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(54) **HEATING CELL, HEATER USING SAME, HEATING SYSTEM AND USE THEREOF**

(57) The present invention details a solution to the problem of transforming, with high efficiency, microwave energy into heat by means of heating units in the form of low-power heating cells that allow microwave energy to be propagated along transverse electromagnetic mode

electrical transmission lines to ceramic materials with high dielectric loss in the microwave region. Said low-power heating cells are integrated in a heating unit. The set of heating units form a heating system with microwave energy that uses an electric low-power line.

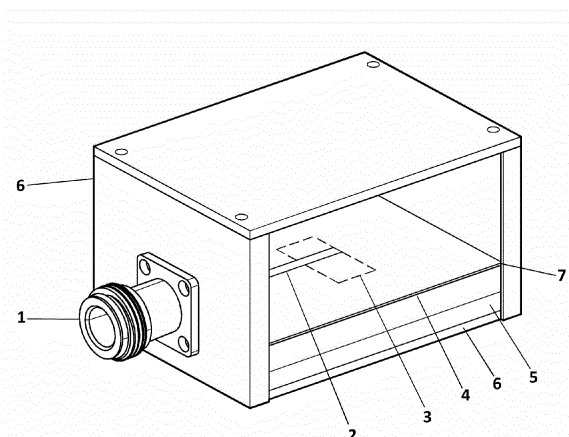


FIG. 1

Description**OBJECT OF THE INVENTION**

5 **[0001]** The present invention belongs to the field of heat generation systems, in particular to a heating system that uses ceramic pieces as heat emission elements which are heated by means of microwave radiation distributed by planar technology.

10 **[0002]** More specifically, the present invention is aimed at a heater element that uses ceramic compositions adapted as transducers that contain microwave radiations susceptors capable of absorbing the microwave radiation and transforming it into heat.

BACKGROUND OF THE INVENTION

15 **[0003]** Thermal radiation, or heat radiation, is the radiation emitted by a body due to its temperature. A radiator is a type of heat emitter with the function of exchanging heat from the heating system to release it into the environment and, generally, it is a device without moving parts nor heat production. Radiators are discrete elements that form part of centralized heating installations. In their origin, the first heating systems used steam and the high surface temperature of the radiators to produce heat exchange by means of radiation. The replacement of steam radiator by water reduced operating temperatures and, given the little surface area of the radiators, means that most of the heat is exchanged by convection.

20 **[0004]** The emission or dissipation of heat from a radiator depends on the temperature difference between its surface area and the surrounding environment and the amount of surface area in contact with that atmosphere. The larger the heat exchange area and greater temperature difference, the larger the exchange. In air conditioning installations and especially heating installations, an emitter is a device that emits heat, releasing it into the inhabited environment.

25 **[0005]** A heater incorporates heat generation elements and a thermal radiator or thermal emitter. An example would consist of an apparatus which is heated by an electrical resistance incorporated inside the thermal emitter. In this example it uses the term of thermal radiator, however, the difference between a radiator and a heater lies in the fact that the radiator does not produce energy, it limits to being a dissipator of the heat that reaches the radiator, generally through a network of pipes where through a carrier fluid circulates which has been heated in a heat producing device situated in another place.

30 **[0006]** An electrical heater is generally a unitary element that uses an electrical resistance to produce heat. Electrical resistances have high energy consumption that requires a significant electrical power. Typically, a unitary element consumes around 2 kW/h. According to standard ISO 7730 thermal comfort is defined as "the condition of mind that expresses satisfaction with the thermal environment." This parameter is not simple to calculate since it considers for this numerous factors from location, orientation and ventilation of the property to activities performed in it and dress of its inhabitants. For typical conditions of use, it is estimated that the optimum comfort temperature is 22 °C.

35 **[0007]** A heating system requires a set of heating elements which involves considerable power supply. The radiation efficiency basically depends on the thermal inertia of the heat exchange material. Normally, this material is metal, which makes continuous electricity supply necessary to maintain its high temperature, since the metal materials have very low specific heat. Ceramic heaters that incorporate a ceramic element have a greater thermal inertia. A heater with ceramic element will need between 80-100 W for every m², depending on the average insulation quality. A typical 80 m² home would require at least between 6 and 8 kW/h of minimum contracted electricity to need the heating system demands.

40 **[0008]** The advantages of electrical heaters are related to the absence of gas emissions or waste in the place of heat production, i.e. in the heater.

45 **[0009]** With the aim of increasing the efficiency of heating systems, heat accumulators are incorporated for their sustained and prolonged release during a certain time. One of the elements used as heat accumulators are ceramic blocks with high thermal inertia due to their low thermal conductivity and high density. An application of heaters with thermal accumulator is related to accumulating heat in hours of excess heat production and releasing this without electricity consumption in hours of greater demand. Heating systems with ceramic accumulators have the limitations related to the use of electrical resistances and their low efficiency, since due to the effect of the same thermal inertia which allows these ceramic materials to release their heat very slowly, one of the limitations of the state of the art is related to the fact that ceramic materials require a very prolonged time for their heating when electrical resistances are used.

50 **[0010]** Therefore, the state of the art requires new solutions that resolve said problems. Among the possible solutions, the use has been considered of microwave radiation as heat generation system.

55 **[0011]** Microwaves are called those electromagnetic waves defined in a determined frequency range; generally between 300 MHz and 300 GHz, which involves an oscillation period of 3×10^{-9} s to 3×10^{-12} s and a wavelength in the range of 1 m to 1 mm. Other definitions, for example, of standards IEC 60050 and IEEE 100, situate their frequency

range between 1 GHz and 300 GHz, i.e. wavelengths between 30 centimetres to 1 millimetre.

[0012] As in the case of other types of electromagnetic waves, microwaves can propagate through dielectric media and be transmitted or reflected in the interfaces formed by the discontinuities between different media. From mid-20th century, some applications have appeared wherein microwave energy has been used as medium to transfer energy to materials, making use of their interaction therewith.

[0013] One of the best known microwave applications is the microwave oven, that uses a magnetron to produce waves at a frequency of approximately 2.45 GHz. These waves make the water molecules vibrate or rotate thus generating heat. Since most food contain a significant part of water, they can easily be cooked in this way. The water, fats and other substances present in food absorb energy from microwaves in a process called dielectric heating. Many molecules are electric dipoles, i.e. they have a partial positive charge at one end and a partial negative charge at the other end and, therefore, they rotate in their attempt to align with the alternate electric field of the microwaves. On rotating, the molecules collide with others and place them in movement, thus dispersing the energy. This energy, when dispersed as molecular vibration in solids and liquids transforms into heat.

[0014] Microwave applicators are typically multimodal cavities, and the interaction between the various electromagnetic modes which are propagated therein and their multiple reflections promote a highly irregular distribution that gives rise to not very homogeneous heating, with the appearance of hot and cold points. Furthermore, these techniques based on multimodal cavities are usually techniques in disadaptation, an aspect which implies that a substantial part of the energy delivered to the load is again reflected towards the source, thus reducing the efficiency of these methods.

[0015] Microwave energy cannot heat all materials: only those which, due to their composition, are capable of absorbing electromagnetic energy and generating heat, such as water. Other materials, such as metals, reflect microwaves in the same way as a mirror reflects visible light. Finally, there are dielectric materials such as ceramics with compositions such as, for example, alumina, which is not capable of absorbing microwave energy, letting it pass through in the same way as light passes through transparent glass.

[0016] Likewise, there is a set of materials called "susceptors" due to their great capacity to absorb electromagnetic energy and turn it into heat, see M. Gupta, Microwaves and metals. John Wiley & Sons, Singapore 2007. They are usually conductive metals such as graphite, although stainless steel, molybdenum, silicon carbide, aluminium or other conductive materials can also be used, which are embedded in a dielectric matrix.

[0017] In the state of the art, different solutions are disclosed to heat a microwave radiation-absorbing body. In some cases, radiators are used with liquids, for example in document DE19949013 or ceramic elements such as in document RO117643 or in document US20060639602 to preferably absorb the microwave radiation and store said energy in the form of heat with the object of maintaining the temperature in a more prolonged manner. The problem not resolved in the state of the art lies in the fact that the transmission of microwaves to a dielectric medium, even if this is a potential susceptor, is not so immediate. A problem in the state of the art consists of, in many cases, the interface between the air and the microwave susceptor being practically a Magnetic Wall, since said materials normally have a very high dielectric constant (for example, water - $\epsilon' \approx 76$, hepatic tissue - $\epsilon' \approx 44$ or silicon carbide (SiC) - $\epsilon' \approx 10$) whilst air has $\epsilon' \approx 1$. The solutions used to transform microwave energy into heat are limited by the efficiency of the unit formed by the microwave emitter and the dielectric medium that absorbs the microwaves. The problem consists of the fact that the lack of adapted systems reduces the efficiency, also generating problems of electric discharges on a first level, which are also sources of uncontrolled microwave radiation. In this technical field, document EP2090869 is known, detailing a heating element using microwaves that makes use of an electrical transmission line in the microwave band, a transmission line disposed on a dielectric material.

[0018] In the state of the art, there are also solutions to homogenize the temperature by means of the use of mode agitators and moving elements. However, these solutions require methods which are cumbersome, introduce mechanical elements and are, in any case, undesirable in a domestic heating system.

[0019] This invention tackles a novel solution to the problem of transforming, with high efficiency, microwave energy into heat by means of heating units in the form of low-power heating cells that allow microwave energy to be propagated along transverse electromagnetic mode electrical transmission lines to ceramic materials with high dielectric loss in the microwave region. This heat transduction is performed in adapted manner in high-efficiency regions. Said low-power heating cells are integrated in a unitary heater that has autonomous operation and is characterized in that it generates heat non-reciprocally, i.e. the heating time is considerably less than the heat-release time. The set of unitary heaters form a heating system wherein they are sequentially supplied with microwave energy between the unitary heaters. The heating system thus constituted uses an electrical low-power line which makes it possible to considerably reduce the electricity supply requirements related to conventional high-power heating systems.

DESCRIPTION OF THE INVENTION

[0020] For a better understanding of the invention, a list shall first be provided with the corresponding definitions of the terms used throughout this document.

- The term "heating cell" is understood to mean a minimum structural unit of heat generation comprising a transverse electromagnetic mode electrical transmission line and a high dielectric loss ceramic material.
- The term "microstrip-based heating cell" is understood to mean a heating cell based on microwave signal transmission, which has a conducting strip separated from the ground strip by a layer of dielectric substrate; said heating cell is microstrip-based and corresponds to a transverse electromagnetic mode electrical transmission line formed by a flat conductor placed on a fine substrate, which in turn rests on a ground plane capable of radiating electromagnetic waves to the high loss ceramic material which is interposed in it, thus transferring the energy to it in adapted and resonant form.
- The term "stripline heating cell" is understood to mean a heating cell based on the type of transmission line for TEM modes (Transverse Electromagnetic) called stripline and corresponds to a transverse electromagnetic mode electrical transmission line formed by a conductor embedded in a high loss ceramic material and which absorbs the electromagnetic energy propagated by said transmission line as it advances.
- The term "unitary heater" is understood to mean the heating apparatus that integrates several heating cells of any of the aforementioned classes and which involves the minimal functional autonomous unit.
- The term "heating system" is understood to mean the set of unitary heaters controlled by a computer system.
- The term "power splitter" is understood to mean a device that distributes the power received at its input among n outputs, typically in equal form. Power splitters are used in radiofrequency and microwaves, optical communications etc., to send to various devices the power received by a single port, maintaining the adapted impedances to have a low level of reflected power.
- The term "microwave susceptor" is understood to mean a material that has the capacity to absorb the electromagnetic radiation in the microwave band and turn it into heat that is generally re-emitted in the form of infrared radiation.
- The term "high loss ceramic material" is understood to mean a non-metal and formed inorganic material which has the capacity to absorb the electromagnetic radiation and turn it into heat which is generally re-emitted in the form of infrared radiation.

[0021] A first aspect of the present invention relates to a heating cell comprising a monomodal transverse electromagnetic mode electrical transmission line, a monomodal transverse electromagnetic mode power splitter and an electric charge in the form of high loss ceramic material which is coupled to said electrical transmission line and characterized in that it has electromagnetic wave absorption in the microwave frequency. The heating cells of the heating system are characterized by transforming the electromagnetic radiation at the microwave frequency into thermal energy by heat generation.

[0022] In a preferred embodiment of the first aspect of the present invention, the monomodal transverse electromagnetic mode electrical transmission line may be chosen from:

- microstrip defined as a printed circuit board comprising a conductive metal sheet separated from a ground metal sheet by a dielectric sheet. This transmission line ends in a slot antenna in microstrip ground plane designed to radiate energy directly to the high loss ceramic material with the aim of transferring the energy transported by the line to it.
- stripline defined as a metal central conductor between two ground planes equidistant thereto. The space between the ground planes and the conductor is filled by high loss ceramic material, so that the energy propagation by the transmission line is directly transferred to said high loss ceramic material.

[0023] In a preferred embodiment of the first aspect of the present invention, the microstrip heating cell is characterized in that it has resonant and monomodal electromagnetic mode electric transmission, based on the radiation of a microstrip antenna on a thick layer of microwave susceptor material or electric charge. The microwave susceptor material is placed in the reactive near field area of the antenna, which extends from the source of excitation at a distance of approximately $\lambda/(2\pi)$ where λ is the wavelength of the microwave radiation and π is the pi constant with a value of 3.1416.

[0024] The microstrip heating cell includes in a same metal structure, for example of aluminium, a slot antenna in microstrip ground plane supported on a dielectric substrate plate, powered by a transmission line and connected to an N-type input connector. The load is kept joined to the slot in the form of high loss ceramic material to heat and between both is placed a heat insulation material, transparent to microwaves. The heating cell comprises a reflective metal structure in its base which directs the radiation towards the load in the form of high loss ceramic material. The microstrip cell is reinforced with electrical conductors in all its side walls and also in the free surface area of the high loss ceramic material to heat.

[0025] As is known in the basic theory of antennas, any material placed in the near-field of an antenna can disadapt it due to the electromagnetic field radiated to this region, if it is reflected in anyway, it induces currents in the antenna with a determined phase ratio with the original excitation. Said effect leads to a storage of energy in the free electrons of the antenna during a determined part of the oscillation, followed by the consequent release thereof and creating the

reactive effect that gives this region its name. This obliges the adaptation of impedances for the presented contour condition, giving the microstrip heating cell its resonant character.

[0026] When we take the case of a flat wave travelling in a medium with linear, homogeneous and isotropic losses, all the information relating to the power flow in the medium may be obtained from the Poynting theory. In a dielectric medium, without internal electrical or magnetic sources, the dissipated power may be calculated using the following expression:

$$P_d = \omega/2 \int_V (\epsilon_0 \epsilon'' |E \rightarrow|^2 - \mu_0 \mu'' |H \rightarrow|^2) dV \quad [1]$$

[0027] With P_d being the power dissipated in the material, ω the angular frequency of excitation, ϵ_0 the dielectric permittivity of the vacuum, ϵ'' the complex component of relative permittivity of the material, μ_0 the magnetic permeability of the vacuum, μ'' the complex component of the relative permeability of the material, $E \rightarrow$ the electric field vector and $H \rightarrow$ the magnetic field vector.

[0028] The equation [1] is suitable for calculating the power dissipation for a flat plane propagated inside a material, once inside thereof. Supposing that the material does not have magnetic losses ($\mu'' = 0$), and taking the excitation as an approximation, the integral of the dissipated power can be calculated. To do this, the excitation shall be taken as uniform in the XY plane (the plane coinciding with the face of the closest sample to the antenna) and approximated by a flat wave propagated in the direction of the Z axis. Although the electromagnetic problem is much more complex than this approximation, the dimensions of the sample are small compared with its high thermal conductivity

($k \cong 400 \frac{W}{m} \cdot K$), which makes the error of approximation negligible for the thermal result. In this sense the dissipated power may be determined by means of the following ratio.

$$P_d \cong P_{ent} (1 - e^{-(2\alpha h)}) (1 - \Gamma^2) \eta_r \quad [2]$$

[0029] Where α is the coefficient of losses of the real part of the complex propagation constant γ , which includes the dependency of the excitation frequency f and with the material loss factor $\tan\delta$; h is the thickness of the material sample; Γ is the reflection factor of the antenna; and η_r is the radiation efficiency of the antenna. The radiation efficiency and the reflection factor can be easily optimized by means of the antenna design, therefore having zero effect in the efficiency. The energy absorption efficiency depends on the ratio between the penetration depth ($1/\alpha$) and the sample thickness, a ratio wherein the excitation frequency has key importance. The dissipated power, therefore, depends on the frequency and on the loss factor. These calculations make it possible to establish a range of characteristics of the high loss ceramic material required for its adaptation to high-efficiency regimes.

[0030] In a preferred embodiment of the first aspect of the present invention, the electrical load in the form of high loss ceramic material is coupled to the electrical transmission line and is characterized in that it has electromagnetic wave absorption in the microwave frequency. The microwave absorption in the ceramic material is produced due to the existence of dielectric losses therein, such as, for example, a sintered SiC ceramic or the presence of susceptor particles embedded in a ceramic matrix. The microwave radiation-absorbing elements transform said microwave radiation into heat, which is transferred to the rest of the ceramic matrix by conduction and shall be released into the environment by radiation with the thermal inertia corresponding to a ceramic material. Consequently, this new material behaves non-reciprocally in terms of heating time. And as shall be seen later on, the heating time is faster than the cooling time, resulting in an advantage to obtain high-efficiency heat generators.

[0031] In a preferred embodiment of the first aspect of the present invention the high loss ceramic material is characterized by a loss factor in the microwave frequency of at least 0.10.

[0032] In another preferred embodiment of the first aspect of the present invention, the high loss ceramic material used in the microstrip heating cell consists of a SiC ceramic plate of $5 \times 5 \text{ cm}^2$ of surface area and a thickness of 0.7 cm, with a density of 99% with respect to the theoretical density, relative permittivity and high loss factor ($\epsilon' \cong 10$, $\tan\delta \cong 0.16$). In the proposed scenario and for this high loss ceramic material of dense SiC, the efficiency of the heating cell of the present invention only depends on the adaptation of the microstrip antenna and its radiation efficiency. With the aim of maximizing the radiation efficiencies and given that the calculations in near fields in a material medium with losses may be very complex, it is possible to obtain a reasonable solution by means of electromagnetic simulation. The simulation calculation shows a radiation efficiency of $\eta_r = 99.8\%$ with an impedance adaptation better than $S_{11} = -20 \text{ dB}$, achieving a total efficiency close to 99%. Such a high efficiency value is a clear advantage for the state of the art to enable the transformation of electrical energy into heat with energy losses appreciably less than other systems available in the state of the art of heating systems.

[0033] The dense SiC high loss ceramic material with a mass of 50 grams is characterized by increasing its temperature by 150°C when it is subjected during 30 seconds to microwave radiation of 2.45 GHz inside a conventional 1000 W microwave oven. In terms of power supplied per unit of mass to produce a $\Delta T \sim 50^\circ\text{C}$ required to act as heater, the sample consumes 55.6 kWh.Kg⁻¹. The time required to decrease its temperature from the maximum temperature reached in 1/3 is of 300 seconds. The cooling rate in the range of temperatures of interest, i.e. from 90 to 70°C to maintain the $\Delta T > 50^\circ\text{C}$ required to heat is 0.08 °C.s⁻¹. Where the heating rates of the ceramic plate show values between 4.85 °C/s and 6 °C/s, whilst the cooling rates of said ceramic plate are less than more than one order of magnitude with values less than 0.267 °C/s. The heating rates generated by the absorption of microwaves and the cooling rates generated by heat radiation are different. The high loss ceramic material acts as reciprocal heat generator since it absorbs the microwave energy, generating heat in a time considerably less than that required to release heat into the medium. The difference between the heating and cooling rates may be optimized by means of the composition of the high loss ceramic material. In accordance with the determined temperature increase, the power transfer is not total due to the non-uniform distribution of the fields in the high loss ceramic material and in the microwaves due to the reduced size of the ceramic in comparison with the size of the multimodal cavity.

[0034] In another preferred embodiment of the first aspect of the present invention the high loss ceramic material used in the microstrip heating cell is a composite material comprising at least 50% by weight of SiC particles and the rest is constituted by porosity and a silicon-aluminous compound to maintain the silicon carbide grains consolidated. The production procedure followed is to mix 50% by weight of SiC particles with 32.5% by weight of kaolin clay and 17.5% by weight of a talc mineral. The mixture is homogenized following processes known in the field of ceramic material processing and the mixture is optimized to achieve a suitable paste for dry pressing, for example by wetting means. The pressing is performed by means of uniaxial pressure at a pressure of 250kg/cm² and the pieces obtained dry during 24 hours in an oven at 80°C. Later, the ceramic plates undergo heat treatment in an air atmosphere between 1100 and 1250°C maintaining the heating temperature for at least 30 minutes. The heating rates are greater than 3°C per minute and the natural cooling although not restricted to this thermal cycle.

[0035] In another preferred embodiment of the first aspect of the present invention, the high loss ceramic material used in the microstrip heating cell consists of a porcelain ceramic plate of a composite material of the aforementioned composition of 8x3 cm² of surface area and a thickness of 0.7 cm, comprising 50% by weight of SiC particles with an average particle size greater than 3 μm and with a density of 85% with respect to the theoretical density, relative permittivity and high loss factor ($\epsilon' \geq 13$, $\tan \delta \geq 0.16$).

[0036] In an alternative embodiment of the first aspect of the present invention, the high loss ceramic material used in the microstrip heating cell consists of a porcelain ceramic plate of a composite material of the aforementioned composition of 14.8x14.8 cm² of surface area and a thickness of 1.1 cm. The porcelain high loss ceramic material of the aforementioned composition of 1300 grams of mass is characterized in that it increases its temperature by 120°C when it is subjected during 90 seconds to microwave radiation of 2.45 GHz inside a conventional 1600 W microwave oven. In terms of power supplied per unit of mass to produce a $\Delta T \sim 50^\circ\text{C}$ required to act as heater, the sample consume 3.9 kWh.Kg⁻¹. The time required to decrease its temperature from the maximum temperature reached in 1/3 is of 1260 seconds. The cooling rate in the range of temperatures of interest, i.e. from 90 to 70°C to maintain the $\Delta T > 50^\circ\text{C}$ required for heating is 0.025°C.s⁻¹.

[0037] The high loss ceramic material formed as a composite material comprising SiC particles has an advantage for the absorption of microwave energy since it requires power consumption per unit of mass appreciably lower than those used for a dense SiC plate and the cooling rate is also slower. Additionally, the composite materials are formed according to procedures known in the ceramics industry thus providing a large availability of forms and dimensions within the limits of the art and which are advantageous for providing elements for the high loss ceramic material.

[0038] In another alternative embodiment of the first aspect of the present invention, the microstrip heating cell is modified incorporating a conductor plane in the free face of the high loss ceramic material so that the surpluses of the power absorption are not lost in free space on again being reflected to the sample and the antenna, and finally being absorbed after various reflections between the electric walls of the cell. The conductor plane is formed, for example, by a metal material such as aluminium, tin, stainless steel or by a coating which has metal conduction, for example, a silver plate coating. In this way, it manages to make the energy absorption percentage independent from material thickness. This new design has a considerable advantage since to avoid the inefficiency of the heating unit it incorporates a conductor plane which also has the advantage of improving device safety as it prevents microwave radiation exiting the heating unit. Another advantage of the present invention on incorporating an electrical load in the form of high loss ceramic material is that it avoids the non-uniformity of the electric field given its reduced size with respect to the source and the thermal conductivity of said ceramic particles.

[0039] In an even more preferred embodiment of the first aspect of the present invention, the conductor plane in the free face of the high loss ceramic material of the heating cell incorporates metal channels to increase its surface area and more efficiently transfer heat to the air. The increase in the heat exchange area in the conductor plane allows the upward flow of heated air and acting as calorific energy dissipator and radiator element. The metal conductor plane with

high surface area has an advantage as it acts as heat dissipator element.

[0040] In another even more alternative embodiment of the first aspect of the present invention, the stripline heating cell is characterized in that it has a monomodal electromagnetic mode electrical transmission with high losses and very broad band. The stripline cell comprises a conductor housed inside a ceramic material with high dielectric losses which acts as microwave susceptor or electrical load, thus forming a transmission line with very high losses, which is absorbent in a frequency band comprising the microwave frequency region among which is included the ISM band of 2.45 GHz.

[0041] The ceramic particles used in the stripline cell are physically coupled to the electromagnetic energy transmission antenna to maximise energy absorption in the form of microwave radiation and its effective conversion into heat. This physical coupling is characteristic of the type of transmission line used in the present invention. Additionally, the dimensions and properties of the electrical load in the form of high loss ceramic material need to be adapted to the parameters of the electromagnetic energy transmission line.

[0042] In any of the possible embodiments of the first aspect of the invention, the heating cell where it is of stripline type, is characterized in that the central conductor is a metal material whose resistance to the passage of electricity is very low. The best electrical conductors are metals, such as copper, gold, iron and aluminium, and their alloys, although there are non-metal materials that may also fulfil this function. The form of the central conductor is chosen from the typical forms presented for metal conductors such as circular-section wires obtained by wire drawing techniques or rectangular section-sheets obtained by rolling. The form of the central conductor of the stripline line is reproduced in negative inside the high loss ceramic material. Whilst the high loss ceramic material used in the stripline heating cell is a ceramic material such as the aforementioned comprising 50% by weight of SiC particles and the rest is constituted by porosity and a silicon-aluminous compound to maintain the silicon carbide grains consolidated.

[0043] The ceramic material has an internal cavity of sufficient dimensions to house the central conductor. This cavity is previously made by a sintering process of the material or is made on the sintered ceramic materials by machining the ceramic pieces following methodologies known in the state of the art. There is the possibility that the high loss ceramic material used in the stripline heating cell comprises two pieces of high loss ceramic materials so that a cavity or negative has been made on one of the respective faces of dimensions corresponding to the length of the central conductor and to half of its section. The two pieces join together so that the stripline line is linked inside. The ceramic pieces can be joined, for example, using an adhesive. The use of ceramic adhesives which withstand high temperatures result in an advantage for the correct operation of the device. The use of pieces of ceramic materials which reproduce in negative the stripline line gives a clear advantage for the manufacturing of stripline heating cells as it allows economically reproducing pieces of suitable dimensions based on the large flexibility of forms of the ceramic processes.

[0044] In those embodiments where the heating cell is stripline type, the form of the central conductor and its thickness depends on the cross-section of the transmission stripline line, being chosen according to this to obtain the desired propagation characteristics. The stripline heating cell is converted in an electromagnetic radiation transducer into heat with the capacity of converting the power of the wave that is propagated into heat by means of a minimum transmission line length. The stripline line ends in a short-circuit and has a sufficient length to transduce all the power accepted in a large bandwidth. As is known from the transmission lines theory, the loss of power in a transmission line loaded with a short-circuit may be determined by means of the following formula:

$$P_{loss} \Big|_{Z_L = \infty} = \frac{|V_0^+|^2}{2Z_0} (e^{2\alpha l} - e^{-2\alpha l}) \quad [3]$$

With P_{loss} being the power loss in the material that fills the transmission line, V_0^+ the value of the incident voltage wave in said line, Z_0 , the characteristic impedance of the line, α the aforementioned loss coefficient and l the length of the transmission stripline line.

[0045] Both the progressive wave and the regressive wave produced by the reflective load contribute to the power loss following an exponential law that only depends on the line length (l) and the loss coefficient (α_l). Taking a possible form of the cylindrical central conductor, figure 11 shows the characteristic impedance of the line for different diameters of the central line (D) at the frequency of 2.45 GHz.

[0046] The heating cell of the first aspect of the present invention, the based heating system may have a monomodal transverse electromagnetic mode power splitter comprising n outputs, with n being a positive natural number greater than 1. A non-normalized power splitter distributes the power in at least two transmission lines in an equal manner maintaining the adapted impedances to have a low level of reflected power. A particular case consists of the use of Wilkinson-type power splitters that have an even number of output elements.

[0047] The use of power splitters has the advantage of uniformly distributing the power in the different electromagnetic mode electrical transmission lines. The incorporation of a number of at least two microstrip heating cells or stripline heating cells allows the use of a magnetron-type source of microwave radiation with powers of up to 1000 W. The

microwave radiation is conducted through a coaxial guide, and the coupling between the microwave radiation generated by the magnetron and said distribution network is performed by means of the use of a coupler, for example, a WR340 guide-coaxial adapter. Since the power of a magnetron is clearly greater than the power that may be dispersed by means of a single heating cell, the use of power splitters allows dividing it so that, for example, from a magnetron which has 800 W of microwave radiation and by means of 7 power splitters it is possible to supply 8 heating units which can dissipate a maximum power in each one of them of 100 W. The use of 15 splitters also provides a supply of microwave energy for the supply of 16 heating units which can dissipate a maximum power, each one of them, of 50 W.

[0048] In a preferred embodiment of the second aspect of present invention, the high loss ceramic material used corresponds to a single piece whose surface area is sufficient to house the microstrip antennas in a number such that the power supplied by the magnetron may be dissipated. This aspect results in a clear advantage for the generation of heating units for heating systems as it allows the use of ceramic surface area of a larger size than that described in the preferred embodiments of the first aspect of the present invention. Likewise, another advantage is that of homogeneously and efficiently heating an electromagnetic radiation-absorbing ceramic piece in the microwave range of a surface area of dimensions greater than that required for a unit cell.

[0049] In another preferred embodiment of the second aspect of present invention the high loss ceramic material used corresponds to two pieces in which surface area a cavity or negative has been made of dimensions corresponding to the length of the central conductor and to half of its section so that the stripline lines are housed in a number such that the power supplied by the magnetron may be dissipated.

[0050] In another preferred embodiment of the second aspect of present invention the high loss ceramic material used corresponds to a piece wherein the stripline lines are housed such that the power supplied by the magnetron can be dissipated.

[0051] In a third aspect of the present invention, it consists of a heating system comprising heaters which in turn comprise the heating cells of the first aspect of the invention comprising a transverse electromagnetic mode electrical transmission line and ceramic particles coupled with dielectric losses. Each unitary heating system comprises a control system which allows synchronizing the electricity supply time so that only one of the unitary heating system is consuming energy and limited to the maximum power of the magnetron, for example 800 W. Each unitary heating system uses a time to heat by absorption of microwave energy which is a time appreciably less than that required to dissipate the calorific energy stored by said charge. In this way, it is possible to have heating times of the heating cells sufficient to have a set thereof at the required temperature to be able to be used as heating system. For example, 6 heating systems which require 1 minute to be heated from 20 °C to 80 °C consuming 800 W they can act in synchronized manner by means of the corresponding control system to be heated with a maximum total power of 800 W. In this way, this embodiment results in a clear advantage with respect to the state of the art in heating systems as it allows having a high efficiency system limiting the power supplied by the electrical installation.

[0052] The synchronization system between the different heating cells is performed by means of a wifi-type wireless system or wired such as PLC-type, resulting in a clear advantage, since it allows coupling different unitary heaters without the need for their being interconnected physically. The heating system also comprises a temperature data capture system, a programming system and an algorithm to efficiently distribute the heating times between the different unitary heating systems so that it uses the electricity efficiently. The heating system thus designed has the advantage of being flexible in its configuration.

[0053] In another preferred embodiment of the third aspect of the present invention, the heating system that comprises heating cells comprising a transverse electromagnetic mode electrical transmission line and ceramic particles coupled with dielectric losses is used to provide thermal comfort in the form of heating for spaces such as: domestic rooms, offices, commercial premises, industrial premises and in general inhabited spaces.

[0054] In any of the different aspects of the invention described here, the thermal heater may have an operating control to be integrated in a network of radiators which form a heating system with a considerable improvement in energy efficiency over a network of radiators of any other technology.

[0055] A fourth aspect of the invention relates to the use of the heating system using microwave radiation of the third aspect of the invention for thermal comfort in the form of heating for spaces as domestic rooms, offices, commercial premises, industrial premises and, in general, inhabited spaces.

DESCRIPTION OF THE DRAWINGS

[0056] To complement the description being made and in order to aid towards a better understanding of the characteristics of the invention, in accordance with a preferred example of practical embodiment thereof, a set of drawings is attached as an integral part of said description wherein, with illustrative and non-limiting character, the following has been represented:

Figure 1. Shows a diagram of the microstrip heating cell comprising an N-type input connector, a metal transmission

line, a slot antenna in microstrip ground plane, a thermal insulating material transparent to microwaves, a high dielectric loss ceramic material, a metal structure which completely encloses the cell whose base forms the reflector plane and the dielectric substrate plate which supports the microstrip *line*).

Figure 2. Shows a graphic called Smith chart that represents the reflection factor of the stripline heating cell both in module and in phase in accordance with the electrical length of the cell. From the figure it is deduced that both module and phase are decreasing with the electrical length, considering the responses contained inside the broken line as sufficient.

Figure 3. Shows a graphic which represents the parameter S_{11} as the ratio between the reflected microwave signal with respect to the input signal of the efficiency parameter in accordance with the microwave frequency for a microstrip heating cell when it is designed for radiation in free space, loaded with a microwave susceptor and finally redesigned to be adapted using a high loss ceramic material.

Figure 4a-4c. Shows heating graphics of high loss ceramic materials in a multimodal microwave oven in accordance with the exposure time to microwave radiation.

Figure 5. Shows a diagram of the stripline heating cell comprising ground planes, high loss ceramic material and a transmission line formed by a central conductor.

Figure 6. Shows a graphic which represents the parameter S_{11} as the ratio between the reflected microwave signal with respect to the input signal or the efficiency parameter in accordance with the microwave frequency for a stripline heating cell for different lengths of the transmission line.

Figure 7. Shows a diagram of the stripline heating cell comprising transmission lines in a single piece comprising ground plane, high loss ceramic material and transmission lines formed by central conductors.

Figure 8. Shows a diagram of a grouping of microstrip heating cells for the uniform heating on a larger piece of high loss ceramic material, by means of the use of microstrip lines in Wilkinson splitter configuration, and slot antennas in ground plane.

Figure 9. Shows a diagram of the components that integrate a heating unit, namely the heating cells, Wilkinson power splitters, non-normalized power splitter, the coaxial guide transition, the magnetron and the pertinent connections using coaxial cable.

Figure 10. Shows a diagram of the components integrating a heating system, namely different heating units, a control unit and a data connection for the control that can be wifi or PLC.

Figure 11. Shows a table that relates the diameter of the central conductor of the stripline cell with the characteristic impedance of the line viewed from the excitation plane.

Figure 12. Shows a table where it shows the value of the dispersion parameter S_{11} and the corresponding percentage of power absorbed at the frequency of 2.45 GHz for different lengths of transmission line, once the diameter of the central conductor of the line in $D=1$ mm has been fixed.

PREFERRED EMBODIMENT OF THE INVENTION

[0057] As practical embodiment of the invention, and without limiting character thereof, various examples of embodiment of the heating cells are described below, powered by a stripline transmission line, of one of the aspects of the invention that simply implement the main concepts object of this invention.

[0058] In the first aspect of the invention relating to a heating cell from microwave radiation, said heating cell comprises in a metal structure (6) equipped with a base, at least one input connector (1), a monomodal transverse electromagnetic mode electrical transmission line (2) acting as an antenna (3) and that is made at least of metal and/or ceramic material, a high dielectric loss ceramic material (5,9) where to the antenna (3) is fixed, and a reflector plane defined by the base of the metal structure (6) and located along the electrical transmission line (2), with λ being the wavelength of the incident radiation in the cell, with the reflector plane directing said microwave radiation towards the high dielectric loss ceramic material (5,9).

[0059] Additionally, it is possible to equip the heating cell with a monomodal transverse electromagnetic mode splitter.

[0060] In a possible first embodiment, the heating cell from microwave radiation may have the electrical transmission line (2) defined by a conductive metal sheet separated from a ground metal sheet by a dielectric sheet and fixed to a slot of the high dielectric loss ceramic material (5) and supported by a dielectric substrate plate (7). In this possible embodiment, the heating cell additionally comprises an insulating material transparent to microwaves (4), located between the high dielectric loss ceramic material (5,9) and the antenna (3) when the electrical transmission line (2) is a conductive metal sheet separated from a ground metal sheet by a dielectric sheet.

[0061] In a possible second embodiment the heating cell from microwave radiation may have the electrical transmission line (2) defined by a metal central conductor (10) which is located inside the high dielectric loss ceramic material (9), an area comprised in an axis of symmetry of the high dielectric loss ceramic material (9) between two ground planes equidistant to the metal central conductor (10).

[0062] In the case of choosing the second option, the metal central conductor (10) is located in an area comprised in a vertical axis of symmetry of the high dielectric loss ceramic material (9), which preferably divides the high dielectric loss ceramic material (9) in two equal parts.

[0063] Likewise, the central conductor (10) is preferably located in a cavity of the high dielectric loss ceramic material (9), a cavity which more preferably has dimensions respectively corresponding to the length of the central conductor, which is preferably greater than 10 cm and half of the section of the central conductor, and the central conductor (10) has, in any of the referred examples, a circular, square or rectangular cross-section.

[0064] The operation of one of the aspects of the invention can be observed in light of figures 4a-4c where in figure 4a it shows a graphic referring to the heating-cooling of a SiC ceramic plate, with 5x5 cm² of surface area and a thickness of 0.7 cm, with a density of 99% with respect to the theoretical density; the heating is performed in a 1000 W microwave oven; figure 4b shows a graphic referring to the heating-cooling of the high loss ceramic material (5,9) with 50% by weight of SiC particles and the rest is constituted by porosity and a silicon-aluminous compound to maintain the silicon carbide grains consolidated; the plate of 14.8x14.8 cm² of surface area and a thickness of 1.1 cm has 1300 grams of mass; the heating is performed in a 1600 W microwave oven; and figure 4c shows a graphic referring to the heating-cooling curves of consecutive cycles.

[0065] It also provides the possibility that the high dielectric loss ceramic material (5,9) has a conductor plane, preferably of a material comprising aluminium, in at least one of its faces, preferably in a face where the line is not coupled.

[0066] Example 1. Heating cell with the slot antenna in microstrip ground plane (3) using said high dielectric loss ceramic material (5) of figure 1 comprising SiC, preferably more than 50% by weight of SiC.

[0067] It relates to a microstrip-type heating cell enclosed in the same metal structure (6), preferably aluminium, the antenna (3) is of slot-type in ground plane, i.e. microstrip-type powered by the transmission line (2) and connected to the N-type input connector (1). The slot antenna (3) in ground plane, fixed by means of adhesive to an alumina fibre sheet which acts as heat-insulating material transparent to microwaves (4) at working temperatures of the heating cell and, after this the high loss ceramic material (5) which may preferably be a 100% SiC plate. The metal structure (6)

defines in its base an aluminium reflector plane located $\frac{\lambda}{4}$ from the antenna (3) therefore given that this is located in said slot of the high loss ceramic material (5) at the same distance from the slot of the high loss ceramic material (5). With the reflector plane designed to direct an incident wavelength λ radiation in the cell towards the high dielectric loss ceramic material (5). The layout of the elements that form the cell shall be schematized in figure 1.

[0068] The power that the slot antenna (3) can withstand in ground plane powered by a microstrip line or a stripline transmission line may reach 300 W at this frequency. Due to safety questions, the power must be limited to 100 W in a surface area of 5x5 cm² supposing that it is completely adapted (VSWR $\geq$ 20 dB). For the dense 100% SiC plate of 6 mm thickness and surface area of 5x5 cm² the total mass would be:

$$m(g) = 3.153 \frac{g}{cm^3} \cdot 5 \cdot 5 \cdot 0.6 cm^3 \cong 50g$$

$$m(g) = 3.153 \frac{g}{cm^3} \cdot 5 \cdot 5 \cdot 0.6 cm^3 \cong 50g$$

[0069] To increase the temperature of this piece from 20 °C to 80 °C, i.e. a temperature increase $\Delta T = 60$ °C in a time of 1 min = 60 s it requires:

$$Power = \frac{50 \cdot 60 \cdot 0.7}{60} = 35 W < 100 W \text{ (power limit)}$$

$$Power = \frac{50 \cdot 60 \cdot 0.7}{60} = 35 \text{ W} < 100 \text{ W (power limit)}$$

[0070] Therefore, it would achieve an adequate plate heating so that said heating unit acts as heat generator element.

[0071] Fig. 3 shows the measured responses of the antenna when it is designed for radiation in free space, after loading with a microwave susceptor and finally redesigned and reprinted for the adaptation in the presence of high loss ceramic material (5). The simulations show a radiation efficiency of $\eta_r = 99.8\%$, as expected given the low substrate losses, and the measurements show an impedance adaptation better than $S_{11} = -20 \text{ dB}$, achieving a total efficiency close to 99%.

[0072] **Example 2.** Stripline heating cell using high loss ceramic material (9) of figure 5, porcelain high loss ceramic material (9) with 50% by weight of SiC.

[0073] In this case we have a stripline-type heating cell comprising said central conductor of a metal material (10), preferably copper of 1 mm in diameter which was machined from a copper sheet. The form of the metal central conductor (10) of the stripline line is negatively reproduced inside the high loss ceramic material (9) consisting of a porcelain-type compound comprising 50% by weight of SiC particles and the rest is constituted by porosity and a silicon-aluminous compound to maintain the silicon carbide grains consolidated.

[0074] Fig. 7 shows the reflection factor against the frequency in this figure, it is possible to observe a metal central conductor (10). The stripline heating cell behaved as a broadband device. The energy transfer had an efficiency greater than 99%, since all the energy absorbed by the device becomes heat without any kind of leaks or reflections.

[0075] With any of the possible heating cell configurations, and adding power splitters, and at least one magnetron, we have a microwave radiation heater, since the magnetron shall be responsible for generating the microwave radiation required by the heating cell. The heater may be additionally equipped with a communication unit and a control unit.

[0076] If required according to installation, it is possible to define a heating system using microwave radiation by means of the interconnection of a series of microwave radiation heaters as described in the previous paragraph. For its optimum operation, it is possible to implement in this system both a control algorithm and a smart control system.

Claims

1. Heating cell from microwave radiation **characterized in that** it comprises, enclosed in a metal structure (6) equipped with a base:

- at least one input connector (1),
- a monomodal transverse electromagnetic mode electrical transmission line (2) acting as an antenna (3),
- a high dielectric loss ceramic material (5,9) where to the antenna (3) is fixed, and
- a reflector plane defined by the base of the metal structure (6) and located $\frac{\lambda}{4}$ from the electrical transmission line (2), with λ being the wavelength of the incident radiation in the cell, with the reflector plane directing said microwave radiation towards the high dielectric loss ceramic material (5,9).

2. Heating cell from microwave radiation according to claim 1, additionally comprising a monomodal transverse electromagnetic mode splitter.

3. Heating cell according to claim 2, wherein the monomodal transverse electromagnetic mode electrical transmission line (2) is selected from among:

- a conductive metal sheet separated from a ground metal sheet by a dielectric sheet and fixed to a slot of the high dielectric loss ceramic material (5) and supported by a dielectric substrate plate (7), and
 - a metal central conductor (10) which is located inside the ceramic material (9) between two ground planes equidistant to the metal central conductor (10); and
- in that the heating cell additionally comprises a thermal insulation material transparent to microwaves (4), located between the high dielectric loss ceramic material (5) and the antenna (3) when the electrical transmission line (2) is a conductive metal sheet separated from a ground metal sheet by a dielectric sheet.

4. Heating cell according to any of claims 1 to 3, wherein the high dielectric loss ceramic material (5,9) has a value of dielectric losses in the electromagnetic radiation region of microwaves ≥ 0.10 .

5. Heating cell according to any of claims 1 to 4, wherein the high dielectric loss ceramic material (5) comprises a proportion of at least 50% by weight of SiC.
- 5 6. Heating cell according to any of claims 1 to 5, wherein the high dielectric loss ceramic material (5) comprises a conductor plane on at least one of its faces.
7. Heating cell according to claim 5, wherein the conductor plane is of a material that comprises aluminium.
- 10 8. Heating cell according to claim 3, wherein the metal central conductor (10) is located in an area comprised in an axis of symmetry of the high dielectric loss ceramic material (9).
9. Heating cell according to claim 8, wherein the axis of symmetry is a vertical axis of symmetry that divides the high dielectric loss ceramic material (9) in two equal parts.
- 15 10. Heating cell according to claim 3, wherein the metal central conductor (10) is located in a cavity of the high dielectric loss ceramic material (9), a cavity that has dimensions respectively corresponding to the length of the metal central conductor (10) and to half of the section of the metal central conductor (10).
- 20 11. Heating cell according to claim 3 or any of 8 to 10, wherein the metal central conductor (10) has a length greater than 10 cm.
12. Heating cell according to claim 3 or any of 8 to 11, wherein the metal central conductor (10) has a cross-section that is selected from among the group consisting of:
25 - circular,
 - square, and
 - rectangular.
- 30 13. Microwave radiation heater, comprising at least one heating cell such as that described in claims 1 to 12, power splitters and at least one magnetron.
14. Microwave radiation heater according to claim 13, additionally comprising a communication unit and a control unit.
- 35 15. Heating system using microwave radiation, comprising interconnected a series of microwave radiation heaters, according to any of claims 13 or 14, a control algorithm and a smart control system.
- 40 16. Use of the heating system using microwave radiation, according to claim 16, for thermal comfort in the form of heating for spaces such as domestic rooms, offices, commercial premises, industrial premises and, in general, inhabited spaces.

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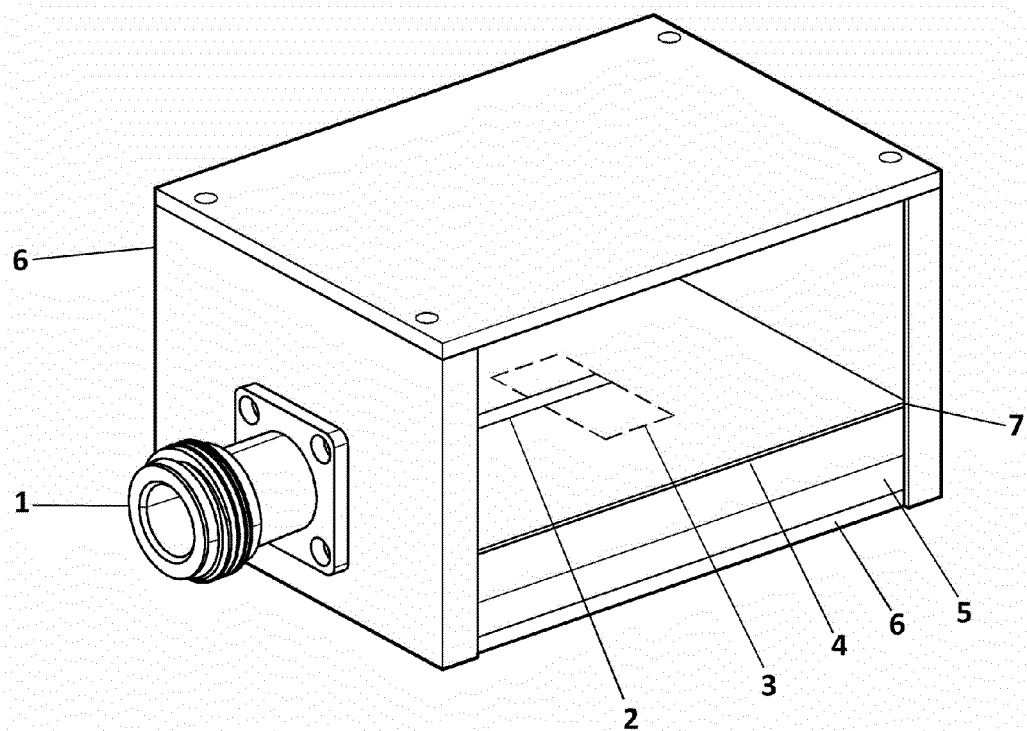
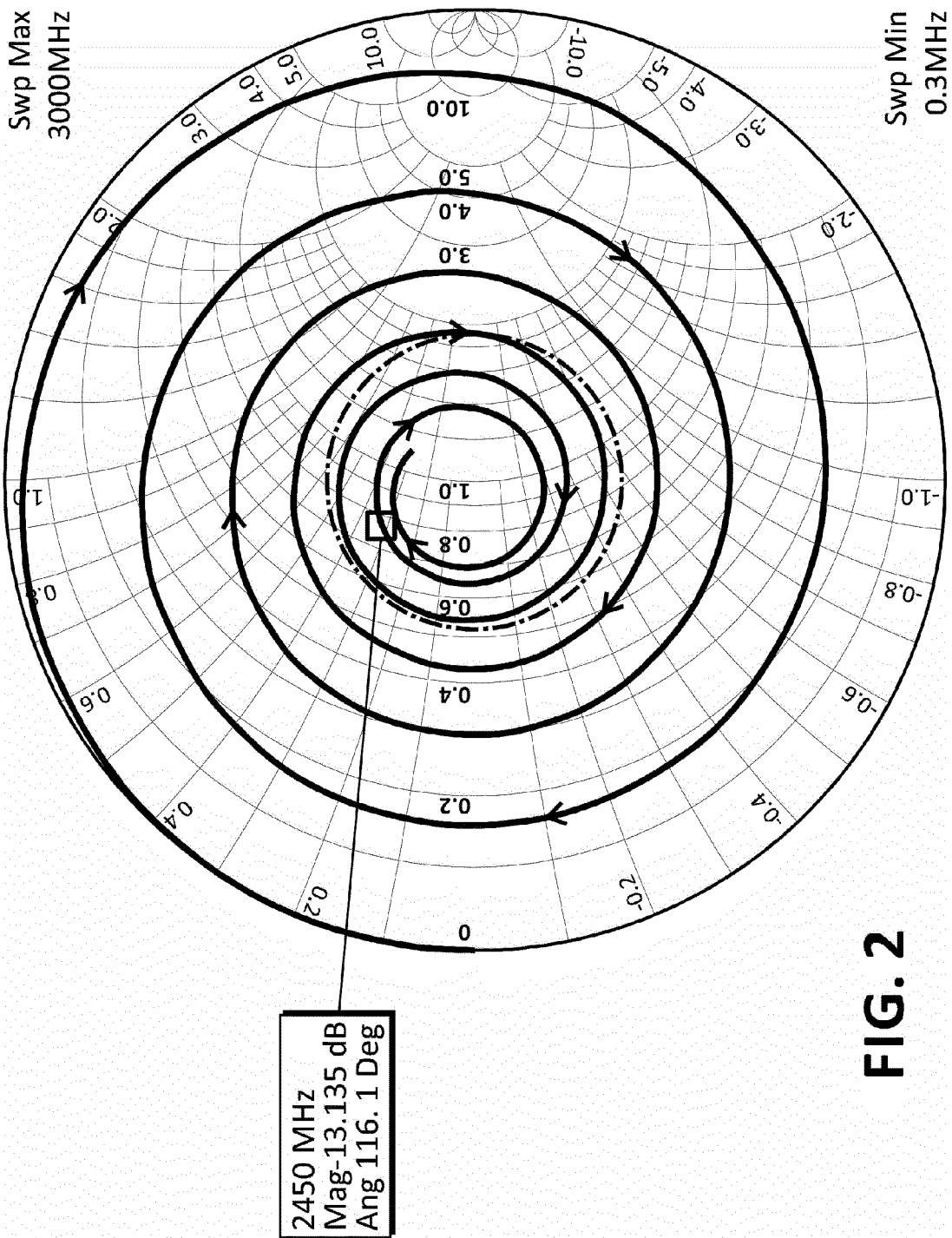
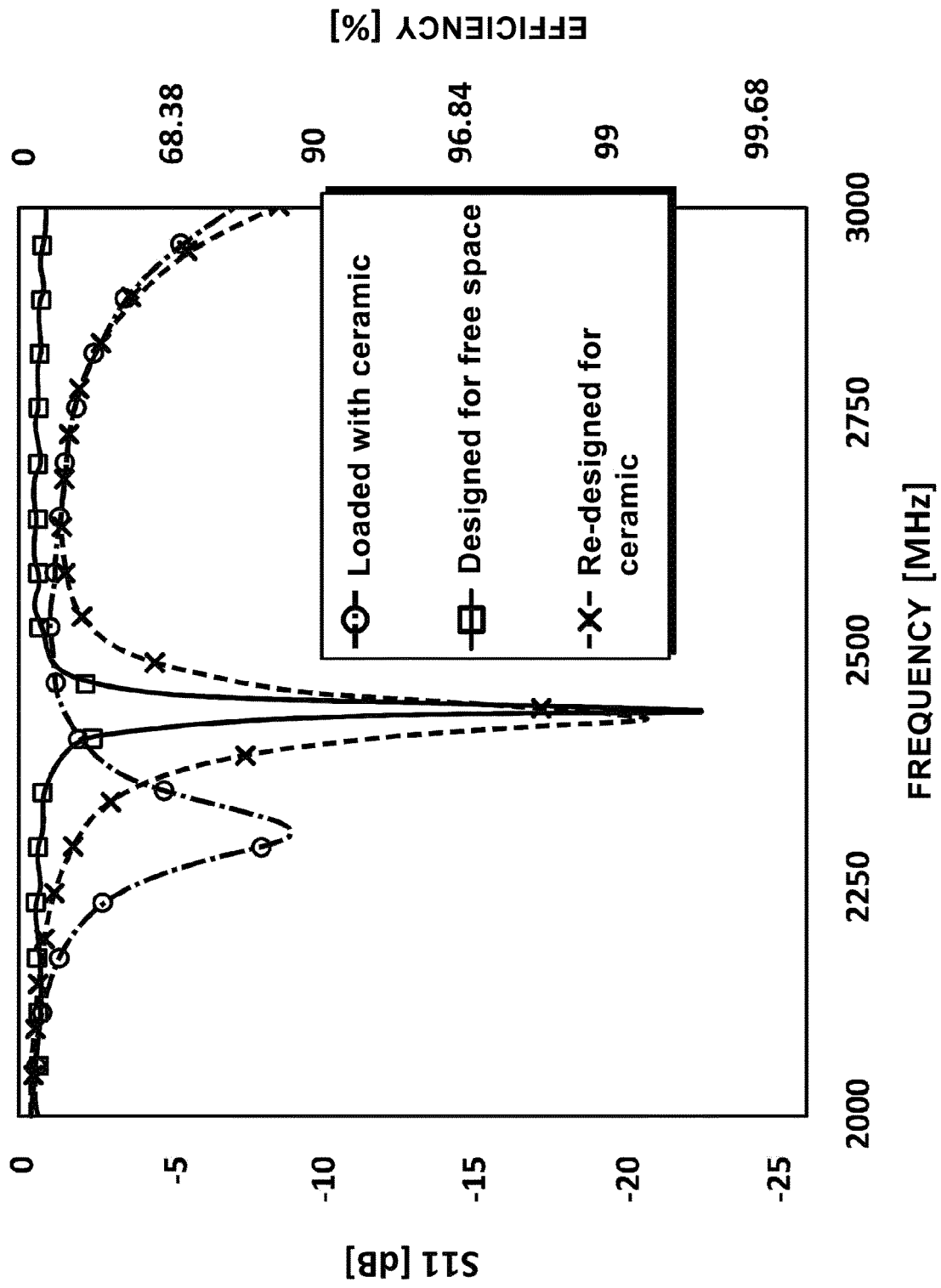
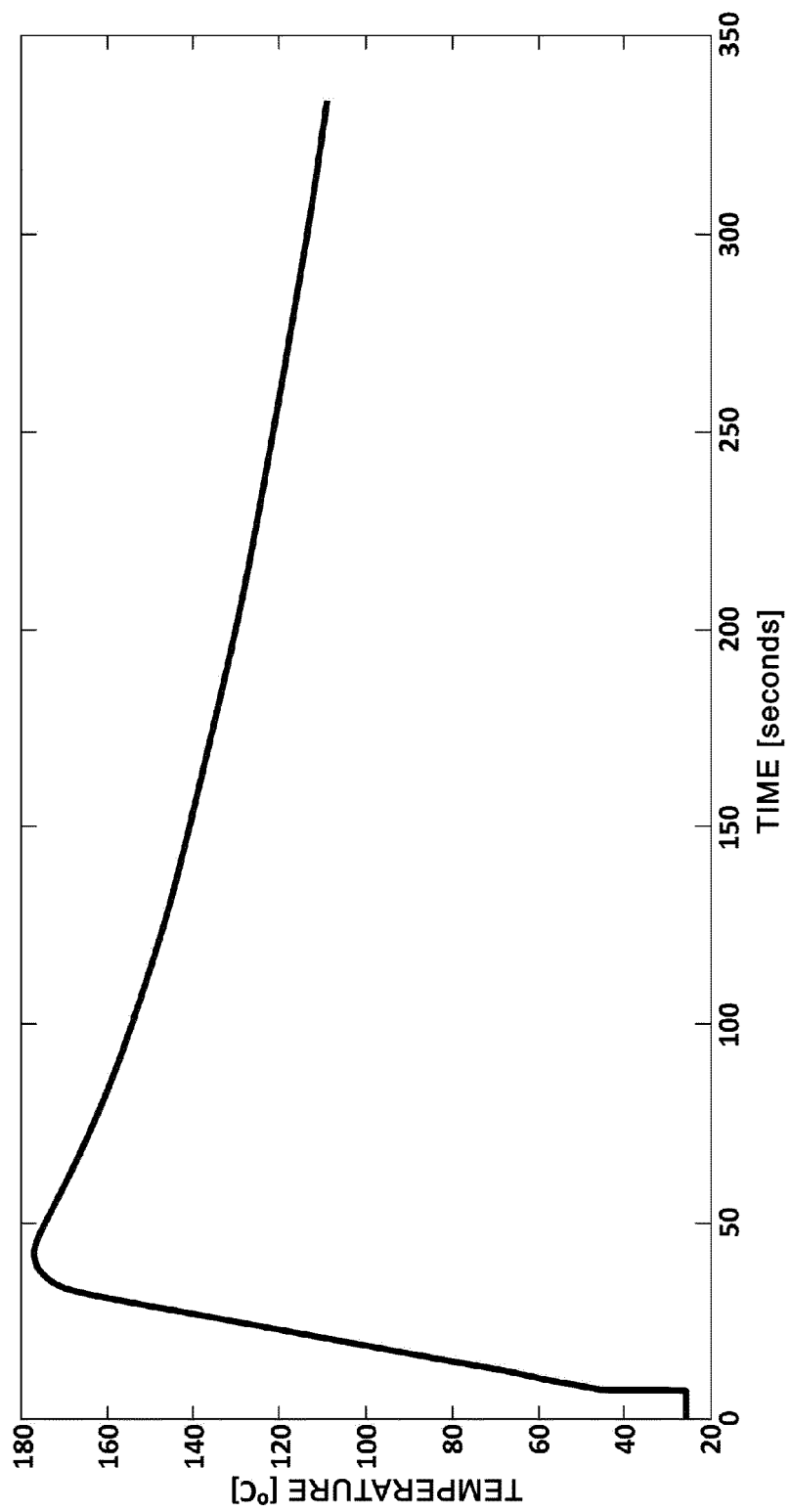
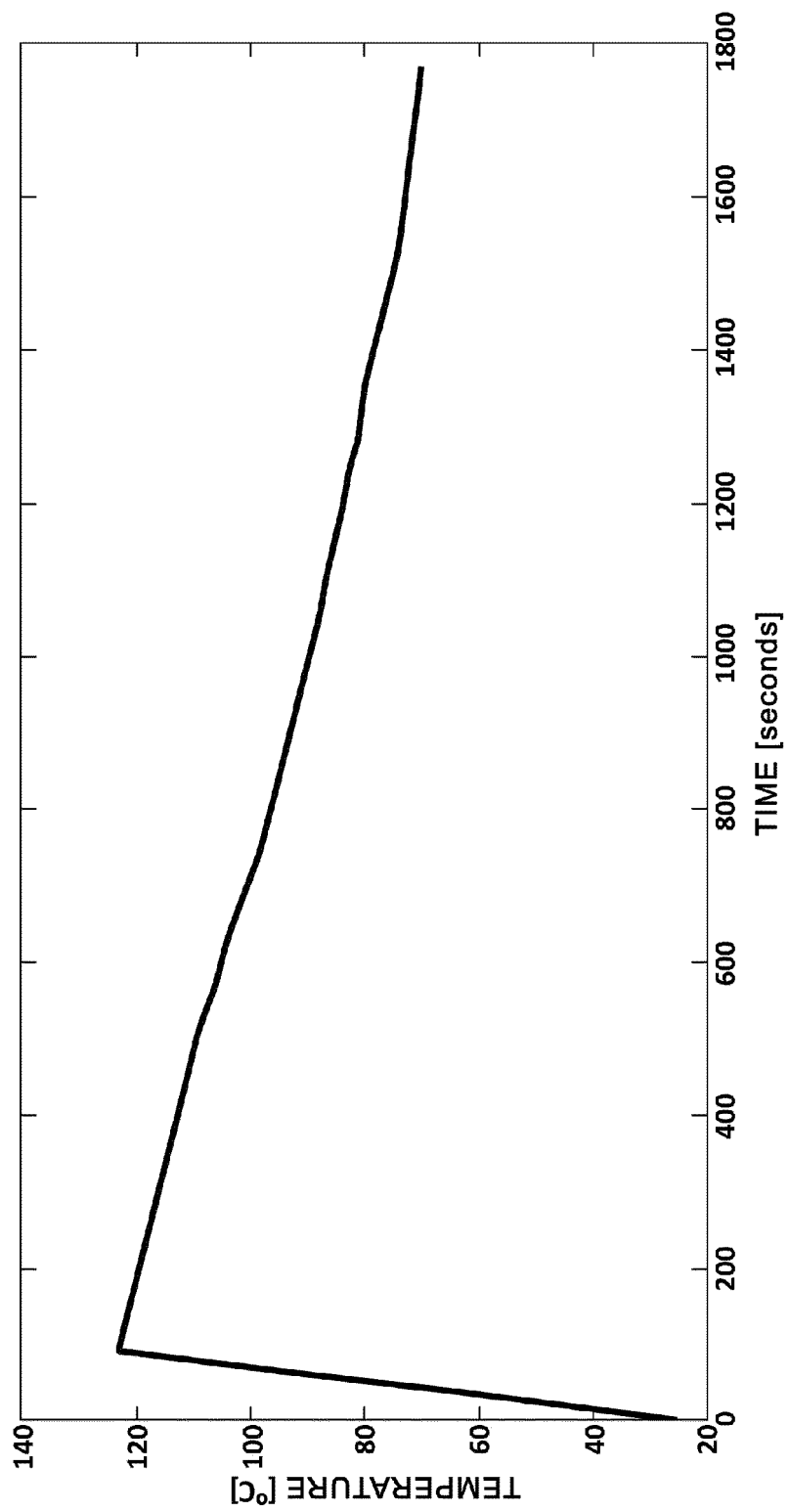


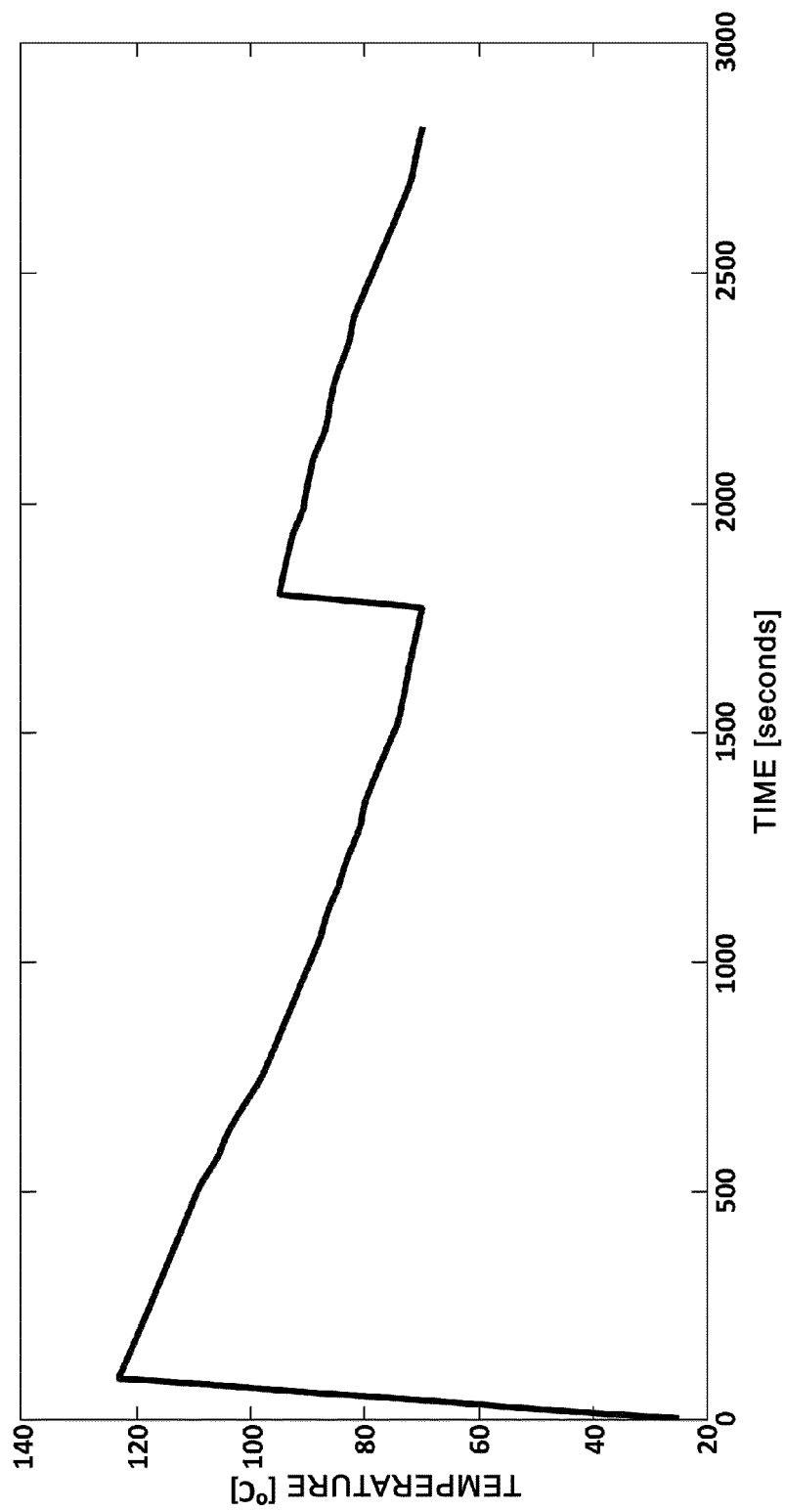
FIG. 1

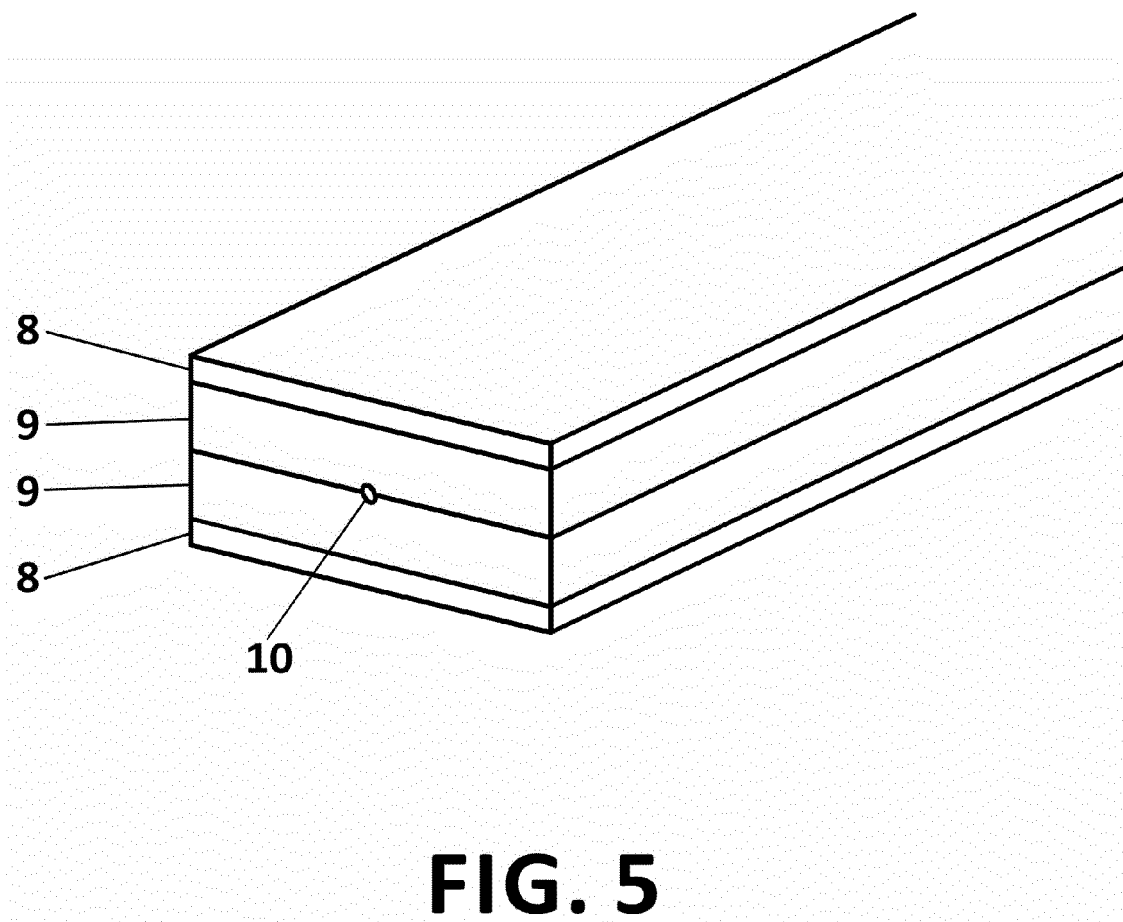




**FIG. 4A**

**FIG. 4B**

**FIG. 4C**



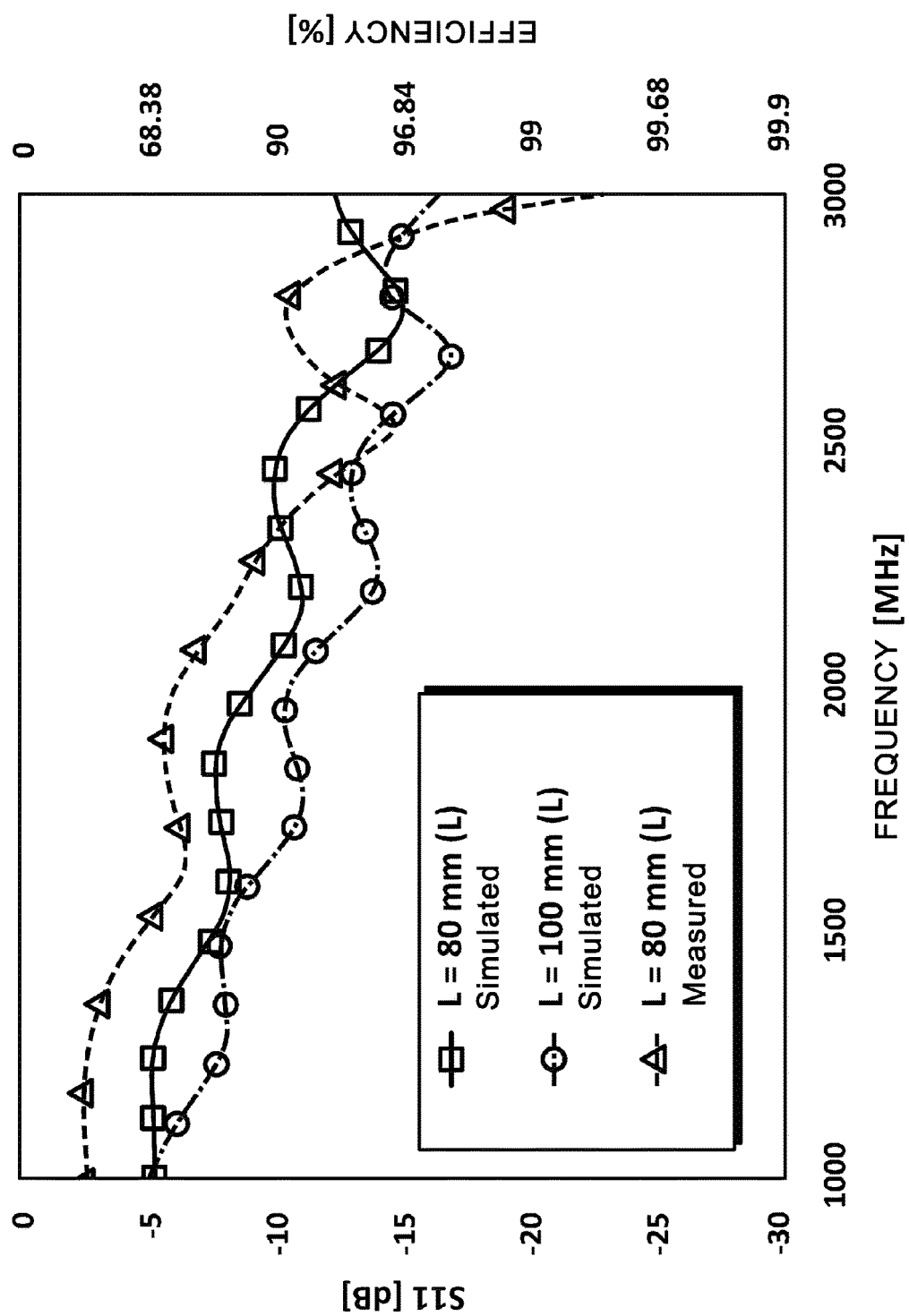
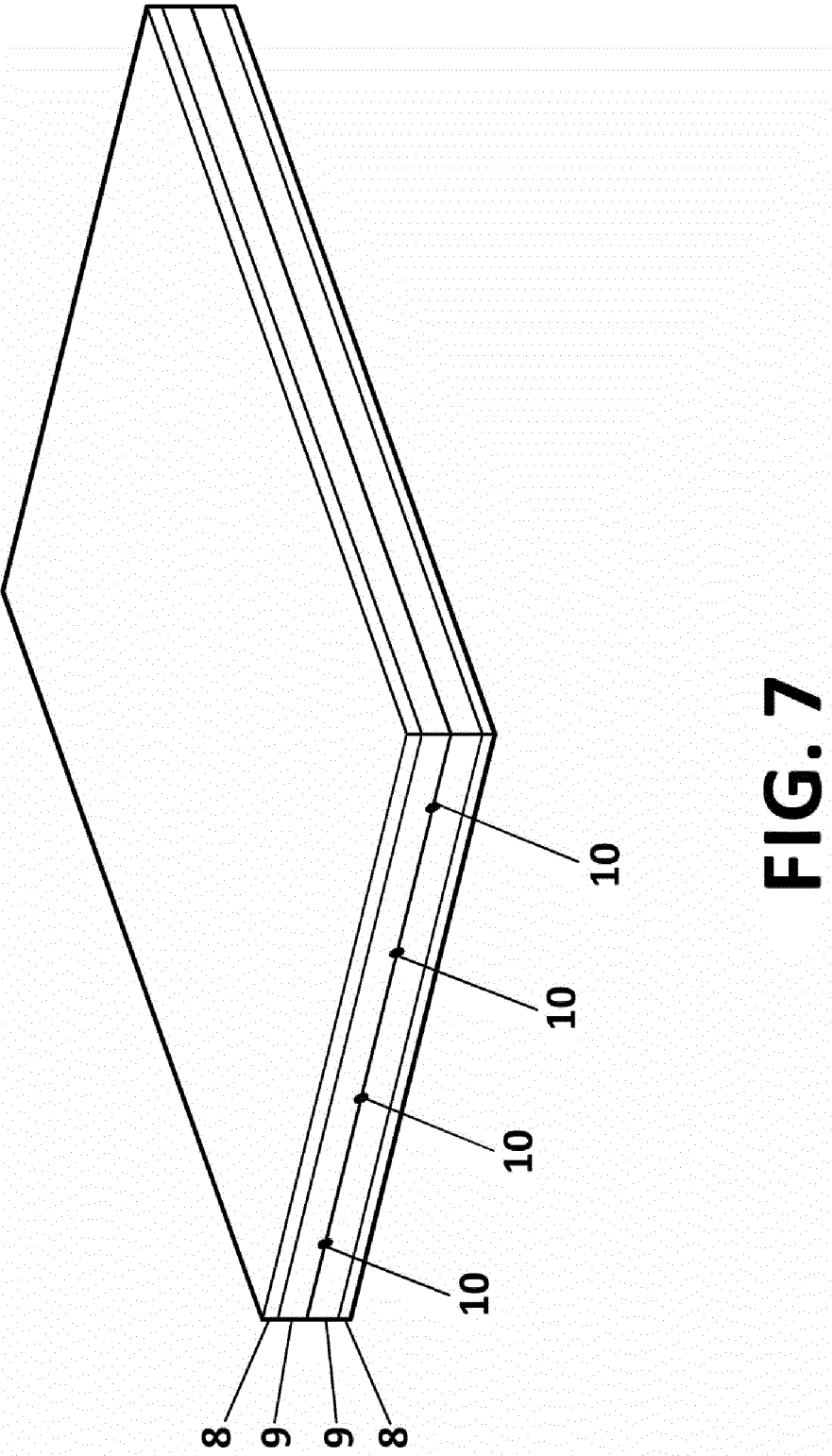


FIG. 6



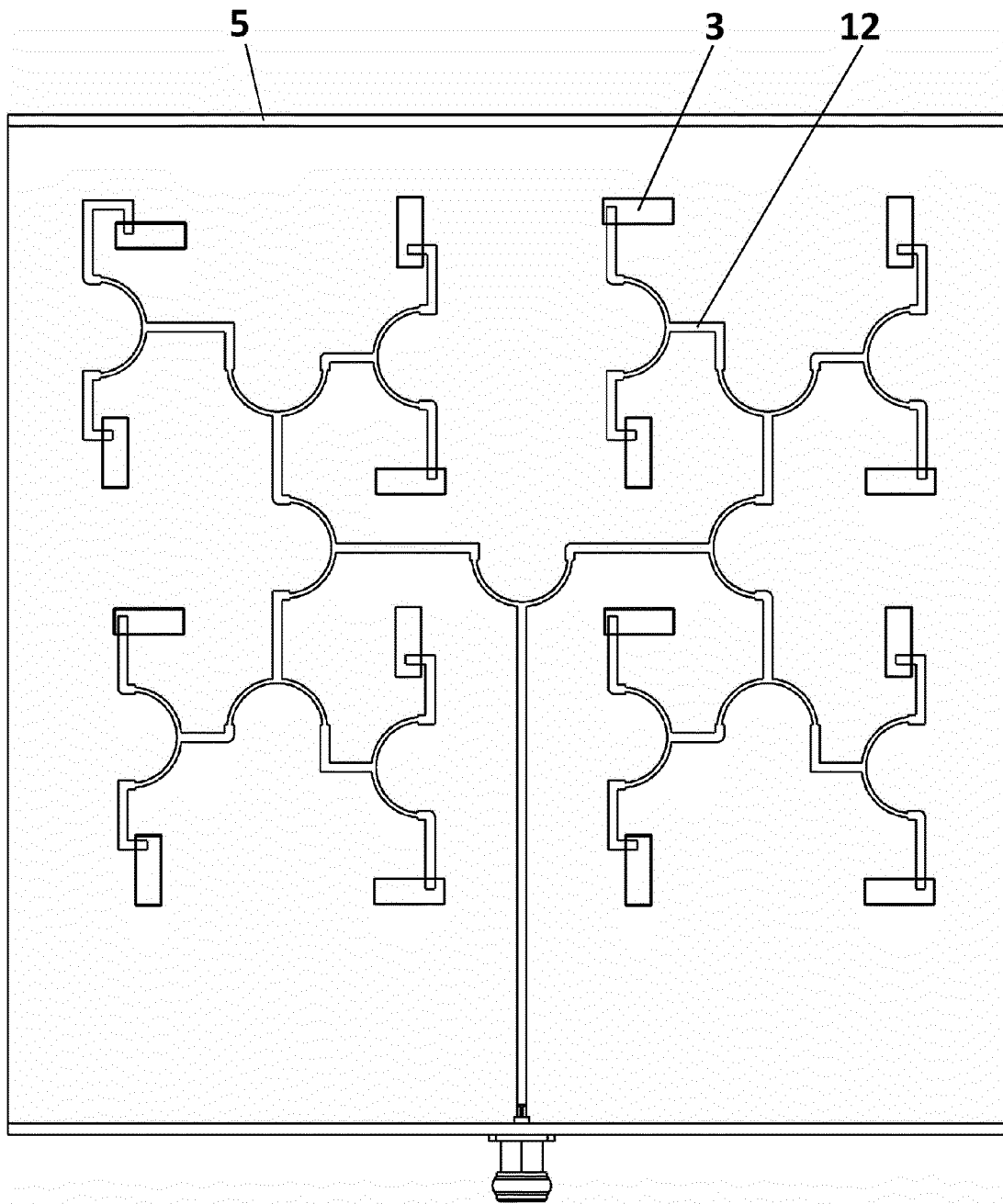


FIG. 8

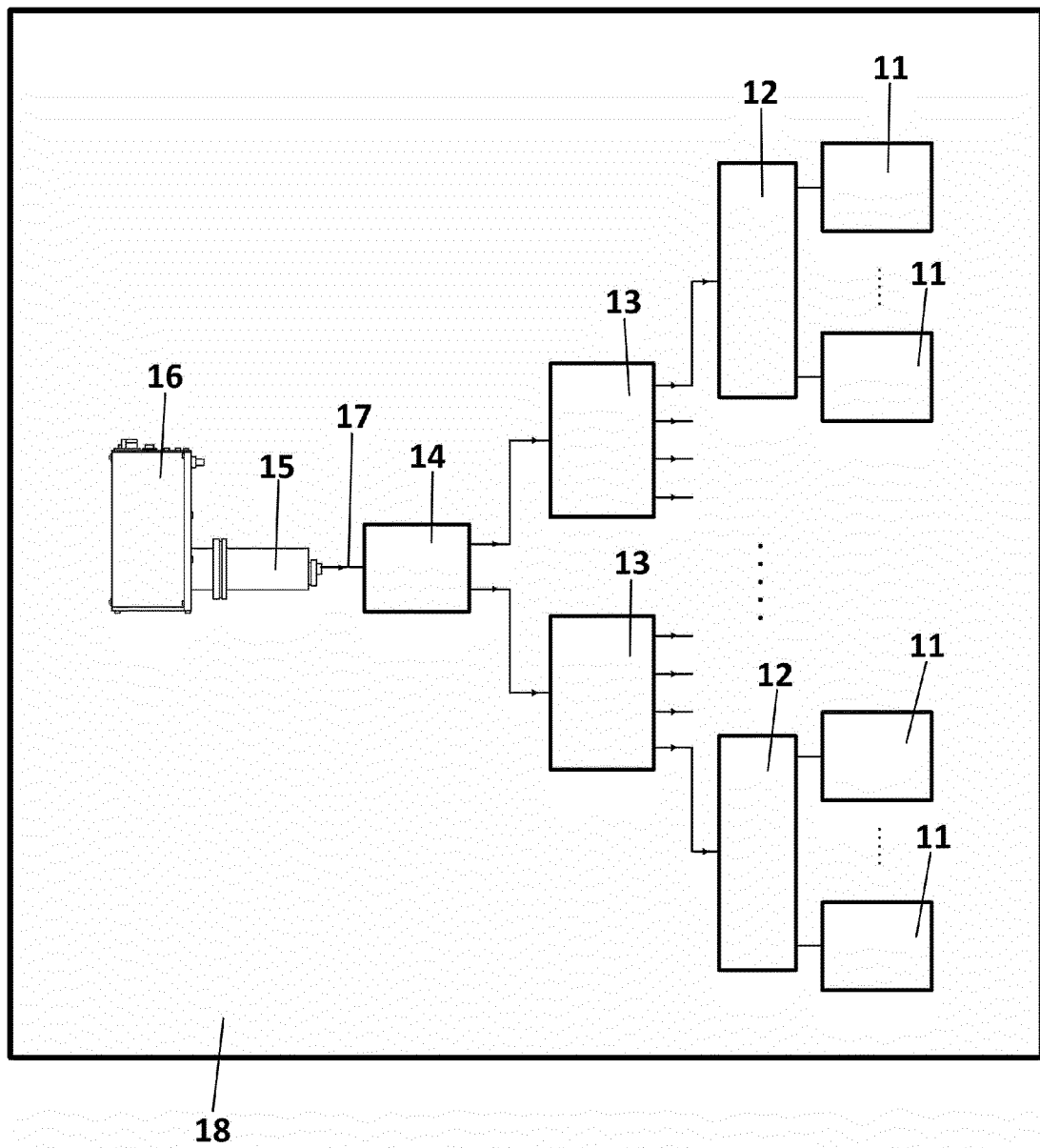
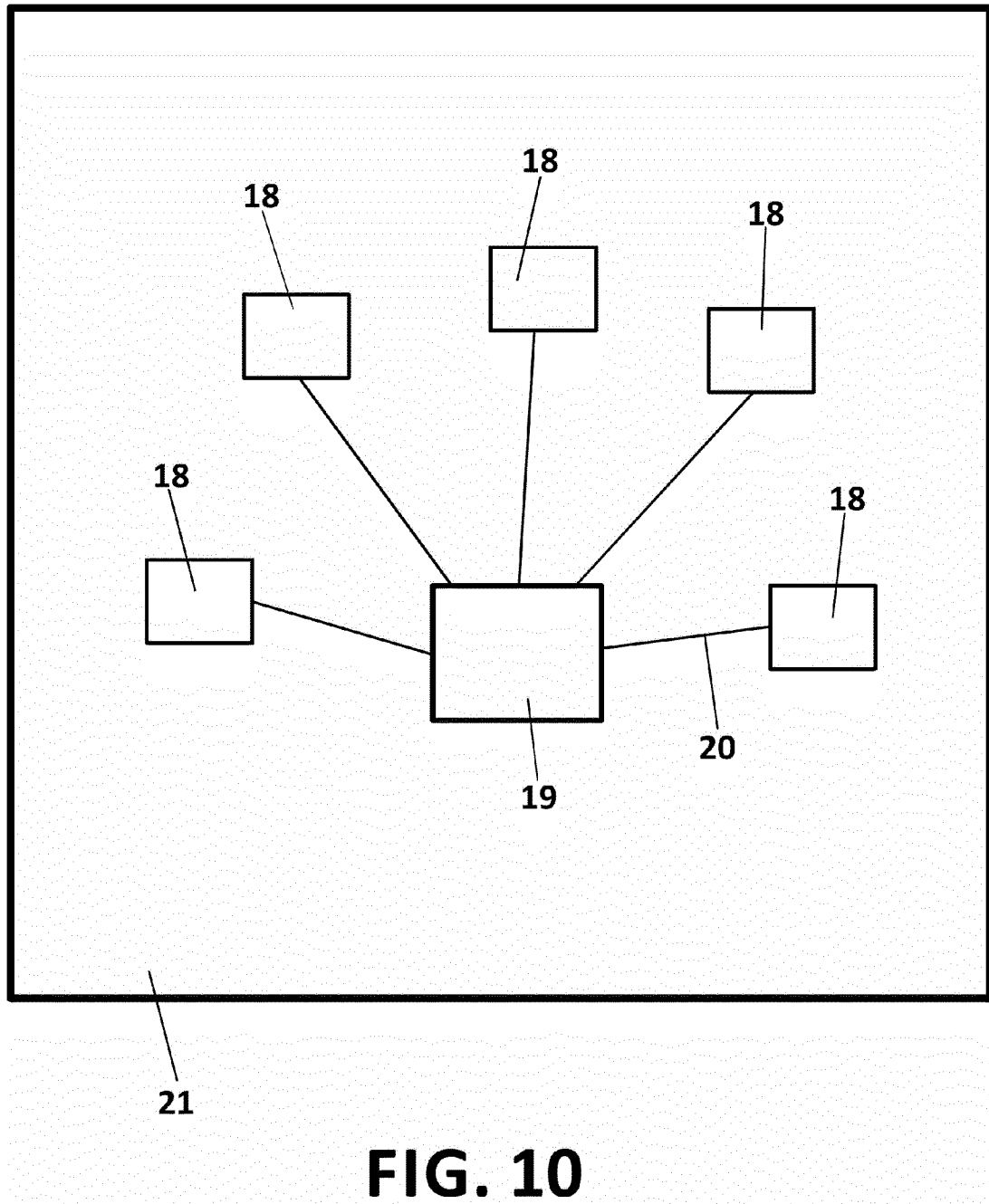


FIG. 9



Central conductor diameter	Characteristic Impedance Z_0
0.3 mm	$72.454 + j 2.81$
0.5 mm	$62.008 + j 2.82$
1 mm	$48.627 + j 2.84$
1.5 mm	$40.837 + j 2.84$
2 mm	$35.355 + j 2.84$

FIG. 11

Line length L	S_{11}	Percentage of absorbed power
80 mm	10.06 dB	90.14 %
100 mm	13.13 dB	95.14 %
120 mm	15.28 dB	97.035 %
150 mm	23.54 dB	99.56 %

FIG. 12

INTERNATIONAL SEARCH REPORT

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5	A. CLASSIFICATION OF SUBJECT MATTER		
	F24C7/02 (2006.01) H05B6/64 (2006.01) According to International Patent Classification (IPC) or to both national classification and IPC		
	B. FIELDS SEARCHED		
10	Minimum documentation searched (classification system followed by classification symbols) F24C, H05B		
	Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
15	Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) EPODOC, INVENES, WPI		
	C. DOCUMENTS CONSIDERED TO BE RELEVANT		
20	Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
	Y	EP 2090869 A1 (SURPASS IND CO LTD) 19/08/2009, paragraphs [29 - 33]; figures 1 - 2.	1-16
25	Y	US 4179595 A (SAINT GOBAIN) 18/12/1979, column 3, lines 22 - 36; column 2, lines 5 - 32; column 4, lines 27 - 35; figures 1 and 3.	1-16
30	A	US 5337065 A (THOMSON CSF) 09/08/1994, abstract; column 3, lines 7 - 22; figure 1.	3,8-12
	A	US 5293171 A (CHERRETTE ALAN R) 08/03/1994, column 7, lines 14 - 28; figure 5.	3,6-7
35	A	GB 2081559 A (SANYO ELECTRIC CO) 17/02/1982, abstract; figure 2.	3
40	☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
45	* Special categories of cited documents: "A" document defining the general state of the art which is not considered to be of particular relevance. "E" earlier document but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure use, exhibition, or other means. "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
50	Date of the actual completion of the international search 21/12/2015		Date of mailing of the international search report (22/12/2015)
55	Name and mailing address of the ISA/ OFICINA ESPAÑOLA DE PATENTES Y MARCAS Paseo de la Castellana, 75 - 28071 Madrid (España) Facsimile No.: 91 349 53 04		Authorized officer E. Pina Martínez Telephone No. 91 3498552

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/ES2015/070712

C (continuation).	DOCUMENTS CONSIDERED TO BE RELEVANT	
Category *	Citation of documents, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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INTERNATIONAL SEARCH REPORT

International application No.

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