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(71) Applicant: MONASH UNIVERSITY [AU/AU]; Wellington Road, Clayton, Victoria 3800 (AU).

(72) Inventors: KARMAKAR, Nemai, C.; 138 Jells Road, Wheelers Hill, Victoria 3150 (AU). AMIN, Emran, M.; 2 Highland Avenue, Hampton Park, Victoria 3976 (AU).

(74) Agent: PHILLIPS ORMONDE FITZPATRICK; Level 21, 22 & 23, 367 Collins Street, Melbourne, Victoria 3000 (AU).

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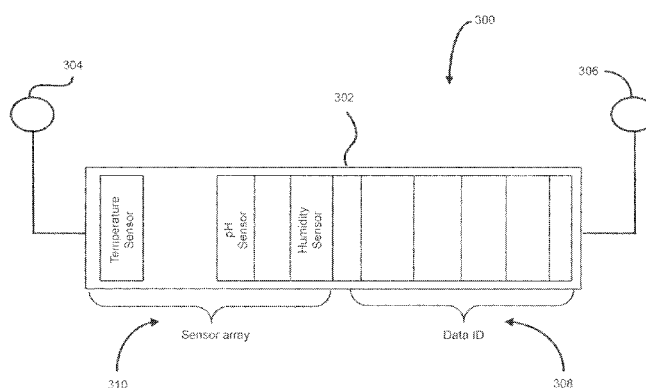


Figure 6

(57) Abstract: The invention relates generally to radio frequency transponders, and more particularly to an RFID tag having information encoded therein which may be retrieved by applying a suitable RF signal and identifying resonances in a corresponding RF frequency response, the RFID tag including: a substrate; a planar conductive multi-resonator structure disposed on the substrate, the multi-resonator structure including a plurality of substructures each of which is associated with a different resonance frequency, the value of each resonance frequency being dependent upon the substructures, the presence and/or absence of resonance responses from a first group of substructures at corresponding characteristic frequencies being used to encode digital information; and one or more dielectric elements disposed on a second group of substructures, each dielectric element having a permittivity which changes as a function of a sensed environmental parameter to thereby cause a shift in the resonance response of that substructure. The invention also relates to methods of manufacturing such radio frequency transponders.



Radio Frequency Transponder

Field of Invention

[1] The present invention relates generally to radio frequency transponders, and more particularly to passive transponder structures for encoding identifying information and/or other data and for sensing one or more environmental parameters, such as humidity and temperature. The present invention also relates to methods of manufacturing such radio frequency transponders.

Background of the Invention

[2] There exist many applications in which it is advantageous to mark articles with identifying information that can be detected and/or read by electronic means. These applications include logistics, sales and security. Radio Frequency Identification (RFID) tags are a common means of providing such machine readable information. Recently efforts have been made to integrate the sensing of environmental parameters such as temperature, humidity, radiation or pressure, into a RFID tag.

[3] Some existing RFID tags incorporating such environmental parameter sensors are active and semi active types, or in other words include on board power sources and micro controls to drive environmental parameter sensing circuits. Such RFID sensors are costly, bulky and rigid in operation, have a finite life time and require ongoing maintenance.

[4] In order to further reduce cost and tag complexity, chipless RFID tag sensors have recently been developed. A chipless RFID tag sensor provides identification data as well as monitoring one or more physical parameters of tagged objects but does not include a microprocessor to enable data processing on the tag itself. Chipless RFID tag sensors can be manufactured for a lower cost, have a longer storage life, greater robustness and lower radiated power than do traditional chipped RFID tag sensors.

[5] Several approaches have been proposed to realise a chipless RFID tag with an integrated environment sensor. In one such approach, a temperature sensor is provided by providing three different layers of magnetic material on the RFID tag which have a magnetic spectrum that changes with temperature. Another approach has been to provide a passive Surface Acoustic Wave (SAW) based RFID temperature and pressure sensor in which a physical or chemical reaction changes the Radar Cross Section (RCS) of the SAW, thereby affecting the response of the RFID tag sensor. Although such SAW sensor tags are the only commercially available chipless tag sensors currently available, they have the disadvantage of being non-planar, involving complexity circuitry and requiring a cumbersome multistep fabrication process.

[6] An inkjet printed antenna loaded with carbon nanotubes for sensing ammonia gas has also been developed. Although such an antenna acts as a passive wireless sensor node, the antenna does not incorporate a data identification mechanism for incorporation into a fully chipless platform.

[7] It would be desirable to provide an RFID tag encoding digital information and sensing one or more environmental parameters that is robust, simple to manufacture, low cost, and planar in order to enable easy affixation to tagged objects. It would also be desirable to provide an RFID tag encoding digital information and providing sensing of one or more environmental parameters that ameliorates or overcomes one or more problems or inconveniences of known RFID tag sensors.

[8] The discussion of existing documents, acts, materials, devices, articles and the like is included in this specification solely for the purpose of providing a context for the present invention. It is not suggested or represented that any or all of these matters formed part of the prior art base or were common general knowledge in the field relevant to the present invention as it existed before the priority date of each claim of this application.

Summary of the Invention

[9] One aspect of the invention provides an RFID tag having information encoded therein which may be retrieved by applying suitable RF signal and identifying residences in a corresponding RF frequency response, the RFID tag including:

a substrate;

a planar conductive multiresonator structure disposed on the substrate, the multiresonator structure including a plurality of substructures each of which is associated with a different resonance frequency, the value of each resonance frequency being dependent upon the substructures, the presence and/or absence of resonance responses from a first group of substructures at corresponding characteristic frequencies being used to encode digital information; and one or more dielectric elements disposed on a second group of substructures, each dielectric element having a permittivity which changes as a function of a sensed environmental parameter to thereby cause a shift in the resonance response of that substructure.

[10] In accordance with preferred embodiments, the term "RFID tag" encompasses a range of devices that are responsive to suitable RF excitation: In particular the scope of the invention encompasses passive circuits having multiple frequency resonances, antennas having similar resonance properties, and combinations of resonators and antennas, such as a multi-resonance structure coupled to a suitable wideband antenna.

[11] The term "RF" or "radio frequency", as used herein, encompasses frequencies commonly utilised in the propagation or electromagnetic radiation for communications and other purposes, and includes at least those frequencies in the range of 3 kHz to 300 GHz. Of particular interest, in relation to resonance structures formed in accordance with embodiments of the present invention, are those frequencies in the micro wave and millimetre wave ranges e.g., RF frequencies exceeding 1 GHz.

[12] The term "dielectric", as used herein, encompasses a broad range of low conductivity materials providing suitable substrates for conductive structures formed

in accordance with embodiments of the invention. These include materials specifically designed for use as substrates for electrical circuits (such as the FR4 and other materials commonly used in printed circuit board manufacture), as well as other materials such as polymers and paper from which articles such as security documents, bank notes and other negotiable instructions may be fabricated.

[13] Advantageously, embodiments of the invention are able to include information encoded within a multi-resonance structure, which may be retrieved by applying an appropriate RF excitation, such as an impulse, a wire band signal or a swept narrow band signal, wherein the information may be recovered by analysing the corresponding frequency response. More particularly, in preferred embodiments, the presence and/or absence of resonance responses in amplitude and/or phase at corresponding characteristic frequencies is used to encode digital information. Through the use of a multi-resonance structure which comprises a plurality of substructures with which the plurality of resonances are associated, the resonance response, and hence the encoded information may be modified by suitable formation of the individual substructures.

[14] In one or more embodiments, the resonance responses of the first and second group of substructures are in different frequency bands.

[15] In one or more embodiments, the first and second groups of substructures are distinct from each other and do not include any common substructures.

[16] In one or more embodiments, one or more substructures are common to both the first and second group of substructures

[17] In one or more embodiments, one or more of the substructures are in the form of a slot monopole, split ring resonators or E-coupled LC resonators.

[18] In one or more embodiments, the multi-resonator structure includes multiple slots in a rectangular monopole and a complementary ELC resonator.

[19] Another aspect of the invention provides a method of manufacturing an RFID tag according to any one of the preceding claims, including the steps of:

applying sensing material to the substrate to form the dielectric elements; and
applying conducting material to the substrate to form the substructures.

[20] In one or more embodiments, the sensing material is firstly applied to the substrate, and the conducting material is subsequently applied to the substrate.

[21] In one or more embodiments, conducting material is firstly applied to the substrate, and the sensing material is subsequently applied to the substrate.

[22] In one or more embodiments, one or both of the forming steps includes applying the material via a printing head.

[23] In one or more embodiments, the RFID tag detects multiple environmental parameters and a number of different sensing materials are applied to the substrate via separate printing heads.

[24] In one or more embodiments, one or more of the dielectric elements are formed from a sensing material selected from the group consisting of a temperature sensing material, a humidity sensing material, a pH sensing material, a strain sensing material, a gas sensing material, a light sensing material, a pressure sensing material, and an electric field sensing material.

[25] In one or more embodiments, one or more of the dielectric elements are formed from a humidity sensing material and the humidity sensing material is selected from the group consisting of oxides (preferably metal oxides), tantalum and silicon containing materials, hydrophilic polymers and hydrophobic polymers.

[26] In one or more embodiments, one or more of the dielectric elements are formed from a humidity sensing material and the humidity sensing material is a hydrophilic polymer selected from the group consisting of poly(amino acids) such as gelatin, polysaccharides such as dextran, polyamides such as poly(4,4'-oxydiphenylene-pyromellitimide) (Kapton) and poly(lauryllactam) (Nylon 12), poly(ethylene vinyl acetate), and poly(vinyl alcohol).

[27] In one or more embodiments, one or more of the dielectric elements are formed from a temperature sensing material and the temperature sensing material is

selected from the group consisting of liquid crystals, ionic plastic crystals, conductive polymers, polymer mixtures containing conductive polymers, sublimate materials, graphene and nanostructured metal oxides.

[28] In one or more embodiments, one or more of the dielectric elements are formed from a sublimate material.

[29] In one or more embodiments, one or more of the dielectric elements are formed from a pH sensing material and the pH sensing material is selected from the group consisting of polyaniline (PANI), poly(3,4-ethylenedioxythiophene) (PEDOT) and poly(acrylic acid).

[30] In one or more embodiments, one or more of the dielectric elements are formed from a strain sensing material and the strain sensing material is selected from the group consisting of conducting composites, conducting polymers and elastomeric polymers.

[31] In one or more embodiments, one or more of the dielectric elements are formed from a gas sensing material and the gas sensing material is selected from the group consisting of conductive carbon nanoparticles, semiconducting oxides, platinum and conducting polymers and composites thereof.

[32] In one or more embodiments, one or more of the dielectric elements are formed from a light sensing material and the light sensitive material is selected from the group consisting of CdS photoresistors and UV sensitive conducting polymers, preferably a UV sensitive conducting polymer which is a polythiophene polymer such as poly(3-hexylthiophene).

[33] In one or more embodiments, one or more of the dielectric elements are formed from a pressure sensing material and the pressure sensing material is selected from the group consisting of piezoresistive films, microelectromechanical (MEMS) polysilicon membranes, monocrystalline silicon, poly(urethane) rubber, plastic films and silicon membranes.

[34] In one or more embodiments, one or more of the dielectric elements are formed from an electric field sensing material and the electric field sensing materials

selected from the group consisting of nanostructured metal oxides, ferromagnetic materials having magneto-elastic property, diamond, and polydimethylsiloxane (PDMS).

[35] In one or more embodiments, the method further includes the step of applying a protective coating to the substrate.

[36] Further preferred features and advantages of the invention will be apparent to those skilled in the art from the following description of preferred embodiments of the invention, which should not be considered to be limiting of the scope of the invention as defined in the preceding statements, or in the claims appended hereto.

Brief Description of the Drawings

[37] Preferred embodiments of the invention will now be described with reference to the accompanying, in which like reference numerals represent like features, and wherein:

[38] Figure 1 is a schematic diagram depicting an RFID tag system according to an embodiment of the present invention;

[39] Figure 2 is a schematic diagram of an RFID tag forming part of the RFID tag system of Figure 1;

[40] Figure 3 is a plan view of a stepped impedance resonator forming part of the RFID tag of Figure 2;

[41] Figure 4 is an isometric view of a substructure including a dielectric element for sensing an environmental parameter which forms part of the RFID tag of Figure 2;

[42] Figure 5 is a plan view of the substructure of Figure 4;

[43] Figure 6 is a schematic diagram of a second embodiment of an RFID tag in accordance with the present invention;

[44] Figure 7 shows a plan and a side view of a multiresonator structure forming part of a third embodiment of an RFID tag in accordance with the present invention;

[45] Figure 8 is a graph showing a resonance response of the multiresonator structure of Figure 7;

[46] Figure 9 is a schematic diagram depicting steps involved in the manufacture of an RFID tag in accordance with the present invention;

[47] Figure 10 is a graph showing measured transmission coefficient (calibrated) (S_{21}) vs. frequency for an RFID tag with a poly(vinyl alcohol) coating for humidity sensing according to an embodiment of the present invention;

[48] Figure 11 is a graph showing measured transmission coefficient (calibrated) (S_{21}) vs. frequency at relative humidity from 35% to 85% for an RFID tag with a poly(vinyl alcohol) coating for humidity sensing according to an embodiment of the present invention;

[49] Figure 12 is a graph illustrating the shift in measured resonant frequency with relative humidity for an RFID tag with a poly(vinyl alcohol) coating for humidity sensing according to an embodiment of the present invention, where the curve is normalized by the resonant frequency at minimum relative humidity (35%);

[50] Figure 13 is a graph showing measured transmission coefficient (S_{21}) at an initial and final condition for an RFID tag with a phenanthrene coating for temperature sensing according to an embodiment of the present invention; and

[51] Figure 14 is a graph showing measured resonant frequency of an RFID tag with a phenanthrene coating for temperature sensing versus temperature during a heating and cooling process.

Detailed Description of Preferred Embodiments

[52] Figure 1 shows an RFID tag system 100 including a chipless RFID tag 102 incorporating a multiresonator structure 104. Multiresonator 104 is disposed on, and coupled to a receiving antenna 106 and a transmitting antenna 108. The receiving antenna 106, multiresonator structure 104 and transmitting antenna 108 are all fabricated on a single substrate. For example, the elements 104, 106 and 108 may be formed on a dielectric substrate using conventional PCB manufacturing techniques, or

may be printed onto a substrate using suitable conductive inks. Additional steps in the manufacturing process of the RFID tag 102 will be described below in relation to specific embodiments of the invention.

[53] An RFID reader, or interrogator, 110 includes suitable transmitting/receiving electronics, as will be well-known to persons skilled in the relevant art, as well as a transmitting antenna 112 and a receiving antenna 114. As will be appreciated, although the system 100 includes an RFID reader 110 and a chipless tag 102 having separate transmit and receive antennas, in alternative embodiments a single antenna may be used by the reader 110 and/or the tag 102 for both transmitted and receiving of radio frequency signals.

[54] The RFID interrogator 110 transmits a RF signal which comprises a plurality of frequency components f_1 to f_n , as indicated in the transmitted signal spectrum 116, having magnitude component 116a and phase component 116b. Equivalently, the interrogator 110 may transmit a wideband RF signal or an impulse having a broad corresponding frequency spectrum. The transmitted signal 116 is received by the tag antenna 106, coupled to the multiresonator structure 104, and the resulting signal coupled to the tag transmit antenna 108, from which it propagates to the interrogator receiving antenna 114.

[55] Due to properties of the multiresonator 104, individual frequency components of the signal 116 received by the chipless tag 102 are coupled to the transmitting antenna 108, whilst other frequency components may be reflected absorbed or otherwise modified in the magnitude and/or phase. Accordingly, the return signal from the tag 102, represented by the spectrum 118, having magnitude component 118a and phase component 118b, includes one or more frequency components present in the signal 116, in accordance with properties of the multiresonator structure 104.

[56] Accordingly, the interrogator 110 is able to process the frequency response of the chipless tag 102, in which the information may be encoded in accordance with the properties of the multiresonator structure 104. The example, the presence of particular frequency components (such as components f_1 , f_3 and f_n of the spectrum 118a) may be interpreted, in a digital system, as representing binary "1s". Conversely,

the absence of frequency components (such as f_2 or the spectrum 118b) may be interpreted as a binary "0". Since the presence or absence of each such frequency component depends on the properties of the multiresonator structure 104, the structure of the multiresonator structure 104 may be used to encode information in the RF frequency response of the chipless tag 102.

[57] Alternative, or additionally, the phase component 118b of the signal 118 transmitted back to the RFID interrogator may be modified in accordance with the properties of the resonator 104. For example phase "jumps" or other variations in phase response may arise characteristic frequencies, such as f_2 and f_3 of the spectrum 118b. Such features of the transmitted signal phase may be used, either alone or in combination with analysis of the magnitude response 118a in order to retrieve information encoded within the multiresonator structure 104.

[58] As such, the multiresonator 104, and hence the tag 102, may be assigned a unique identifier (ID) or "spectral signature". The spectral signature is obtained by interrogating the tag 102 when using a multi-frequency signal 116. The tag 102 retransmits the received signal, with information encoded in the magnitude and/or phase of the transmitted frequency spectrum.

[59] Multiresonator 104 shown in Figure 1 is formed from a plurality of substructures each of which is associated with a different resonance frequency. The value of each resonance frequency dependent upon the substructures.

[60] The addition of a dielectric element to a substructure can transform that substructure into a sensor of a particular environmental parameter, such as humidity, temperature and the like. A suitable dielectric element can be chosen which has a permittivity that changes as a function of the desired sensed environmental parameter. This change in permittivity results in a shift in the resonance response of that substructure.

[61] Accordingly, it is possible in a single RFID tag to encode digital information in a first group of substructures where the presence and/or absence of resonance responses at corresponding characteristic frequencies is used to retrieve that encoded digital information. By adding one or more dielectric elements to a second

group of substructures, where each dielectric element has a permittivity which changes as a function of a sensed environmental parameter to thereby cause a shift in the resonance response of that substructure, it is possible for that same RFID tag to sense one or more different environmental parameters.

[62] Dielectric materials exhibit a very wide range of electro-physical properties which are suitable for sensing environmental parameters. Their electrical behaviour ranges from the best insulators (e.g., Al_2O_3 and MgO) through wide-band gap and narrow-band gap semiconductors (TiO_2 , SnO_2 and Ti_2O_3 , respectively).

[63] A first embodiment of such an RFID tag is shown in Figure 2. In the depicted RFID tag 200, a multiresonator structure 202 including a first group 204 of substructures and a second group 206 of substructures is connected in series between two cross polarised UWB monopole antennas 208 and 210 for signal reception and transmission. Each resonator substructure attenuates an RF interrogation signal from an RFID reader at a distinct frequency to signify a signal data bit within a frequency spectrum 212. In the arrangement depicted in Figure 2, each substructure is formed by a stepped impedance resonator (SIR) structure. Multiple SIR structures are cascaded to form the multiresonator structure 202. Moreover, the SIR structure 206 of the tag is modified by the addition of a suitable dielectric element to enable humidity sensing, thereby resulting in a planar, printable chipless RFID humidity sensor.

[64] More generally, it will be appreciated that Figure 1 depicts an N bit chipless RFID tag with cascaded SIR filters. Here, the first $(N-1)$ SIR filters 204 are for data encoding and the N^{th} SIR 206 is modified for humidity sensing. Each SIR filter of the tag 200 has unique resonance frequency depending on its structural parameters. Thus modification of a particular SIR will not affect the other resonance frequencies.

[65] Stepped impedance resonators (SIRs) are transmission line resonators utilizing quasi-TEM modes. SIRs have advantages over uniform impedance resonators (UIR) in their wide degree of freedom of design, compact size and ease of fabrication. The basic structure 203 of the exemplary three element half wave SIR is shown in Figure 3(a).

[66] This structure 230 is symmetric at the mid centre 'O' and comprises two cascaded quarter wave tri- step SIRs 232 as shown in Figure 3(b). The characteristic impedance of the three steps is Z_1 , Z_2 and Z_3 having electrical length θ_1 , θ_2 and θ_3 . Thus, the overall electrical length of the half wave SIR is, $2\theta_T = 2 (\theta_1 + \theta_2 + \theta_3)$. An open ended $\lambda/2$ type SIR resonates at a frequency corresponding to the total electrical length. At the resonance frequency the structure acts as a bandstop filter, attenuating most of the transmitted power. The overall admittance Y_s looking into the open end in Figure 3(b) can be calculated from the equivalent impedance Z_s ,

$$Z_s = \frac{j \left(Z_1 Z_2 \tan \theta_2 + Z_1 Z_3 \tan \theta_3 + Z_1^2 \tan \theta_1 - \frac{Z_1^2 Z_2}{Z_3} \tan \theta_1 \tan \theta_2 \tan \theta_3 \right)}{Z_1 - Z_2 \tan \theta_1 \tan \theta_2 - Z_3 \tan \theta_1 \tan \theta_3 - \frac{Z_1 Z_2}{Z_3} \tan \theta_2 \tan \theta_3} \quad (1)$$

[67] As can be seen in Figure 4, a coplanar waveguide (CPW) line consists of a dielectric substrate 242 with a centre strip line 240 on the top surface. The centre strip line 240 is separated by a narrow gap 244, 246 from two ground planes on either side. In this arrangement, the top plane of the CPW line is filled with air having permittivity, ϵ_0 . The size of (i) the centre strip (S), (ii) the gap (W), (iii) the height (h_1), and (iv) relative permittivity (ϵ_{r1}) of the substrate 242 determines the effective dielectric constant and characteristic impedance of the CPW line.

[68] However, the transmission properties of the CPW line sandwiched between two dielectric substrates depends also on the height (h_2) and relative permittivity (ϵ_{r2}) of a top dielectric 248 applied to the multiresonator substructure formed by the remaining elements depicted in Figure 4. The characteristic impedance (Z_0) of a CPW line between two dielectrics is given by,

$$Z_0 = \frac{30\pi}{\sqrt{\epsilon_{eff}}} \frac{K(k_0^1)}{K(k_0)} \quad (2)$$

[69] Here, ϵ_{eff} is the effective dielectric constant and $K(k_0)$ is the modulus of complete elliptic integrals,

$$k_0 = \frac{S}{S + 2W} \quad (3)$$

$$k_0^1 = \sqrt{1 - k_0^2} \quad (4)$$

[70] Also, the effective dielectric constant is given by,

$$\varepsilon_{eff} = 1 + q_1(\varepsilon_{r1} - 1) + q_2(\varepsilon_{r2} - 1) \quad (5)$$

[71] Here, q_1 and q_2 are the partial filling factor depending on the structural parameters of a CPW line.

[72] For the CPW line 240 shown in Figure 4, the characteristic impedance can be related to the top dielectric properties. Hence, a top dielectric with hydrophilic/hydrophobic nature can be used to incorporate relative humidity change to the CPW line parameters.

[73] This principle is used in the CPW based tri step SIR structure depicted in Figures 2 to 4 to incorporate humidity sensing. As the top dielectric 248 changes its relative permittivity (ε_{r2}) with humidity, characteristic impedance and electrical length of each resonator unit corresponds to this change accordingly. This affects the overall resonance condition given in (1) and the SIR structure resonates at a shifted frequency. By calibrating this frequency shift against the humidity change a microwave humidity sensor can be developed.

[74] In one embodiment, a coplanar tri-section SIR filter is designed in CST Microwave Studio operating at 1025 MHz. To create a SIR structure in a CPW line, the microstrip SIR structure is cut away from the continuous 50ohm line. The simulation is performed on Taconic TLX-0 substrate having relative permittivity $\varepsilon_r=2.45$ and $\tan\delta=0.0019$ and substrate thickness, $h_1=0.5\text{mm}$. The layout of the exemplary SIR filter 250 is shown in Figure 5.

[75] In one or more embodiments, a humidity sensitive Kapton HN polyamide (Kapton) is used to incorporate relative humidity sensing. Kapton polyamide films are produced through heated polycondensation. Due to moisture absorption by the polyamide, hydrolysis effect takes place which modifies the internal electrical polarization. The modified electrical polarization results permittivity change of the polyamide.

[76] Kapton polyamide has a linear change with humidity according to the datasheet by Dupont. Kapton film has relative permittivity of 3.25 at 25% humidity and room temperature 23°C. At this temperature, Kapton's relative humidity (ϵ_r) changes linearly with humidity (RH) given by,

$$\epsilon_r = 3.05 + 0.008 \times RH \quad (6)$$

[77] Kapton's (ϵ_r) changes from 3.05 to 3.85 for humidity change of 0% to 100% at 23°C. In one or more embodiments, a Kapton film of thickness ($h_2 = 0.1$ mm) is used as a top dielectric 248 (Figure 4). The Kapton film covered the whole SIR structure thus each unit has characteristic impedance relating to Kapton's dielectric properties.

[78] In the embodiment depicted in Figures 2 to 5, the RFID tag includes a substructure and associated dielectric element for detecting one environmental parameter only. In other embodiments though, an RFID tag may include a series of substructures each designed to detect a different environmental parameter. Figure 6 shows a generic layout of a chipless RFID tag sensor 300 including multiresonator structure 302 disposed between and coupled to a receiving antenna 304 and a transmitting antenna 306. The multiresonator structure 302 includes a number of radar cross sectioning (RCS) scatterers which embed a distinct frequency signature when illuminated by an ultra-wide band (UWB) signal. A first set 308 of scatterers carry the data ID of the tag. A second of scatterers 310 carry environmental parameter sensing information. In this case, each scatter forming part of the second set 310 operates independently from the others. The set of scatterers 310 are designed to respond to a change in a particular environmental parameter such as temperature, pH, humidity, presence of a noxious gas and impact.

[79] Each of the “scatterers” forming part of the set of scatterers 310 can be formed in the previously described manner. That is, each scatterer includes a substructure of the multiresonator structure 302 and has a resonance frequency the value of which is dependent upon the substructure. The planar conductive substructure is formed on a substrate, and one or more dielectric elements are disposed on the substructures forming part of the set of scatterers 310. Each dielectric element has a permittivity which changes as a function of the sensed environmental parameter to thereby cause a shift in the resonance response of that substructure.

[80] Various organic and inorganic materials can be used as sensing materials at microwave frequency bands and mm wave frequency bands starting from UWB 3GHz up to 60GHz. Organic and inorganic materials useful as sensing materials are preferably dielectric materials that have a low specific conductivity, which may be in the order of 10^5 S/m, or less. In one or more embodiments, materials useful as sensing materials may be substantially non-conductive.

[81] Dielectric elements for detecting an environmental parameter are formed from at least one sensing material. The sensing material will be selected on the basis of the environmental parameter of interest. The environmental parameter of interest may be temperature, humidity, pH, strain, gas, pressure, electric fields light, or a combination of these parameters. A sensing material useful for chipless RFID sensors of the invention may undergo a change in its dielectric or conductive property in response to a change in an environmental parameter, resulting in a resonance frequency shift that can be quantified as sensing data.

[82] Examples of materials identified by the Applicant as suitable sensing materials for low cost chipless RFID sensors include but are not limited to (1) ionic plastic crystals, the ionic conductivity of which changes due to organic molecule defects and movement of crystals, (2) conductive polymers (such as PEDOTs), the conductivity of which increases with a frequency increase, (3) composite/conjugate polymer – mixed with conductive and nonconductive polymer, and (4) nanostructured metal oxides which exhibit multifunctional properties and are very susceptible to external environmental changes, such as pressure, temperature, and electric fields.

[83] Conjugated polymers cover a very large conductivity range from insulators over semi-conductors to conducting materials. Examples of suitable conjugated polymers include polyaniline (PANI), polyacetylene (PA), polypropylene (PP), polythiophene and derivatives of these polymers.

[84] Composite polymers are composites with different polymer matrix materials. Suitable composite polymers can detect environmental parameters such as temperature, humidity, pH etc. values of the surrounding environment

[85] With respect to ionic plastic crystals, the ionic conductivity for plastic crystals changes due to organic molecule defects and the movement of crystals. One example of a suitable ionic plastic crystal is N-methyl-N-butylpyrrolidiniumhexafluorophosphate (P14PF6) which has three phase transitions e.g. at about -15 °C which represents the crystallization of the supercooled phase II to a low temperature phase III; at 14°C, phase III then transforms to the higher temperature phase (phase II); at 43°C, phase II transforms to phase I, which subsequently melts at 70°C. Ionic plastic crystals are a good candidate for temperature sensing materials.

[86] Among the different conducting polymers used in practical applications, poly(3,4-ethylenedioxythiophene) (PEDOT) is a particularly robust conducting material. The conductivity of PEDOT is thought to depend on the pH level, with the highest conductivities at low pH, but the change is not dramatic except for pH value exceeding 11. The changes are reversible over a wide pH range. This result indicates that PEDOT can be used as a pH sensing material.

[87] Nanostructured metal oxides such as zinc oxides and indium tin oxides exhibit multifunctional properties, and are very susceptible to external environmental changes, such as temperature and electric fields.

[88] In one or more embodiments a dielectric element is formed from a temperature sensing material that is capable of detecting a change in temperature in various environments. Some examples of temperature sensing materials that may be employed include liquid crystals, ionic plastic crystals, conductive polymers (such as polyaniline (PANI) and poly(3,4-ethylenedioxythiophene (PEDOT)), polymer mixtures containing conductive polymers (such as poly(3,4-ethylenedioxythiophene)

poly(styrenesulfonate) (PEDOT:PSS)), phenanthrene, graphene and nanostructured metal oxides (such as zinc oxide and indium tin oxide).

[89] In one or more embodiments a dielectric element is formed from a temperature sensing material that undergoes at least one phase transition in response to temperature. For instance, ionic plastic crystals such as N-methyl-N-butylpyrrolidiniumhexafluorophosphate undergo phase transitions at defined temperatures, which results in a change in permittivity as a function of the temperature. Other temperature sensing materials that exhibit a phase transition with temperature are sublimate materials such as phenanthrene, naphthalene, benzene and anthracene. For instance, phenanthrene is a polycyclic hydrocarbon which can undergo sublimation and transform directly from solid to gas phase without passing through an intermediate liquid phase. The enthalpy of phase transition for the sublimation of phenanthrene is 90.5 kJmol^{-1} and transition temperature is about 72°C . After the transition temperature, there is a drastic increase of dielectric constant ϵ_T which is permanent if the vapour is not de-sublimated. Therefore, this property may be used to realise a temperature threshold sensor for a chipless RFID tag that triggers at the transition temperature of phenanthrene.

[90] In one or more embodiments a dielectric element is formed from a temperature sensing material that exhibits a change in an optical or electrical property in response to temperature. For example, liquid crystals may exhibit a change in colour with temperature while nanostructured metal oxides such as zinc oxide and indium tin oxide may experience a shift in optical absorbance with temperature. The optical absorption edge of a zinc oxide thin film has a regular red-shift with temperature, which corresponds to a linear relationship between the band gap energy of zinc oxide and temperature. This relationship makes zinc oxide particularly suitable as a temperature sensing material.

[91] Liquid crystal preassembly can also change in conduction/dielectric constant due to the temperature of the phase transition and the significant energy involved in the phase transition. The conductivity of ZnO strongly varies with temperature. The variation of the complex permittivity of ZnO also varies with a change in frequency and temperature.

[92] In one or more embodiments a dielectric element is formed from a humidity sensing material that is capable of detecting a change in relative humidity (RH) in various environments. In one set of embodiments a dielectric element is formed from a humidity sensing material selected from the group consisting of oxides (preferably metal oxides), tantalum and silicon containing materials, hydrophilic polymers and hydrophobic polymers.

[93] In one embodiment the humidity sensing material is an oxide, preferably a metal oxide, such as zinc oxide, indium oxide, aluminium oxide or stannic oxide.

[94] In another embodiment the humidity sensing material is selected from the group consisting of tantalum and silicon containing materials.

[95] In another embodiment the humidity sensing material is a polymer. The polymer may be a suitable hydrophobic or hydrophilic polymer that is responsive to a change in environmental moisture.

[96] In one embodiment the humidity sensing material is a hydrophobic polymer. Hydrophobic polymers suitable for humidity sensing may be polar but non-ionic and somewhat hygroscopic. Examples of hydrophobic humidity sensing polymers include polyimides and esters.

[97] In another embodiment the humidity sensing material is a hydrophilic polymer. Hydrophilic polymers are useful materials for detecting humidity due to their high moisture sensitive properties and solubility in water. Hydrophilic polymers employed for humidity sensing may be natural polymers, including poly(amino acids) such as gelatin, and polysaccharides such as dextran, or they may be synthetic polymers, including polyamides such as Kapton (poly(4,4'-oxydiphenylene-pyromellitimide)) and Nylon 12 (poly(lauryllactam)), poly(ethylene vinyl acetate), certain polyelectrolytes and poly(vinyl alcohol). In one set of embodiments, a dielectric element may be formed from Kapton polyamide as a humidity sensing material. In another set of embodiments a dielectric element may be formed from poly(vinyl alcohol) (PVA) as a humidity sensing material. PVA is a hygroscopic polymer material that absorbs water that has the potential to take up to 25% of water from humid ambient air. PVA has been found to have negligible sensitivity to some

gases (such as NH_3 , NO_2 and CO) and low hysteresis characteristics in sensing ambient humidity.

[98] In one or more embodiments a dielectric element is formed from a pH sensing material that is capable of detecting a change in pH in various environments. Conducting polymers such as polyaniline (PANI) and PEDOT and some hydrophilic polymers such as poly(acrylic acid) can exhibit a change in resistivity in response to pH, making these polymers suitable as pH sensing materials.

[99] In one or more embodiments, a dielectric element is formed from a light sensing material. Examples of light sensing materials include CdS photoresistors and UV sensitive conducting polymers. In one set of embodiments the light sensing material is a UV sensitive conducting polymer which is a polythiophene polymer such as poly(3-hexyl thiophene).

[100] In one or more embodiments a dielectric element is formed from a strain sensing material that is capable of detecting a change in stress, strain, shear, or load in various environments. Strain sensing materials may include conducting composites or conducting polymers such as PEDOT, or elastomeric polymers such as polyurethane rubber.

[101] In one or more embodiments a dielectric element is formed from a gas sensing material that is capable of detecting a change in the level of a gas in various environments. Gas sensing materials may include conductive carbon nanoparticles such as carbon nanotubes, including single wall carbon nanotubes (SWCNT) and multiwalled carbon nanotubes (MWCNT), semiconducting oxides, platinum and conducting polymers such as polypyrrole, polythiophene and its derivatives, polyaniline, and composites thereof.

[102] In one or more embodiments a dielectric element may be formed from a pressure sensing material that is capable of detecting a change in pressure in various environments. Pressure sensing materials may be selected from the group consisting of piezoresistive films, microelectromechanical (MEMS) polysilicon membranes, monocrystalline silicon, poly(urethane) rubbers, plastic films and silicon membranes.

[103] In one or more embodiments a dielectric element is formed from an electric field sensing material that is capable of detecting a change in electric field in various environments. Examples of electric field sensing materials include nanostructured metal oxides such as zinc oxides and indium tin oxides, ferromagnetic materials having magneto-elastic property, diamond, and polydimethylsiloxane (PDMS).

[104] A dielectric element may undergo a permanent or reversible change in dielectric or conductivity property in response to a change in an environmental parameter. For example, a dielectric element may be formed from a temperature sensing material that exhibits a reversible dielectric property change with temperature. Alternatively, a dielectric element may be formed from a temperature sensing material that undergoes an irreversible change in dielectric behaviour once a temperature threshold has been reached.

[105] A selected sensing material may be multifunctional in that the material would be capable of detecting changes that occur for different environmental parameters. For example, conducting PEDOT-based polymers can be used to detect changes in different environmental parameters such as temperature, pH, strain and humidity.

[106] Whilst multiresonator substructures in the form of stepped impedance resonators (SIRs) have been described here above, it will be appreciated that a variety of other substructures may be used. For example, for compact RFID tags, a variety of frequency selective surfaces may be formed, such as a slot monopole, split ring resonators (SRR) and E-coupled LC (ELC) resonators. Various other frequency selective surfaces and structures will be apparent to a skilled addressee in this field.

[107] For example, Figure 7 depicts another embodiment of an RFID tag which advantageously provides a compact arrangement integrating multiple slot resonator substructures and a complementary ELC resonator substructure for sensing an environmental parameter. The multiple slot resonator 330 depicted in Figure 7 includes multiple slots 332, 334 and 336 in a rectangular monopole. The multiple slot resonator carries the data ID to enable identification of the article to which the RFID tag is affixed. An ELC resonator 338 is formed between the slots of the multiple slot resonator 330 and operates as a sensing resonator.

[108] In this case an ELC resonator is chosen for its high electric field density between parallel plates 340 and 342 forming part of the ELC resonator 338. A polymer material or other dielectric element 344 having the same properties are the top dielectric 248 shown in Figure 4 is formed under the capacitive plate of the ELC resonator 338. For a slight change in the dielectric properties of this polymer material, a significant and detectable shift in the RCS spectrum is observed.

[109] Figure 8 depicts measured results of a fabricated chipless RFID tag sensor having the form depicted in Figure 7. In this case, a humidity sensitive polymer was used to incorporate moisture sensing within the RFID tag. From Figure 8, it can be seen that at relative humidities of 55%, 65% and 75% the resonance frequencies of slots 332, 334 and 336 (referenced slots a, b and c in Figure 8) remained stable, the resonance frequency of the ELC resonator varied significantly from approximately 7.15GHz to 6.85 GHz between those values of relative humidity.

[110] In the above described exemplary embodiments, the first group of substructures encoding the ID or other digital information borne by the RFID tag and the second group of substructures, on which one or more dielectric elements in order to sense one or more different environmental parameters, are distinct from each other and do not include any common substructures. However, in other embodiments one or more substructures may be common to both the first and second group of substructures.

[111] By way of illustration, the multiresonator structure discussed above in relation to Figure 7 includes multiple slots 332, 334 and 336 in a rectangular monopole and the ELC resonator 338. Whilst the dielectric 344 formed under the capacitive plate of the ELC resonator 338 causes the resonance frequency of the ELC resonator 338 to vary as a function of the sensed environmental parameter of humidity, that variance occurs within a known frequency band (in this case from 6.7 to 7.15 GHz). Provided the presence or absence of a resonance frequency is detected within that band, that presence or absence can be interpreted as a binary "0" or "1". Accordingly, the ELC resonator 338 could encode one bit of a multi-bit binary code together with other substructures that do not sense an environmental parameter.

[112] The above described RFID tag can be manufactured in a simple low cost manner, as depicted in Figure 9. In this manufacturing method, inkjet printing techniques are used to print chipless RFID tag sensors directly onto a substrate formed from a polymer paper or other suitable material.

[113] In this exemplary embodiment, a polymer substrate 400 is driven by a roller 42 under control of computer-controlled machine operating system (not shown). The roller 402 causes the substrate 400 to be driven underneath two printing heads, namely a first printing head 404 for depositing sensing material and a second printing head 406 for depositing conducting material used to form the substructures of the multiresonators forming part of each RFID tag.

[114] In a first step, the printing head 404 or like dispenser delivers a desired quantity (typically in the range of microliters) and a desired pattern of sensing material on the polymer substrate 400. Secondly, conducting material is deposited from the printing head 406 onto the substrate and the sensing material as required in order to create conductive tracks for the substructures of the multiresonator structure of each RFID tag. By using such a manufacturing process, the structure depicted in Figure 7 is able to be simply and cost effectively generated by depositing two separate materials from the printing heads 404 and 406 onto the substrate 400 as it is driven past each of these two printing heads.

[115] It will be appreciated that in other embodiments, the order in which the sensing material and the conducting material are deposited on the substrate may be reversed, so that the conducting material is firstly deposited on the substrate as shown in the structure depicted in Figure 4 and then the dielectric sensing material is deposited on top of the conducting material.

[116] The printed substrate may eventually be coated to eliminate derogation from exposure to the environment, and then packaged to suit a desired application. The coating may also take place from a separate printing head (not shown) or other device which applies a coating directly to the printed substrate 400 as it is driven past another point in the production process. A suitable transparent polymer can be used in the coating.

[117] In cases where the RFID tag detects multiple environmental parameters and therefore requires a number of different sensing materials to be applied to the substrate 400 a number of separate printing heads may be used to apply those different sensing materials to the substrate 400.

[118] Whilst the invention has been described in the foregoing with reference to a number of prototype chipless RFID tag devices, it will be appreciated that embodiments of the invention may be employed in a variety of other applications. For example, antenna/resonator structures embodying the invention may be fabricated on, printed onto, or incorporated into, a variety of different articles including, but not limited to RFID tags, security documents, and negotiable instruments such as bank notes. They may be used accordingly for security and/or authentication purposes, as well as for the identification, detection and/or tracking of various items or articles of interest. Moreover, these devices which include one or more sensors of environmental parameters, can be used in a number of applications. For example, by routinely reading the RFID tags associated with products maintained in temperature controlled environments, it is possible to maintain a thermal history of each of the products in order to ensure that safety standards are maintained.

EXAMPLES

[119] The present invention is described with reference to the following examples. It is to be understood that the examples are illustrative of and not limiting to the invention described herein.

Example 1: RFID Tag for Relative Humidity (RH) Monitoring (RH Monitoring)

[120] To incorporate humidity sensing, an RFID tag is modified by putting polyvinyl alcohol (PVA) 31-50000 on top of the electric inductor capacitor (ELC). The PVA polymer is from Sigma Aldrich and it is dissolved in a solution of H₂O/ Ethanol 3/1 for about 3 hours of magnetic stirring. Afterwards it became completely soluble and transparent. Then, it is carefully poured on top of the ELC using a fine droplet. The amount of PVA used is about 0.2 ml.

[121] To test the sensor operation, an experiment is performed using Miller Nelson Temperature and Humidity controller. The humidity controller is connected to an esky chamber through a water flow sensor. The esky chamber has an air tight lid so that its temperature and humidity can be controlled from outside the tag and a DIGITECH QP- 06013 data logger are placed inside the chamber. The data logger reads and stores the temperature and humidity inside the chamber at a regular time interval. Two horn antennas are connected to a VNA for frequency response measurement. The tag is placed between the two antennas for measuring the transmission coefficient.

[122] By changing the set temperature and humidity of Miller Nelson controller the transmission coefficient (S_{21}) of the tag was measured for different environment conditions (Figure 10). During the experiment, temperature was almost constant at around 22.5°C. However, the relative humidity changed from 60% to 80% inside the chamber.

[123] It is observed that the resonant frequency of the ELC is significantly shifted towards lower frequency % relative humidity (RH). By calibrating this frequency shift, the ambient humidity can be determined.

[124] A detailed analysis of humidity sensing mechanism can be done from Figure 11. Here, an extensive measurement of transmission coefficient is shown for RH change (35-85%). It is found that, minimum power at resonance of the ELC resonator is also affected by RH change. This is due to the variation of imaginary ϵ_T'' of PVA with RH. At high frequency, the imaginary ϵ_T'' increases with humidity and the conductivity decreases and dissipation factor increases accordingly. Figure 12 plots the resonant frequency shift variation with RH. By calibrating the sensitivity curve we can determine RH of an unknown environment.

Example 2: RFID Tag for Temperature detection

[125] To incorporate temperature threshold sensing in a RFID tag, a dielectric material (phenanthrene) having irreversible dielectric behaviour is used.

[126] Tetrahydrofuran (THF) solution is poured on top of ELC using a fine droplet and masking technique. Later, the tag is heated at low temperature (around 40°C) to evaporate THF and a crystal of phenanthrene is formed on the ELC resonator. The thickness of phenanthrene film is 0.2mm.

[127] The experiment is performed in an enclosure where temperature can be controlled. Figure 13 shows the transmission coefficient (S_{21}) of the tag measured at initial and final conditions. At initial condition the resonant frequency of ELC resonator is at 6.95 GHz (measured at room temperature). However, it is shifted gradually to 7.21 GHz after heating till 100°C. This is due to the sublimation of phenanthrene as it is heated beyond its transition temperature. Figure 14 shows resonant frequency vs temperature during heating of the tag and the measured threshold temperature is around 90°C.

[128] Later, the tag is cooled from 100°C to 5°C. As shown in Figure 14, during the cooling process, the resonant frequency remained constant at 7.21 GHz. Hence, after the threshold temperature, the data retains its final position irrespective of temperature variation.

[129] It will be understood that the invention is not limited to the specific embodiments described herein, which are provided by way of example only. The scope of the invention is as defined by the claims appended hereto.

The claims defining the invention are as follows

1. An RFID tag having information encoded therein which may be retrieved by applying a suitable RF signal and identifying resonances in a corresponding RF frequency response, the RFID tag including:

a substrate;

a planar conductive multi-resonator structure disposed on the substrate, the multi-resonator structure including a plurality of substructures each of which is associated with a different resonance frequency, the value of each resonance frequency being dependent upon the substructures, the presence and/or absence of resonance responses from a first group of substructures at corresponding characteristic frequencies being used to encode digital information; and

one or more dielectric elements disposed on a second group of substructures, each dielectric element having a permittivity which changes as a function of a sensed environmental parameter to thereby cause a shift in the resonance response of that substructure.

2. An RFID tag according to claim 1, wherein the resonance responses of the first and second group of substructures are in different frequency bands.

3. An RFID tag according to either one of claims 1 or 2, wherein the first and second groups of substructures are distinct from each other and do not include any common substructures.

3. An RFID tag according to either one of claims 1 or 2, wherein one or more substructures are common to both the first and second group of substructures.

4. An RFID tag according to any one of the preceding claims, wherein one or more of the substructures are in the form of a slot monopole, split ring resonator or E-coupled LC resonator.

5. An RFID tag according to any one of the preceding claims, wherein multi-resonator structure includes multiple slots in a rectangular monopole and a complementary ELC resonator.
6. An RFID tag according to any one of the preceding claims, wherein one or more of the dielectric elements are formed from a sensing material selected from the group consisting of a temperature sensing material, a humidity sensing material, a pH sensing material, a strain sensing material, a gas sensing material, a light sensing material, a pressure sensing material, and an electric field sensing material.
7. An RFID tag according to claim 6, wherein the humidity sensing material is selected from the group consisting of oxides (preferably metal oxides), tantalum and silicon containing materials, hydrophilic polymers and hydrophobic polymers.
8. An RFID tag according to claim 7, wherein the humidity sensing material is a hydrophilic polymer selected from the group consisting of poly(amino acids) such as gelatin, polysaccharides such as dextran, polyamides such as poly(4,4'-oxydiphenylene-pyromellitimide) (Kapton) and poly(lauryllactam) (Nylon 12), poly(ethylene vinyl acetate), and poly(vinyl alcohol).
9. An RFID tag according to claim 6, wherein the temperature sensing material is selected from the group consisting of liquid crystals, ionic plastic crystals, conductive polymers, polymer mixtures containing conductive polymers, sublimate materials, graphene and nanostructured metal oxides.
10. An RFID tag according to claim 9, wherein the temperature sensing material is a sublimate material.

11. An RFID tag according to claim 6, wherein the pH sensing material is selected from the group consisting of polyaniline (PANI), poly(3,4-ethylenedioxythiophene) (PEDOT) and poly(acrylic acid).

12. An RFID tag according to claims 6, wherein the strain sensing material is selected from the group consisting of conducting composites, conducting polymers and elastomeric polymers.

13. An RFID tag according to claim 6, wherein the gas sensing material is selected from the group consisting of conductive carbon nanoparticles, semiconducting oxides, platinum and conducting polymers and composites thereof.

14. An RFID tag according to claim 6, wherein the light sensing materials is selected from the group consisting of CdS photoresistors and UV sensitive conducting polymers, preferably a UV sensitive conducting polymer which is a polythiophene polymer such as poly(3-hexylthiophene).

15. An RFID tag according to claim 6, wherein the pressure sensing material is selected from the group consisting of piezoresistive films, microelectromechanical (MEMS) polysilicon membranes, and monocrystalline silicon, poly(urethane) rubber, plastic films and silicon membranes.

16. An RFID tag according to claim 6, wherein the electric field sensing material is selected from the group consisting of nanostructured metal oxides, ferromagnetic materials having magneto-elastic property, diamond, and polydimethylsiloxane (PDMS).

17. A method of manufacturing an RFID tag according to any one of the preceding claims, including the steps of:

applying sensing material to the substrate to form the dielectric elements; and
applying conducting material to the substrate to form the substructures.

18. A method according to claim 17, wherein sensing material is firstly applied to the substrate, and the conducting material is subsequently applied to the substrate.

19. A method according to claim 17, wherein conducting material is firstly applied to the substrate, and the sensing material is subsequently applied to the substrate.

20. A method according any one of claims 17 to 19, wherein one or both of the forming steps includes applying the material via a printing head.

21. A method according any one of claims 17 to 20, wherein the RFID tag detects multiple environmental parameters and a number of different sensing materials are applied to the substrate via separate printing heads.

22. A method according any one of claims 17 to 21, and further including the step of applying a protective coating to the substrate.

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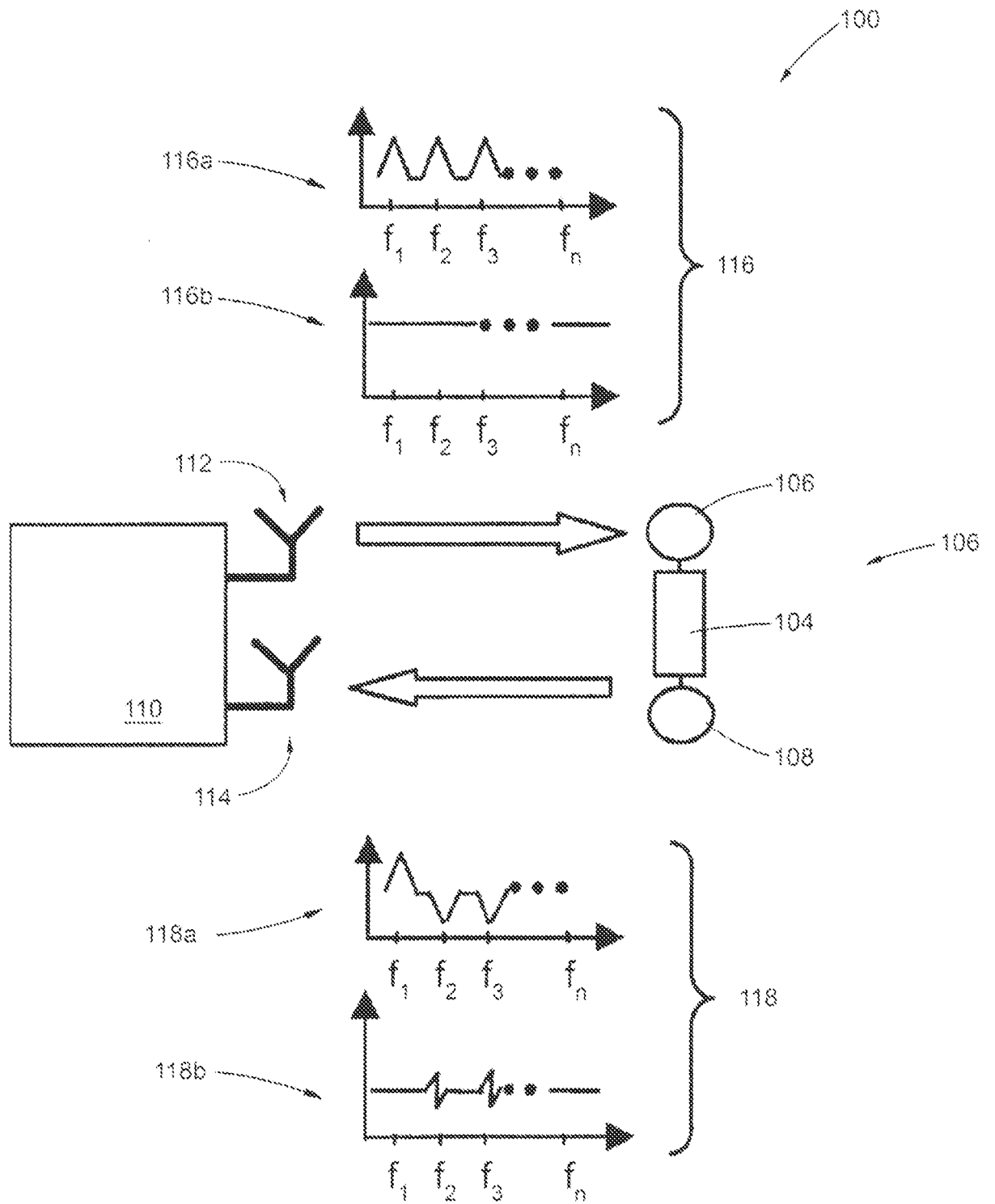


Figure 1

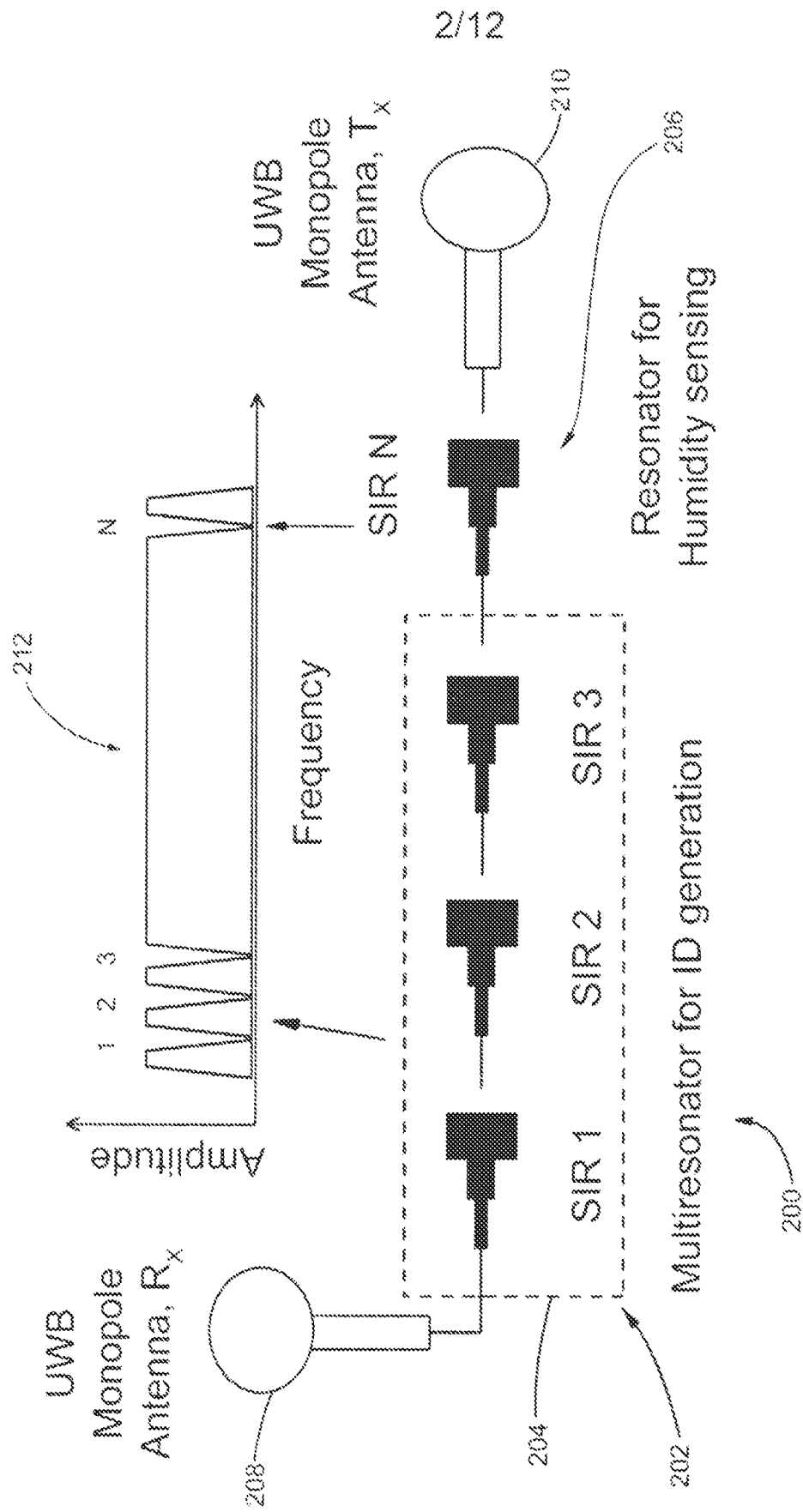


Figure 2

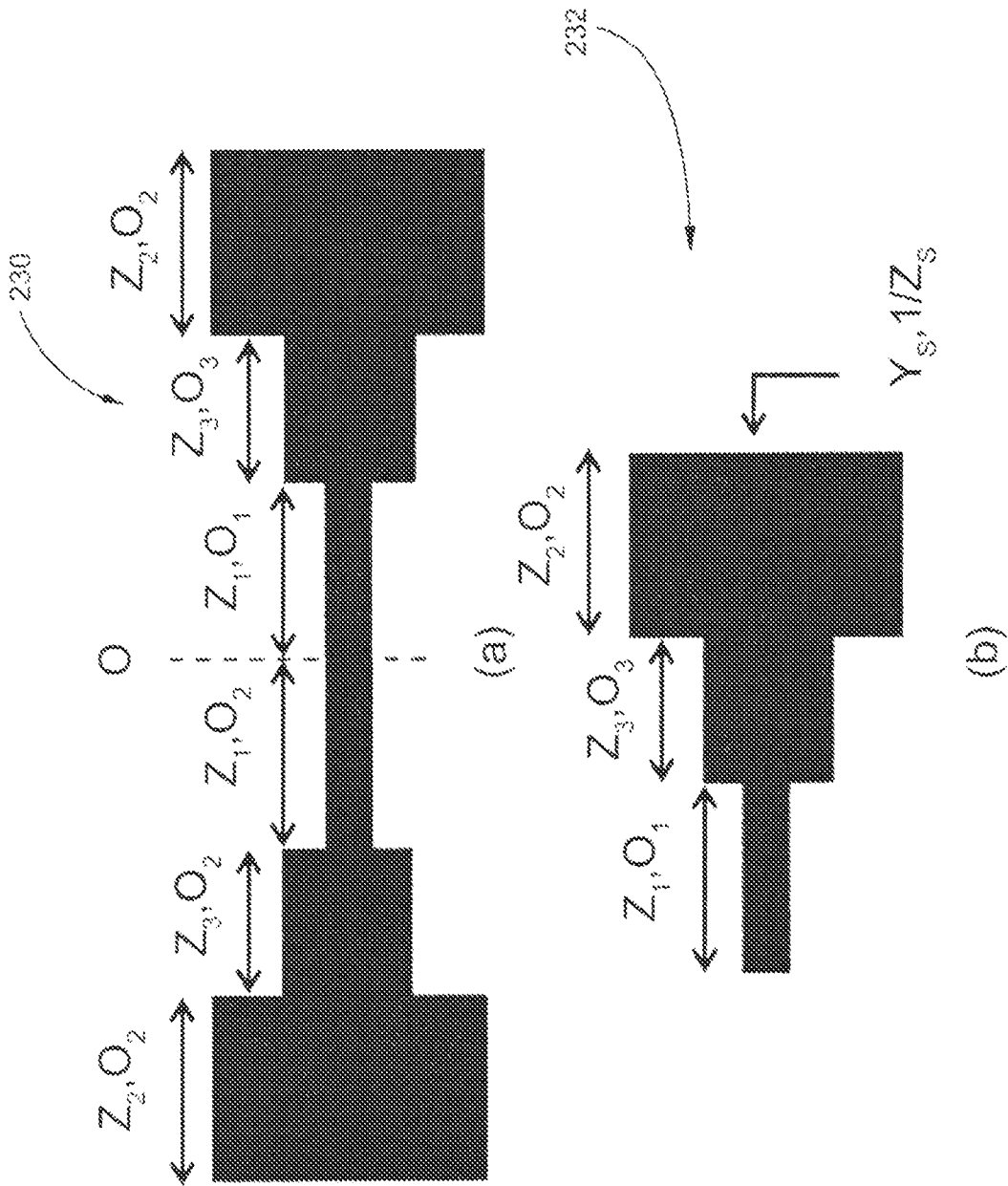


Figure 3

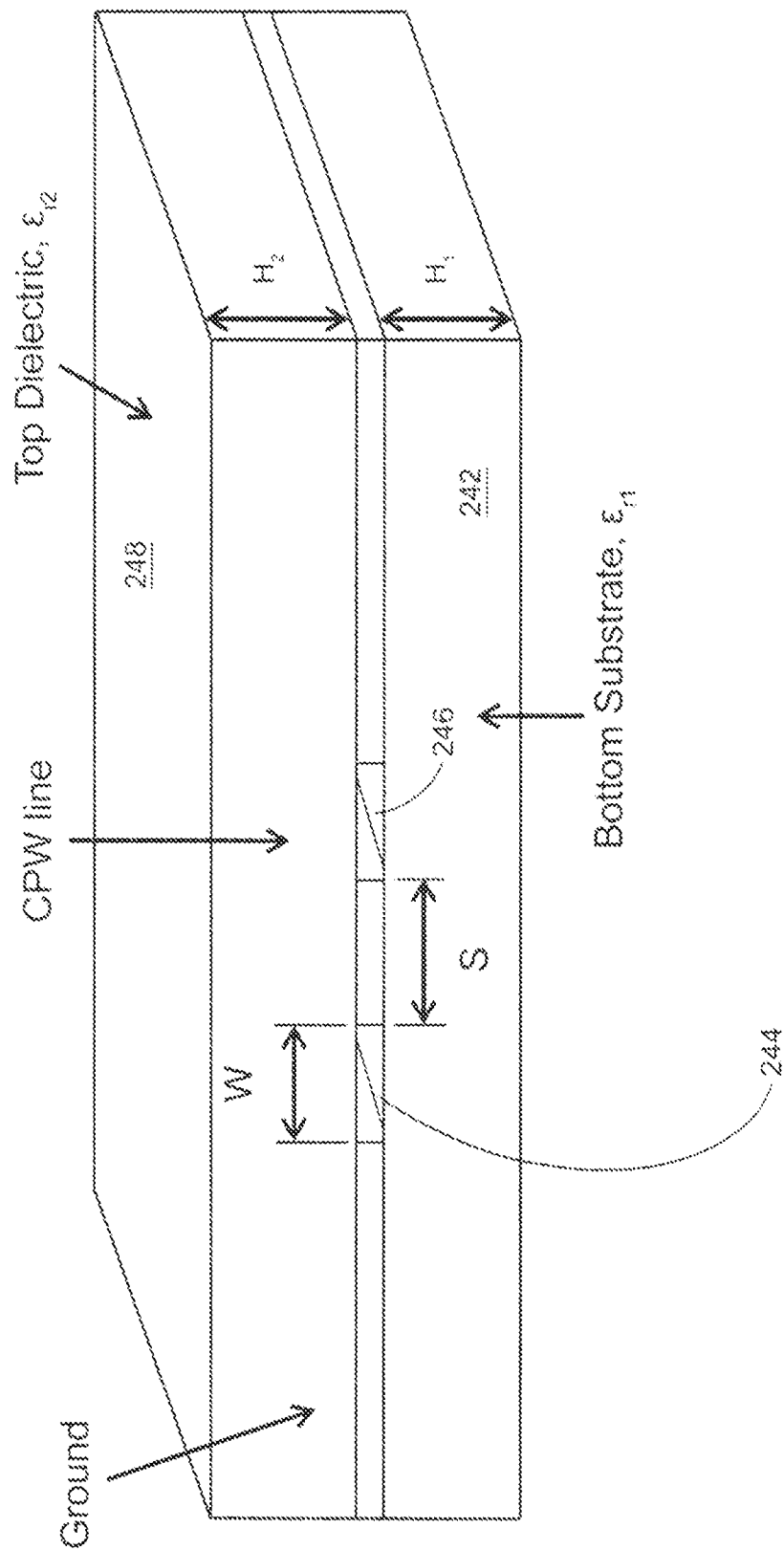


Figure 4

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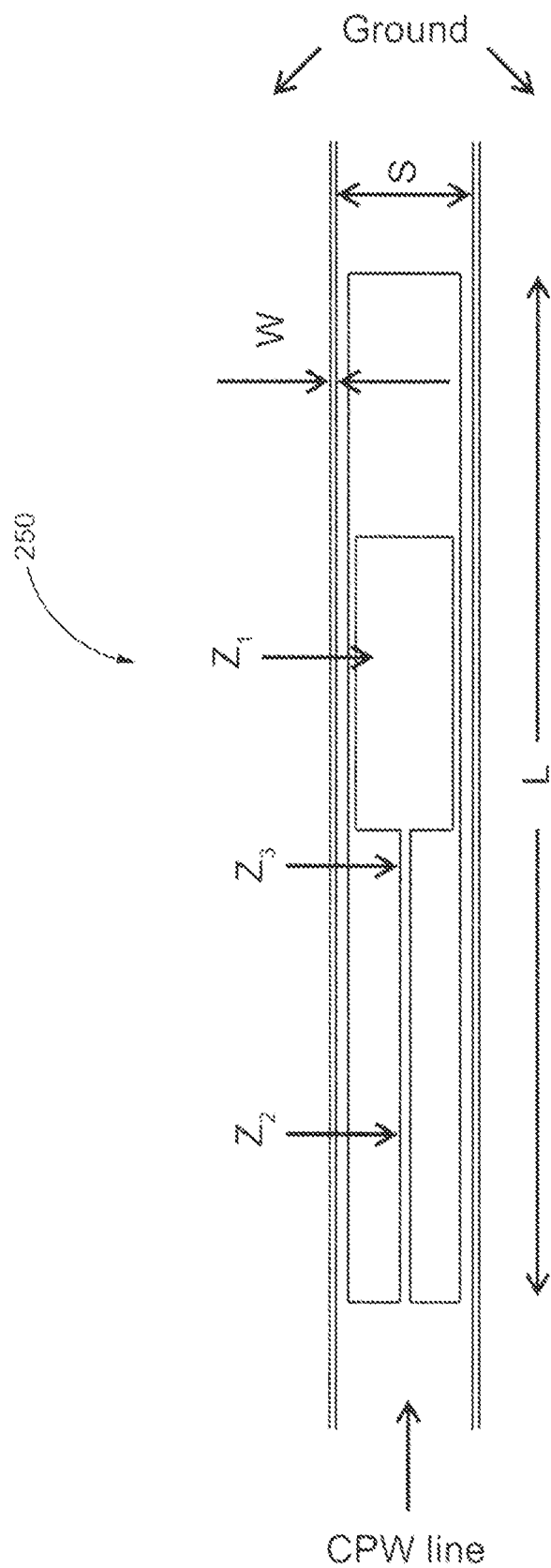


Figure 5

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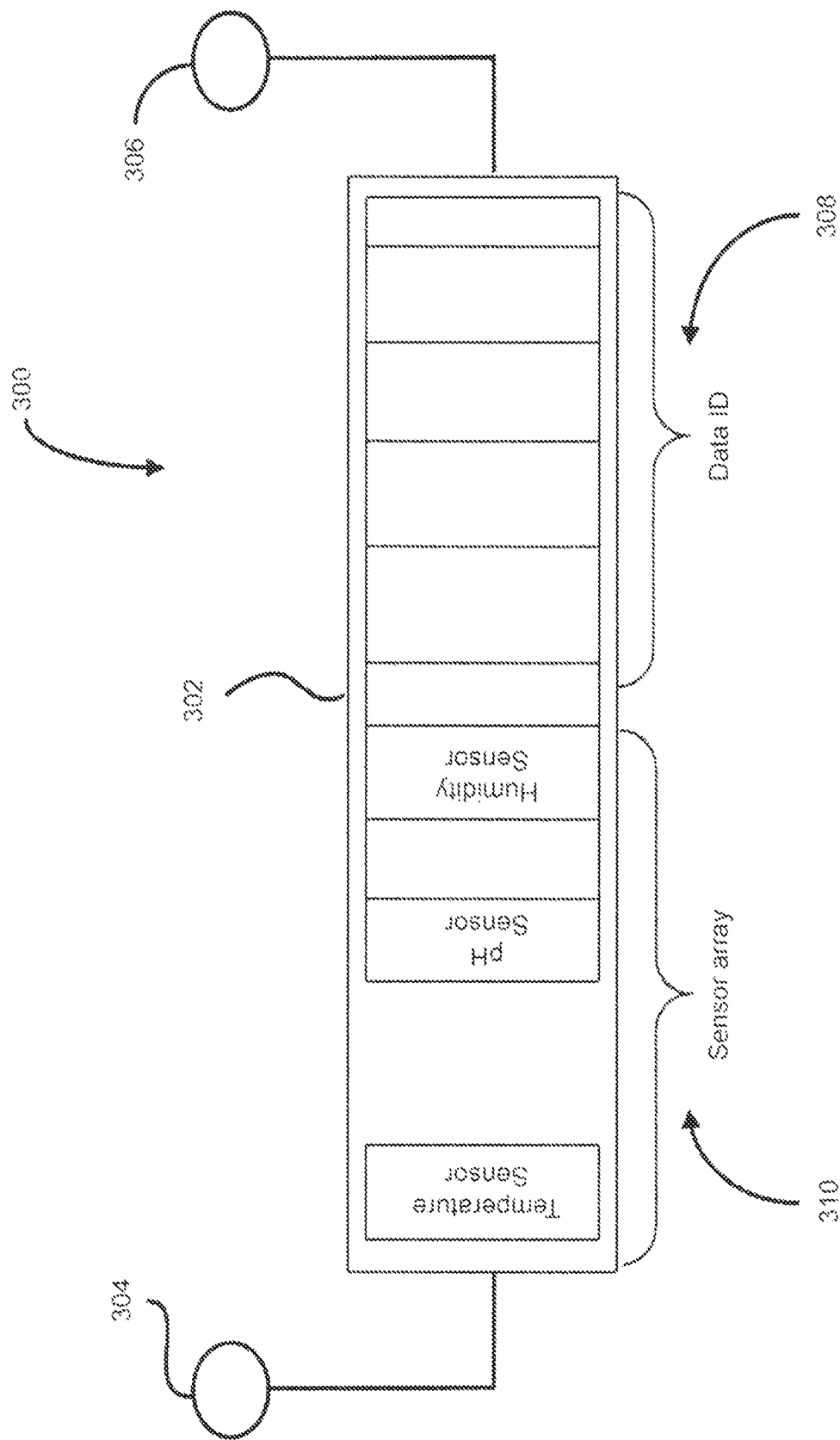


Figure 6

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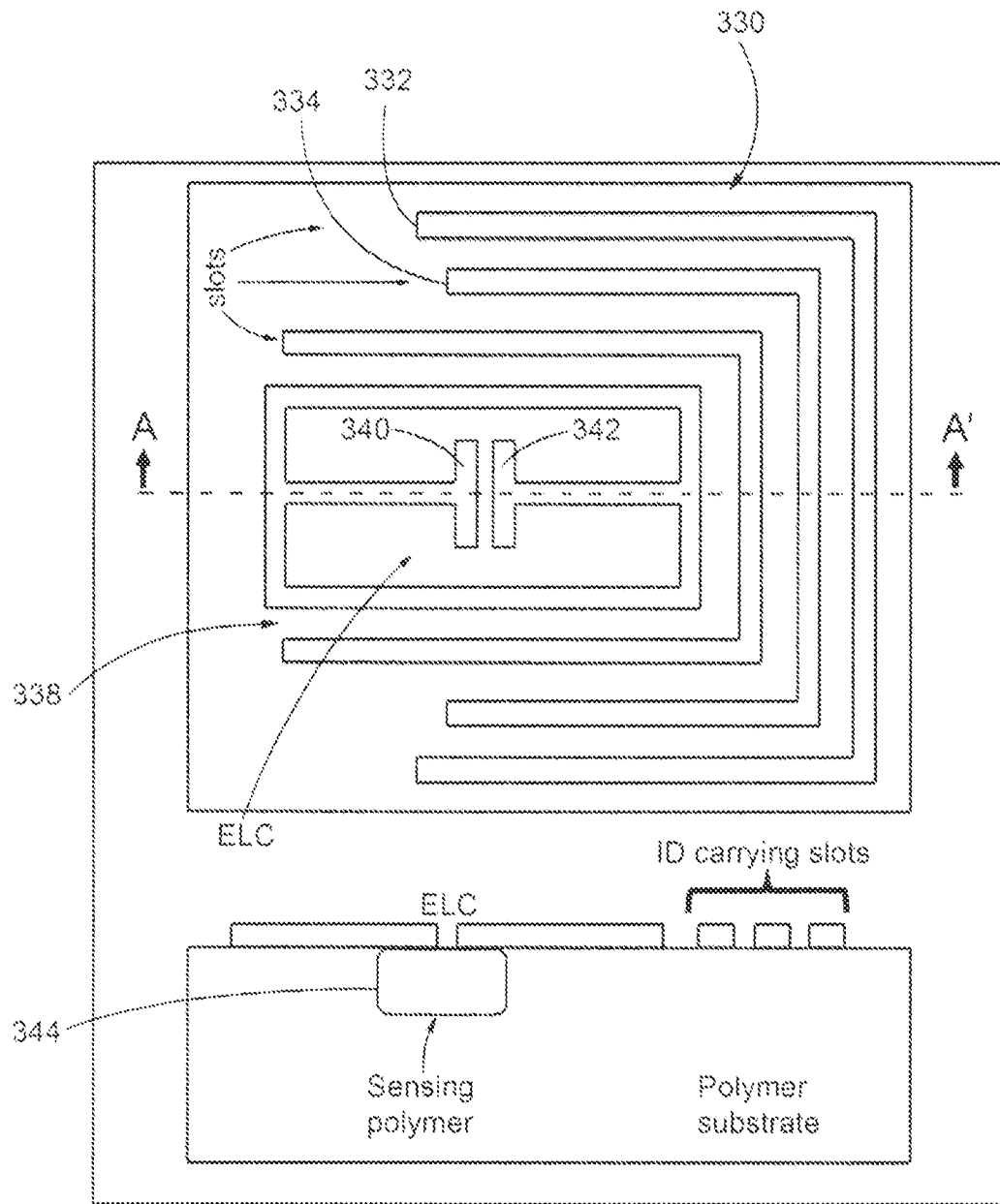


Figure 7

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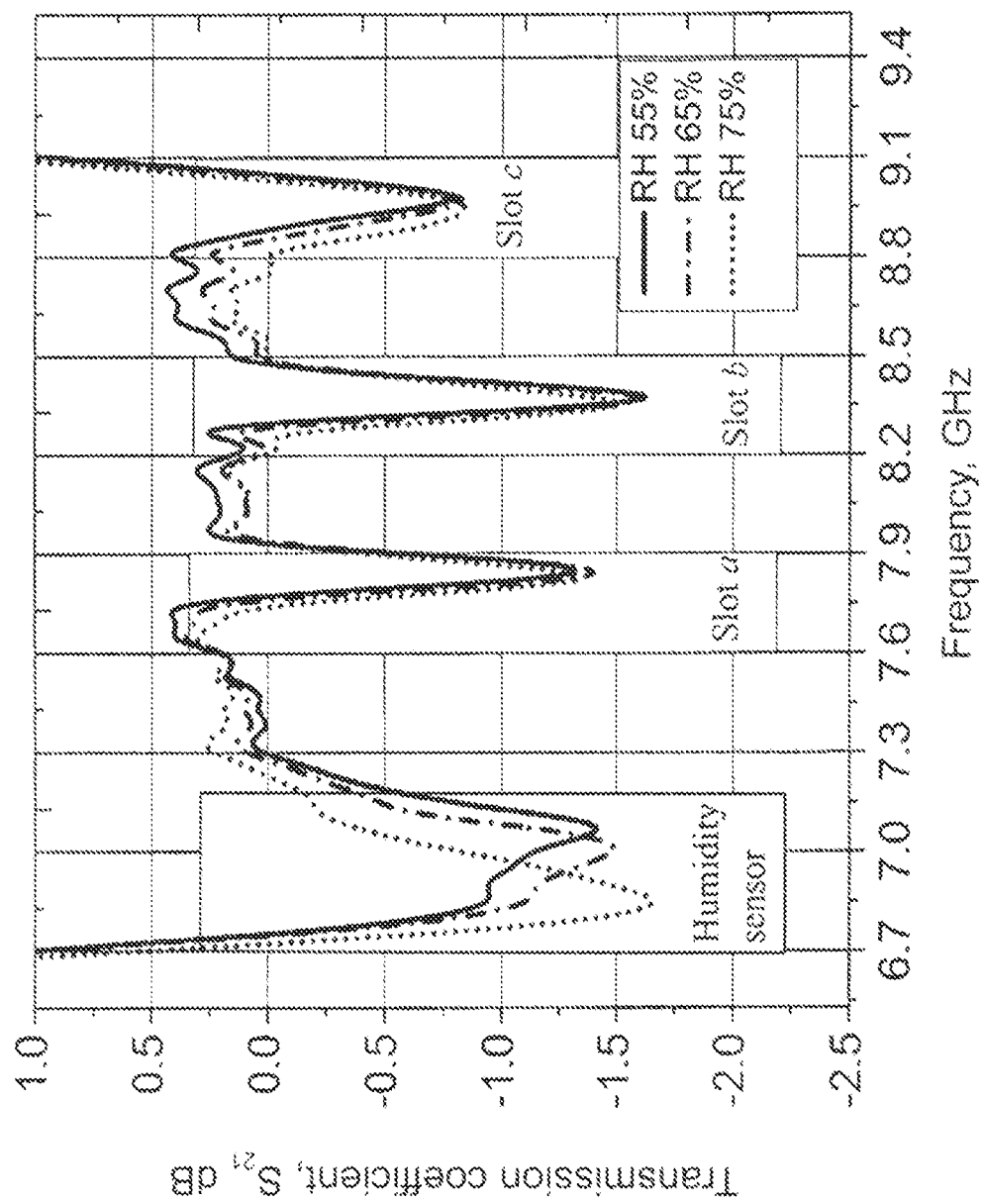


Figure 8

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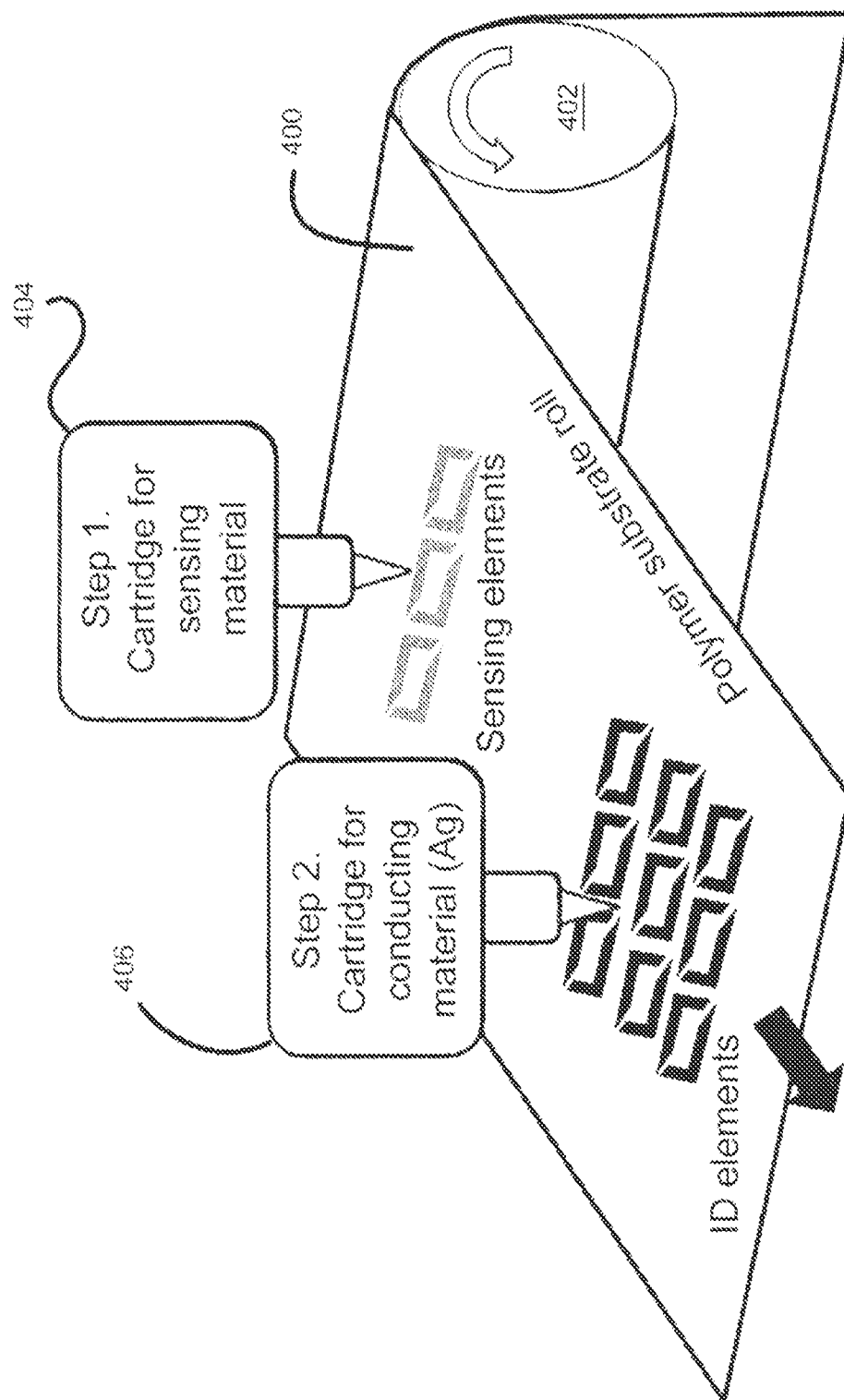


Figure 9

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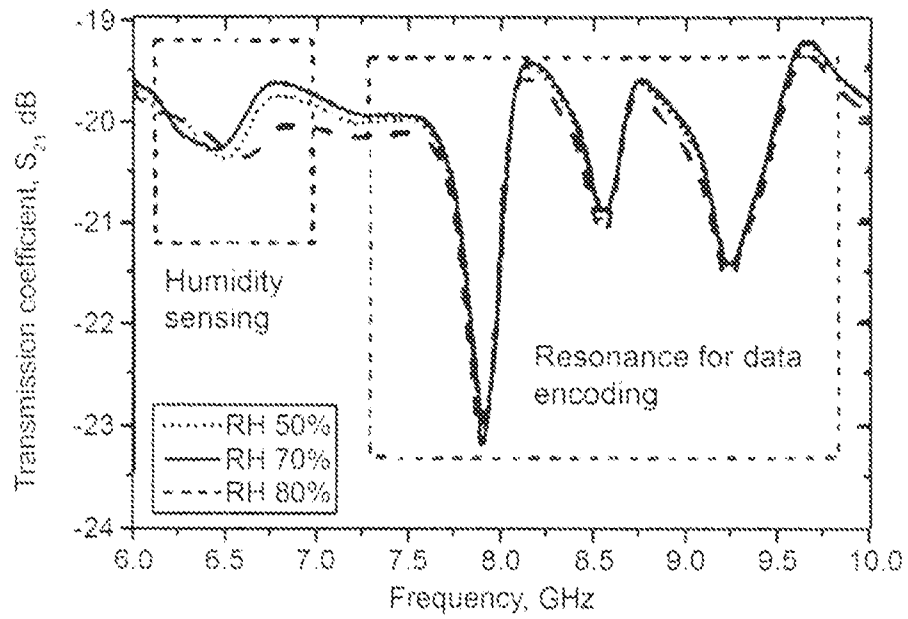


Figure 10

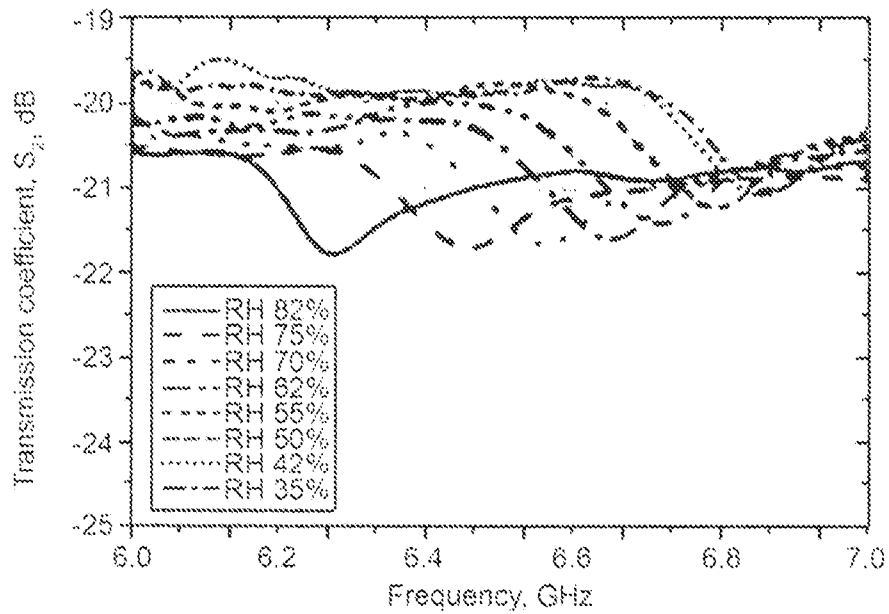


Figure 11

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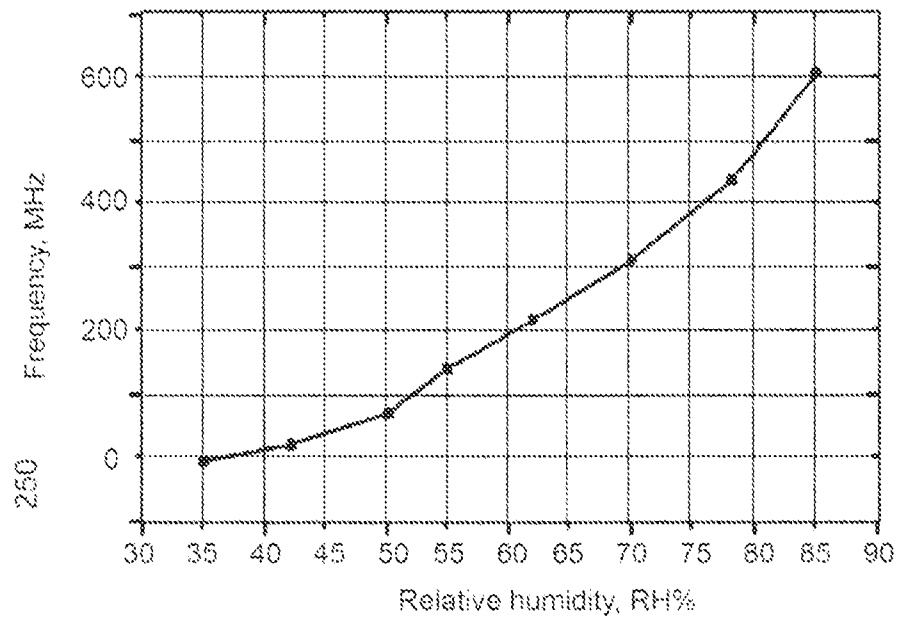


Figure 12

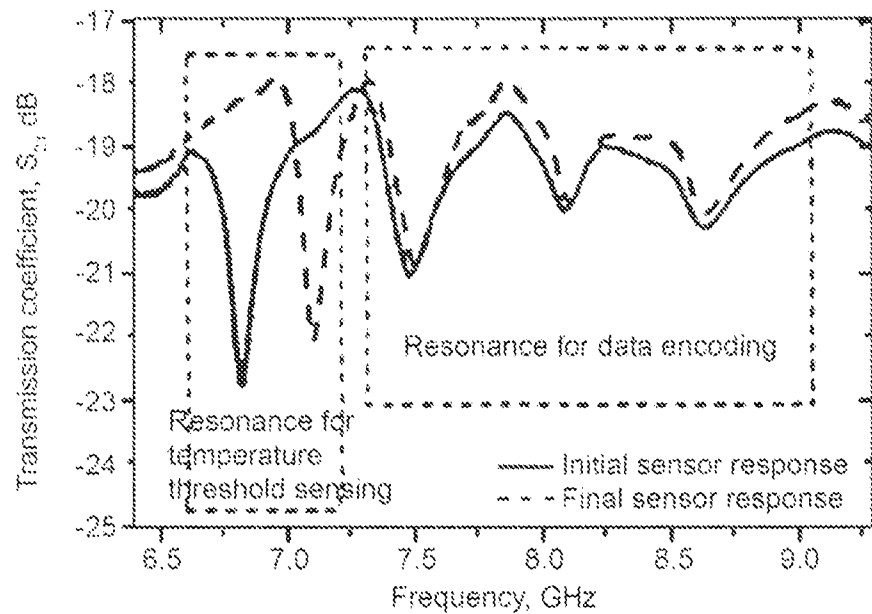


Figure 13

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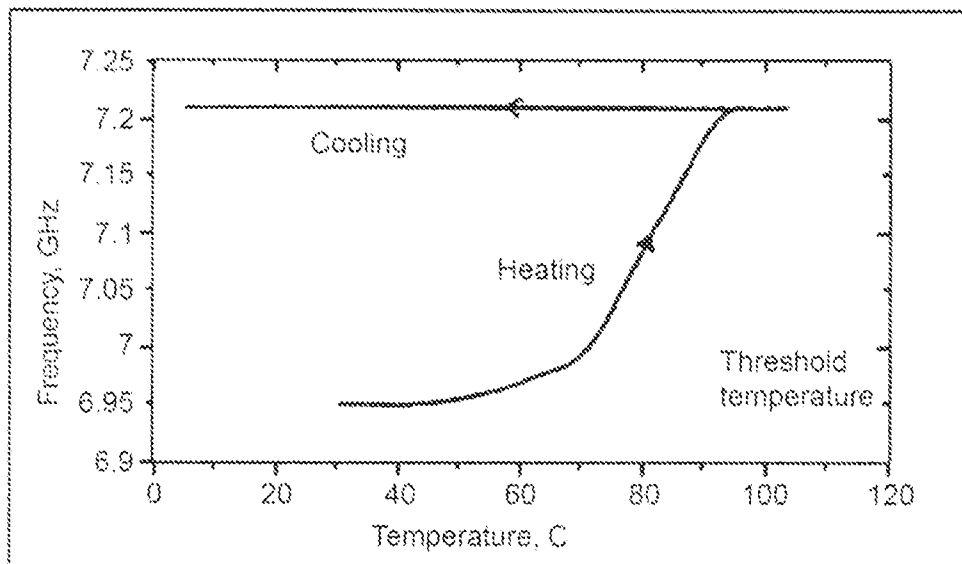


Figure 14

INTERNATIONAL SEARCH REPORT

 International application No.
PCT/AU2013/001276

A. CLASSIFICATION OF SUBJECT MATTER

H01Q 9/26 (2006.01) H01Q 21/00 (2006.01) H01Q 21/24 (2006.01) H01Q 21/26 (2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

Databases: EPODOC, WPI, INSPEC, GOOGLE and GOOGLE PATENTS: keywords (RFID, resonant, structure, digital, coding, sensor, environmental parameters, permittivity, shift, dielectric) & like terms.

Databases: Patentlens: Inventor's (KARMAKAR, Nemai, C.; AMIN, Emran, M.) and applicant's (Monash University) names searched.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
	Documents are listed in the continuation of Box C	



Further documents are listed in the continuation of Box C



See patent family annex

* "A"	Special categories of cited documents: document defining the general state of the art which is not considered to be of particular relevance	"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
"E"	earlier application or patent but published on or after the international filing date	"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
"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)	"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 such documents, such combination being obvious to a person skilled in the art
"O"	document referring to an oral disclosure, use, exhibition or other means	"&"	document member of the same patent family
"P"	document published prior to the international filing date but later than the priority date claimed		
Date of the actual completion of the international search 14 January 2014		Date of mailing of the international search report 14 January 2014	
Name and mailing address of the ISA/AU AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA Email address: pct@ipaustalia.gov.au Facsimile No.: +61 2 6283 7999		Authorised officer Nidhal Odeh AUSTRALIAN PATENT OFFICE (ISO 9001 Quality Certified Service) Telephone No. 0262832498	

INTERNATIONAL SEARCH REPORT		International application No.
C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		PCT/AU2013/001276
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 2013/096995 A1 (PS & D PTY LTD) 04 July 2013 Whole document, see in particular Abstract; Page 3 lines 13-15; Page 4 line 10 to page 5 line 22; Page 13 lines 14-19; Page 14 line 21 to page 15 line 13; page 16 lines 4-28; page 26 line 20 to page 27 line 20; page 28 lines 9-18; page 31 lines 13-26; Fig. 15.	1-22
Y	Gao, J., "Antenna-based passive UHF RFID sensor tags: Design and application", Doctoral dissertation, Sundsvall: Mid Sweden University, 18 June 2013. Whole document, see in particular Page 13; Page 43 section 5.4; Fig 3.2 & 3.3.	1-22

Form PCT/ISA/210 (fifth sheet) (July 2009)

