a termination protocol. An energy application protocol may be defined as any protocol that includes application parameters for controlling non-zero energy delivery to the energy application zone. A termination protocol may be defined a protocol involving application of zero energy to the energy application zone. If the protocol is a termination protocol (**422**: YES), the process ends (**442**). Otherwise, step **424** may be performed, and energy (e.g., RF energy, IR energy, convection heating energy, etc.) may be applied to the energy application zone according to protocol(i) (e.g., the first protocol) determined in step **420**. For example, the protocol may include a correlation between a computed RF feedback and the RF energy to be applied to the energy application zone, and in performing step **424**, the computed RF feedback may be calculated from one or more values of an RF feedback, and energy may be applied accordingly. In other embodiments, the protocol may include other energy application parameters.

[0159] In step **426**, an RF feedback is received from the energy application zone, optionally in the presence of the object. The RF feedback may be monitored during energy application in accordance with protocol (i) (e.g., the first protocol). The feedback may include any RF feedback, either raw RF feedback parameters and/or computed RF feedback. For example, the feedback may include: the S parameters, DR, average DR, input impedance of radiating element(s), power detected in the energy application zone, their respective derivatives, averages, etc.

[0160] In step **428**, the received RF feedback (e.g., its value (s)) may be checked (compared) against a criterion—criterion(i), e.g. to see if the criterion is met. The criterion may be or may be correlated to a processing state of the object. This step may be carried out during the energy application or in an intermission in energy application. Meeting the criterion may be checked continuously during the energy application, or intermittently, e.g. periodically, for example, every 1 sec or 5 sec or 10 sec, etc. Additionally or alternatively, the RF feedback may be checked against the criterion upon occurrence of certain events. For example, the RF feedback may be compared to the criterion when an indication indicative of the object's temperature shows a temperature change larger than 1° C., when an indication indicative of the object's humidity changes by a predetermined amount, every predetermined number of sweeps, etc. The criterion may include one or more RF feedback (e.g., values) correlated with at least one processing state of the object. The criterion may be set according to method **330**, disclosed in the flowchart at FIG. **3**C. The criterion may be recorded on a data storage portion in a machine readable element, on a memory associated with the controller or on a remotely located media accessible to the controller. The controller may receive the criterion from the machine readable element and/or the memory and/or the media.

[0161] In step **428**, the controller may determine if the RF feedback (e.g., its value) meets the criterion. In case the feedback does not meet the criterion yet (step **426**: NO), Energy application may continue using the same protocol determined in step **420** during an (i) time period (e.g., a first time period) before RF feedback received from the energy application zone meets a criterion. Steps **422**, **424**, **426**, and **428** may be repeated until the criterion is met (Step **428**:

YES). When criterion(i) is met, another criterion may be defined in step **430** and i may be set to i=i+1 (step **440**). After the criterion is met protocol(i+1) (e.g., a second protocol) may be determined, step **420** may be repeated, and the energy may be applied to the energy application zone according to the protocol(i+1) during a second time period after RF feedback received from the energy application zone meets criterion(i) (repeating step **424**).

[0162] Cooking experiments for correlating a cooking state of a food item with an RF feedback were conducted in an experimental cooking oven. The cooking oven included similar components as disclosed in FIGS. **1**B and **2**A: a controller, a convection heat source, two radiating elements each contacted to an RF source and a detector, and a temperature sensor. In the first experiment, a ready-to-bake frozen pizza was defrosted and cooked by applying convection heating at 180° C. The temperature of the pizza and the average DR were detected and monitored as function of the cooking time. A sharp change in the slope (the time derivative) of the average DR was detected when the pizza was thawed and a change in the sign of the time derivative (from positive to negative) was observed when the pizza was fully backed.

[0163] FIG. **5** presents two measurements of the average DR (an example of a computed RF feedback) taken from two different radiating elements, during baking experiments of a vanilla cake. An instant vanilla cake mixture was prepared according to the instructions on the mixture package and placed in the same experimental cooking oven used to bake the pizza. The oven was heated to 180° C. The average DR was monitored by the controller every 3 seconds, and the baking state of the cake was monitored visually by a chef periodically. The entire baking time was approximately 30 minutes. The x axis in FIG. **5** is the number of the average DR detection cycles taken every 3 seconds. At the first 350 cycles (17.5 minutes) the average DR increased with time and has a positive time derivative. From approximately 350 to 500 cycles (25 minutes from the beginning of baking) the average DR did not change significantly (the time derivative is approximately zero). At the end of baking, the value of DR decreases in time (i.e., a negative time derivative), indicating that the cake is ready. Similar results were obtained in cooking apple pie.

[0164] Another baking experiment using a frozen pizza was conducted using apparatus and methods according to some embodiments of the invention. The baking experiments were performed in an experimental RF cooking oven (an oven that employs RF energy for processing, e.g., cooking, food objects) comprising two radiating elements. A frozen ready-to-bake pizza at a temperature of −18° C. (deepfreeze) weighing 500 grams and having a diameter of 30 cm was placed in the experimental RF cooking oven. During the baking experiment, an RF feedback of the average DR (i.e., a computed RF feedback) was monitored together with the temperature (i.e., an indication for the processing state) of the pizza at two locations, one in the center and the other at the edge of the pizza. The results of the monitored average DR and the monitored temperature are presented in the graphs of FIG. **6**A. The temperature divided by 100 (i.e. T[° C.]/100) in the center of the pizza is presented in graph **630**, and the temperature divided by 100 at the edge of the pizza is presented in graph **640**. The average DR measured and calculated for the first and second radiating elements are presented in graphs **610** and **620**. The RF energy application protocols are illustrated as line **650**. A first protocol was chosen to be a "thawing protocol" based on the initial processing state of the pizza. The protocol parameters for applying RF energy were: using frequencies between 800-1000 MHz, supplying energy (SE) to the radiating elements of the RF cooking oven as a function of the DR at each frequency, according to the thawing protocol presented in FIG. **6**B. No energy was applied to frequencies associated with a DR higher than 0.7. Monitoring the temperature showed thawing (i.e., a processing state of the object) of the edge part of the pizza after 20 sec and the inner part of the pizza after 120 sec. Monitoring the average DR, and in particular the time derivative of the average DR, showed a change in the slope of the average DR from positive (dDR/dt=positive number) to a small negative or almost no slope (dDR/dt=approximately 0) after the pizza was thawed (e.g., phase change). The change in the derivative of the average DR may be correlated to a "thawing state" and may be used as a criterion for changing from thawing protocol to baking protocol. After 120 sec of applying a 'thawing protocol', a 'baking protocol' was applied using frequencies between 800-1000 MHz, supplying energy to the radiating elements as function of the DR(f) (the dissipation ratio as a function of the frequency) according to the protocol presented in FIG. **6**C. The maximum available energy was applied at all frequencies associated with a DR lower than 0.7, and a linear correlation between the DR and SE were applied at frequencies associated with DR higher than 0.7. The end of baking was indicated by a user (e.g., a chef) based on the color of the topping cheese (i.e., a processing state of the pizza), which became slightly brown when the average DR reached a value of 0.6. The average DR value of 0.6 may be correlated to an end of baking state of a pizza and may be used as a criterion for terminating the RF energy application when the pizza is fully cooked.

[0165] In another baking experiment, a thawed, unbaked pizza weighing 500 grams and having a diameter of 30 cm at room temperature was placed in an experimental RF cooking oven. During the baking experiment, an RF feedback of the average DR was monitored together with the temperature of the pizza at two locations, one in the center (denoted as ch**2**) and the other at the edge of the pizza (denoted as ch**1**). The results of the monitored average DR and the monitored temperature are presented in the graphs of FIG. **7**. The pizza was indicated as being ready and fully baked when the temperature exceeded 85 [deg]C., after approximately 240 sec. The average DR started to rise after 240 sec, and the derivative of the average DR changed from negative to positive. The change in the derivative may be correlated with the baking state of the pizza and may be used as a criterion for applying the RF energy termination protocol.

[0166] FIGS. **8**A and **8**B are illustrations representing two optional machine readable elements comprising a data indicative of instructions (the instructions being configured to cause the at least one controller to control the energy application to process the object) recorded on each element, in accordance with some embodiments of the invention. In FIG. **8**A illustrates a general data indicative of instructions that includes various protocols (e.g., at least a first protocol and a second protocol) and criteria. FIG. **8**B includes an exemplary recorded element with data indicative of instructions for preparing a pizza. The instructions may include a step for determining the initial processing state of the pizza and a thawing protocol (for example, a protocol presented in FIG. **6**B) if the pizza is frozen. The instructions may further include a criterion for determining if the pizza is thawed and a cooking

protocol (for example, a protocol presented in FIG. **6**C) for cooking the pizza. The instructions may include a criterion for determining if the pizza is ready, such as, for example, a change in the derivative of the average DR, as disclosed with respect to FIG. **7**. The instructions may also include a termination protocol.

[0167] As used herein, if a machine (e.g., a controller) is described as configured to perform a task (e.g., configured to cause application of a predetermined field pattern), then, in some embodiments, the machine performs this task during operation. Similarly, when a task is described as being done in order to establish a target result (e.g., in order to apply a plurality of EM field patterns to the object), then, in some embodiments, carrying out the task may accomplish the target result. As used herein, the term predetermined means only that the associated quantity or value is calculated or otherwise determined beforehand. Predetermined values may include values stored in memory; values calculated, observed, measured, read into, received, etc. before commencement of EM energy processing; or any values calculated, observed, measured, read into, received, etc. during such processing.

[0168] In the foregoing Description of Exemplary Embodiments, various features are grouped together in a single embodiment for purposes of streamlining the disclosure. This method of disclosure is not to be interpreted as reflecting an intention that the claimed invention requires more features than are expressly recited in each claim. Rather, as the following claims reflect, inventive aspects lie in less than all features of a single foregoing disclosed embodiment. Thus, the following claims are hereby incorporated into this Detailed Description, with each claim standing on its own as a separate embodiment of the invention.

[0169] Moreover, it will be apparent to those skilled in the art from consideration of the specification and practice of the present disclosure that various modifications and variations can be made to the disclosed systems and methods without departing from the scope of the invention, as claimed. For example, one or more steps of a method and/or one or more components of an apparatus or a device may be omitted, changed, or substituted without departing from the scope of the invention. Thus, it is intended that the specification and examples be considered as exemplary only, with a true scope of the present disclosure being indicated by the following claims and their equivalents.

What is claimed is:

1. An apparatus for determining a correlation of a processing state of an object, indicated by at least one processing state indicator, with RF feedback received from an energy application zone during processing of the object in the energy application zone, the apparatus comprising:

at least one detector, configured to detect the RF feedback from the energy application zone; and

at least one controller, configured to:

receive from the at least one detector the RF feedback;

receive an indication of one or more processing states of the object; and

determine a correlation between the received RF feedback and the one or more processing states.

2. The apparatus of claim **1**, wherein the controller is further configured to record the correlation between received RF feedback values and the indicated processing states.

3. The apparatus of claim **1**, wherein the indication of the processing state of the object is received from the processing state indicator.

4. An apparatus according to any of the preceding claims, further comprising at least one radiating element configured to apply RF energy to the energy application zone, and wherein the RF feedback are detected by the detector in response to RF energy application by the at least one radiating element.

5. The apparatus of claim **4**, wherein the at least one detector is associated with the at least one radiating element.

6. The apparatus of claim **1**, further comprising at least one processing state indicator.

7. The apparatus of claim **1**, wherein the at least one processing state indicator comprises at least one sensor configured to sense a variable indicative of the processing state of the object.

8. The apparatus of claim **1**, wherein the at least one processing state indicator comprises a first user interface configured to receive from a user an indication of the processing state of the object.

9. The apparatus of claim **1**, comprising a second user interface, configured to display a representation indicative of the processing state associated with the object.

10. The apparatus of claim **9**, wherein the second user interface is configured to display an image associated with the RF feedback.

11. The apparatus of claim **8**, wherein the first user interface is configured to display a representation indicative of the processing state associated with the object.

12. The apparatus of claim **9**, wherein the second user interface is configured to provide an audio representation indicative of the processing state associated with the object.

13. The apparatus of claim **9**, wherein the representation indicative of the processing state of the object comprises a representation of the RF feedback detected by the detector.

14. The apparatus of claim **1**, further comprising the energy application zone and at least one heat source configured to heat the object.

15. The apparatus of claim **1**, further comprising the energy application zone and at least one RF source configured to supply RF energy for processing the object.

16. The apparatus of claim **15**, wherein the at least one controller is further configured to cause application of RF energy at a first power level to heat the object and cause application of RF energy at a second power level to generate the RF feedback, wherein the first power level is higher than the second power level.

17. The apparatus of claim **1**, wherein the processing states of the object include an initial state of the object.

18. The apparatus of claim **1**, further comprising a memory, and wherein the at least one controller is configured to record the correlation on the memory.

19. The apparatus of claim **1**, wherein the at least one controller is further configured to record the correlation on a machine readable element associated with the object.

20. A method of determining a correlation between a processing state of an object and RF feedback, comprising:

processing the object;

receiving indication of one or more processing states of the object during the processing of the object;

applying RF energy to an energy application zone and receiving RF feedback from the energy application zone during the processing of the object; and

determining a correlation between the RF feedback and the one or more processing states of the object.

21. The method of claim **20**, further comprising recording the correlation between the RF feedback and the one or more processing states of the object.

22. The method of claim **20**, further comprising receiving from a sensor values of a variable indicative of the at least one processing state of the object.

23. The method of claim **20**, further comprising receiving through a user interface an indication indicative of the one or more processing states of the object.

24. The method of claim **20**, wherein receiving an indication indicative of the one or more processing state of the object comprises receiving an indication of at least one of a phase of the object, a physical property of the object, or a chemical property of the object.

25. The method of claim **20**, wherein the object includes a food item and the processing states include cooking states of the object.

26. The method of claim **20**, wherein recording the correlation comprises recording on a memory associated with a controller associated with the energy application zone.

27. The method of claim **20**, wherein recording the correlation comprises recording on a machine readable element associated with at least one of the object.

28. The method of claim **20**, further comprising controlling processing of an exemplar of the object based on the correlation.

29. The method of claim **20**, further comprising displaying an indication of the one or more processing state of the object.

30. The method of claim **20**, further comprising displaying a representation of the RF feedback received from the energy application zone.

31. The method of claim **29**, wherein displaying includes visual displaying.

32. The method of claim **29**, wherein displaying includes providing an audio displaying.

33. The method of claim **30**, wherein displaying includes visual displaying.

34. The method of claim **30**, wherein displaying includes providing an audio displaying.

35. The method of claim **20**, wherein the RF feedback includes an EM energy absorbability indicator of the object.

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