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(54) Title: PASSIVE WIRELESS SENSING WITH IDENTIFICATION

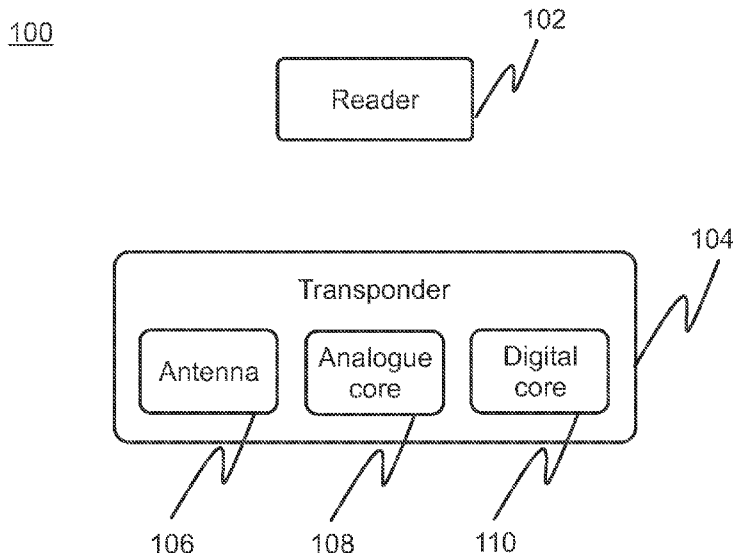


Figure 1

(57) Abstract: A transponder comprising at least one antenna configured to receive signals including protocols and operating energy from a reading device and configured to transmit sensor data to a reading device, a digital core configured to provide logical functions associated with a given protocol including identification information and comprising converter means to provide operating energy to execute said logical functions, an analogue core comprising a low frequency resonant circuit, and a sensing element at least functionally connected with said analogue core. A related system and method is presented.

PASSIVE WIRELESS SENSING WITH IDENTIFICATION

FIELD OF THE INVENTION

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Generally, the present invention relates to passive wireless sensing. Particularly, the present invention relates to a device, system and method for achieving individual differentiation and access of passive wireless sensors.

10 BACKGROUND

Markets for Wireless Sensor Networks (WSN) include process and industrial control, home and building automation, as well as safety and health monitoring. Predictions indicate rapid growth of WSNs: the global market
15 for wireless sensor devices is expected to increase at a 43.1% compound annual growth rate (CAGR). This market growth is enhanced by the penetration of smart sensors based on Micro-Electro-Mechanical Systems (MEMS) technology, which enable smaller size, cost efficiency and lower computing resources compared to traditional sensors.

20

However, it has been identified that the main challenge for the deployment of WSNs is the sensor nodes' power management. Three major research directions addressing this problem are wireless passive sensors, low power wireless solutions (such as Bluetooth LE) and energy harvesting methods.
25 Active sensor nodes constitute the largest use but they are facing problems with battery life expectancies and even though major efforts on energy harvesting development are on-going, new methods call for the development of wireless passive sensors.

30 Several passive technologies have been proposed and are already in use. RFID is by far the most advanced technology but while it is widely utilized for object identification, its penetration for sensing purposes has been rather slow and reading distances for passive sensors are limited to approx. 1 meter. Inductive coupling has been used for many decades but
35 its very limited reading distance (typically a few centimeters) prohibits its far-field wireless usage.

Surface acoustic wave (SAW) devices exhibit high sensitivity and reliability and are found in many applications. Relatively large size, limited reading distance and operational frequency and somewhat high manufacturing cost of SAW sensors are still considered as limiting factors.

5

Harmonic sensors utilize nonlinear elements, such as diodes to generate a backscattered signal at a harmonic frequency when actuated by a reader device with a fundamental tone. Harmonic sensors were initially proposed for automotive applications, and they can provide good performances for target tracking in a high clutter environment, such as tracking insects flying on low altitudes and finding avalanche victims. Harmonic sensors are typically used for identification but have also been proposed for measuring tire pressure of a car.

15 However, the aforementioned technologies are either optimized for identification or for sensing and do not combine sensing and identification, hence limiting severely the number of sensors that can be accessed. RFID is by default a technology meant for logistics, i.e. identification purposes. Few commercial products based on RFID technology provide an external
20 output for connecting a sensor element but the additional internal generic ADC converter adds power consumption. Therefore, (i) the resulting reading distances are decreased (from 10 m to 0.3 m with an 8-bit A/D converter) and (ii) the suitable sensor types are limited. SAW technology can provide with identification but this identification needs to be hard coded
25 on the substrate itself by principally using delay lines. This hard coded identification scheme removes any possible modularity as there is no memory, and adds manufacturing and handling costs.

There is therefore a crucial need of finding a solution that would provide
30 passive wireless sensor readouts and at the same time identification of the sensor element.

SUMMARY OF THE INVENTION

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The objective of the embodiments of the present invention is to at least alleviate one or more of the aforementioned drawbacks evident in the prior art arrangements particularly in the context of passive wireless sensing

with identification. The objective is generally achieved with a device, a system and a method in accordance with the present invention.

5 In accordance with one aspect of the present invention a transponder comprises

-at least one antenna configured to receive signals including protocols and operating energy from a reading device and configured to transmit sensor data to a reading device,

10 -a digital core configured to provide logical functions associated with a given protocol including identification information and comprising converter means to provide operating energy to execute said logical functions,

15 -an analogue core comprising a low frequency resonant circuit, and

-a sensing element at least functionally connected with said analogue core.

20 According to an exemplary embodiment of the present invention the sensing element may be connected in parallel with the low frequency resonant circuit. The sensing element may be capacitive, resistive or inductive, for example.

25 According to an exemplary embodiment of the present invention the low frequency resonant circuit is an RLC circuit.

30 According to an exemplary embodiment of the present invention the analogue core comprises a mixing entity. The mixing entity may be an element selected from the group consisting of diode, MEMS component, ferroelectric element, paraelectric element or micromechanical resonator.

According to an exemplary embodiment of the present invention the analogue and digital core are coupled in parallel.

35 According to an exemplary embodiment of the present invention the converter means may be a rectifier. The rectifier may be a RF to DC converter.

According to an exemplary embodiment of the present invention the logical functions include at least one function selected from the group consisting of anti-collision scheme, listen, talk, send, receive, read or write procedures, defined by the protocol.

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In accordance with another aspect of the present invention a wireless sensing system comprises

-a number of transponders,

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-at least one reading device configured to communicate with said transponders.

According to an exemplary embodiment of the present invention a reading device is configured to obtain identification data and sensor data from at least one transponder and to provide energy to said transponder.

15

In accordance with a further aspect of the present invention a method for wireless sensing comprises

20

-sending commands to a transponder with a reading device
-identifying digitally said transponder,
-obtaining analogically sensor data from said transponder with said reading device.

25

According to an exemplary embodiment of the present invention a method for wireless sensing comprises

-requesting identification code from a transponder with a reading device
30 -transmitting two continuous signal waves at essentially close frequencies from said reading device to said transponder
-generating a voltage across a mixing entity in said transponder
-generating intermodulation products of the two frequencies with said mixing entity
35 -reflecting back current from a low frequency resonant circuit to said mixing entity
-mixing said reflected current with said input frequencies
-measuring the response and solving parameter quantity.

The previously presented considerations concerning the various embodiments of the transponder may be flexibly applied to the embodiments of the system and of the method *mutatis mutandis* and vice versa, as being appreciated by a skilled person.

As briefly reviewed hereinbefore, the utility of the different aspects of the present invention arises from a plurality of issues depending on each particular embodiment.

This invention combines the advantages provided by wireless passive identification chips (identification) and the advantages provided by the intermodulation communication principle (sensing elements). The invention enables long reading distances, accurate measurements, existing protocols and frequency standards compliance, identification and multiple sensor access. The principle provides a novel and low-cost solution to implement industrial intelligence for machine control and reliability, and life-cycle cost reduction but also for medical and housing applications. The invention can revolutionize passive wireless sensing, hence unlocking the potential for widespread deployment of passive wireless sensor networks. It is a strong solution for the full deployment of the Internet of Things and the Industrial Internet.

The expression “a number of” may herein refer to any positive integer starting from one (1).

The expression “a plurality of” may refer to any positive integer starting from two (2), respectively.

The term “exemplary” refers herein to an example or example-like feature, not the sole or only preferable option.

Different embodiments of the present invention are also disclosed in the attached dependent claims.

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BRIEF DESCRIPTION OF THE RELATED DRAWINGS

Next, some exemplary embodiments of the present invention are reviewed more closely with reference to the attached drawings, wherein

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Fig. 1 is an exemplary sketch of an embodiment of a system in accordance with the present invention illustrating one reading device and one transponder.

10 Fig. 2 is an exemplary sketch of an embodiment of a system in accordance with the present invention illustrating one reading device and multiple transponders.

Fig. 3 is an exemplary scheme of an embodiment of a transponder in accordance with the present invention.

15 Fig. 4 is a second exemplary scheme of an embodiment of a transponder in accordance with the present invention.

Fig. 5 is a third exemplary scheme of an embodiment of a transponder in accordance with the present invention.

Fig. 6 is a fourth exemplary scheme of an embodiment of a transponder in accordance with the present invention.

20 Fig. 7 is a fifth exemplary scheme of an embodiment of a transponder in accordance with the present invention.

Fig. 8 is a sixth exemplary scheme of an embodiment of a transponder in accordance with the present invention.

25 Fig. 9 is a seventh exemplary scheme of an embodiment of a transponder in accordance with the present invention.

Fig. 10 is an embodiment of a physical construction of a reading device in accordance with the present invention.

Fig. 11 is an embodiment of a physical construction of a transponder in accordance with the present invention.

30 Fig. 12 is a flow diagram of an embodiment of a method for wireless sensing in accordance with the present invention.

DETAILED DESCRIPTION OF THE EMBODIMENTS

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Figure 1 illustrates an embodiment of a system 100 in accordance with the present invention with a conceptual approach. The system 100 comprises a reading device 102 and a transponder 104. The transponder 104 comprises

an antenna 106, an analogue core 108 and a digital core 110. The transponder 104 is passive and draws its energy from the reading device 102. The digital core 110 provides the logical functions associated with a given protocol. Logic functions include e.g. anti-collision scheme, listen, talk, send, receive, read and write procedures defined by the protocol. The digital core 110 comprises a converter mechanism to give enough power for executing the logical functions. The analogue core 108 comprises a sensing element. Reading distances may be over 10 meter. In some embodiments the reading device 102 may obtain measured values from the transponder 104 from a close proximity up to 15 meters.

Figure 2 illustrates an embodiment of a system 200 in accordance with the present invention comprising a reading device 202 and a plurality of transponders 204a, 204b, 204c, 204d, 204e. The reading device 202 sends an ID request to the transponders 204a, 204b, 204c, 204d, 204e. A transponder with a matching ID starts communicating with the reading device 202 explained in more detail hereinafter.

System 200 may provide a passive wireless sensor network. The transponders 204a, 204b, 204c, 204d, 204e may be placed e.g. in an industrial or domestic environment for measuring different factors such as temperature, pressure, sound, acceleration, humidity, lighting, presence, theft, defects, leakages, air conditioning etc..

Figures 3-9 represent exemplary schemes of embodiments of transponders in accordance with the present invention allowing passive wireless sensing with identification.

The transponder 304 comprises an antenna 306, an analogue core 308 and a digital core 310. The matching network 312 may be e.g. a power splitter, directional coupler, or any reciprocal electronic circuit. The transponder 304 comprises a switch 324 that is actuated upon a matching ID request from a reading device.

As the transponder 304 is passive, it draws its energy from a reading device. A converter mechanism, i.e. e.g. a rectifier 316 (RF to DC converter based on diode topology for example), is connected within the digital core 310 to give enough power for executing the logical functions.

The analogue core 308 is in parallel with the digital core 310. The analogue core 308 comprises a mixing element 318 (for example a diode, MEMS component, ferroelectric element, paraelectric element, micromechanical resonator etc.) and a low frequency resonant circuit 320. An external sensing element 322 (e.g. capacitive, resistive or inductive) is in parallel with the low frequency resonant circuit 320. For example, sensors may be capacitive sensors such as MEMS microphones, MEMS inertial sensors, MEMS pressure sensors, accelerometers, inclinometers or ceramic humidity sensors. A piezo-resistive strain gauge may be used as a deformation sensor or inductive humidity sensor.

The transponder 404 comprises two antennas 406 and 407, an analogue core 408, a digital core 410 and matching networks 412, 413. The transponder 404 comprises a switch 424 that is actuated upon a matching ID request from a reading device. As the transponder 404 is passive, it draws its energy from a reading device. A converter mechanism, i.e. e.g. a rectifier 416 is connected within the digital core 410 to give enough power for executing the logical functions. The analogue core 408 comprises a mixing element 418 and a low resonant circuit 420. An external sensing element 422 is in parallel with the low frequency resonant circuit 420.

The transponder 504 comprises an antenna 506, an analogue core 508, a digital core 510 and a matching network 512. The transponder 504 comprises a switch 524 that is actuated upon a matching ID request from a reading device. A converter mechanism, e.g. a rectifier 516 is connected within the digital core 510 to give enough power for executing the logical functions. The analogue core 508 is in parallel with the digital core 510. The analogue core comprises a mixing element 518 and a low frequency resonant circuit 520. An external sensing element 522 is in parallel with the low frequency resonant circuit 520.

The transponder 604 comprises two antennas 606 and 607, an analogue core 608, a digital core 610 and matching networks 612, 613. The transponder 604 comprises a switch 624 that is actuated upon a matching ID request from a reading device. A converter mechanism, e.g. a rectifier 616 is connected within the digital core 610 to give enough power for executing the logical functions. The analogue core 608 is in parallel with the dig-

ital core 610. The analogue core comprises a mixing element 618 and a low frequency resonant circuit 620. An external sensing element 622 is in parallel with the low frequency resonant circuit 620.

5 The transponder 704 comprises an antenna 706, an analogue core 708 and a digital core 710. Converter mechanisms, e.g. a plurality of rectifiers 716 are connected within the digital core 710 to give enough power for executing the logical functions. The analogue core 708 is in parallel with the digital core 710. The analogue core comprises a low frequency resonant circuit 720. An external sensing element 722 is in parallel with the low frequency resonant circuit 720.

The transponder 804 comprises an antenna 806, an analogue core 808, a digital core 810 and a matching network 812. A converter mechanism, e.g. a rectifier 816 is connected within the digital core 810 to give enough power for executing the logical functions. The analogue core 808 is in parallel with the digital core 810. The analogue core comprises a low frequency resonant circuit 820. An external sensing element 822 is in parallel with the low frequency resonant circuit 820.

20 The transponder 904 comprises an antenna 906, an analogue core 908, a digital core 910 and a matching network 912. A converter mechanism, e.g. a rectifier 916 is connected within the digital core 910 to give enough power for executing the logical functions. The analogue core 908 is in parallel with the digital core 910. The analogue core comprises a mixing element 918 and a low frequency resonant circuit 920. An external sensing element 922 is in parallel with the low frequency resonant circuit 920.

30 Figure 10 represents an example of a physical structure of a reading device 1002 according to the present invention. A reading device 1002 may have the dimensions:

	Preferably	More preferably	Most preferably
Length	1-60 cm	1-40 cm	2-30 cm
35 Width	1-50 cm	1-30 cm	2-15 cm
Height	1-20 cm	1-15 cm	1-10 cm

Figure 11 represents an example of physical structure of a transponder 1004 according to the present invention. The transponder 1004 may have the dimensions:

5		Preferably	More preferably	Most preferably
	Length	1-20 cm	2-15 cm	3-10 cm
	Width	0,5-15 cm	1-10 cm	1-5 cm
	Height	0,1-10 cm	0,2-5 cm	0,2-1 cm

10 Figure 12 is a flow diagram of an embodiment of a method 1200 for wire-less sensing in accordance with the present invention.

At 1202, method start-up, preparative actions may take place. This may comprise setting up and/or calibrating transponders and/or reading devices, for example.

At 1204, the reading device sends the communication commands to the transponders according to the protocol and standard in use (this can be, but not limited to, for example RFID UHF frequency and Gen 2 protocol).

20 The commands include the request for a particular and unique identification code (ID).

At 1206, upon the recognition of the requested ID, all the transponders whose ID do not match with the requested ID output a bias voltage referred to as V_{bias} that is then polarizing the mixing element (see e.g. figures 3 and 4). The biasing of the mixing element changes the operation point of the device in such a manner that the intermodulation response is diminished (or increased). This may be achieved by using the biasing for tuning the RF matching of the mixing element, IF impedance of the mixing element or the nonlinearity of the mixing element, or any combination of these. For example, a diode can be driven out of the nonlinear region by high reverse bias voltage, its IF impedance can be lowered by forward bias, and RF impedance (RF matching) can be changed by both forward and reverse bias. Only the transponder whose ID matches with the request is

30 active, i.e. its mixing element operates accordingly in the nonlinear region.

At 1208, the reading device transmits two continuous waves at two close frequencies (which can be from a few kHz to 100 MHz) of namely f_1 and

f_2 , where also f_Δ is within the allowed frequency band defined by the regulations.

At 1210, when these signals are received by the transponder antenna, it
5 generates a voltage across the mixing element at those frequencies.

At 1212, due to the nonlinear characteristics of the mixing element, the mixing element generates the intermodulation products of the two input frequencies.

10

At 1214, the low frequency resonant circuit of the transponder is designed such that its resonance frequency correspond to the difference frequency $f_\Delta = f_1 - f_2$. The resonant circuit is essentially an RLC-circuit whose capacitance, inductance, or resistance changes according to the changes of
15 physical or environmental parameters. Only the excitation current at the frequency f_Δ is amplified by the RLC-resonant circuit and this current is reflected back to the mixing element.

At 1216, the current reflected back mixes with the input frequencies f_1
20 (and f_2), resulting into the intermodulation frequency $f_{IM} = 2f_1 - f_2$ (and $f_{IM} = 2f_2 - f_1$). Any changes in the impedance of the RLC-resonant circuit originating from changes in the measured quantity will be directly reflected in the value of the difference frequency f_Δ , which will hence influence the value at the intermodulation frequencies.

25

At 1218, consequently by measuring the transponder's response at one of the intermodulation frequencies, the reading device can solve the measured parameter quantity, e.g. temperature, pressure or acceleration.

30 At 1220, method execution is ended.

Transponders as presented in figures 5 and 6, upon the recognition of the matching ID, only the transponder with the matching ID actuates the switch 524, 624 (e.g. transistor, resistor or diode). All the other transponders whose ID is not matching with the request are silent.
35

In figures 5 and 6, the transponders are transmitting their sensor data only one at a time. When one transponder is sending its sensor readings, the

other transponders are silent. In figures 7 and 8, the analogue part takes advantage of the RF to DC scheme within the digital part. No additional mixing element is needed for generating the difference frequency $f_{\Delta} = f_1 - f_2$ as the nonlinear component in the digital core is utilized.

5

As in figures 5 and 6, in figures 7, 8 and 9, the reading device sends the communication commands to the transponders according to the protocol and standard in use. The commands include the request for a particular and unique identification code (ID). Upon the recognition of the matching
10 ID, the transponder with the matching ID replies to the reading device according to the defined protocol. The reading device then transmits two continuous waves at two close frequencies of namely f_1 and f_2 , where f_2 is within the allowed frequency band defined by the regulations. All the transponders whose difference frequency corresponds to the low reso-
15 nance frequency of the resonant circuit will generate an answer at the intermodulation frequency $f_{IM} = 2f_1 - f_2$ by the analog core. However the transponder with the matching ID will answer by the digital core also. Hence the intermodulation response from the analogue core will be modulated by the digital response. Only the desired intermodulation response is
20 digitally modulated and can hence be separated from the others and decoded using standard signal processing (e.g filtering, correlation, convolution etc.).

The scope of the invention is determined by the attached claims together
25 with the equivalents thereof. The skilled persons will again appreciate the fact that the disclosed embodiments were constructed for illustrative purposes only, and the innovative fulcrum reviewed herein will cover further embodiments, embodiment combinations, variations and equivalents that better suit each particular use case of the invention.

30

Claims

1. A transponder comprising
 - 5 -at least one antenna configured to receive high frequency signals including protocols and operating energy from a reading device and configured to communicate back to the reading device,
 - a digital core configured to provide logical functions associated with a
10 given protocol including identification information and comprising converter means to provide operating energy to execute said logical functions,
 - an analogue core comprising a low frequency resonant circuit,
 - 15 -a sensing element functionally connected with said resonant circuit, affecting the resonance frequency thereof, and
 - a mixing entity for providing intermodulation products based on the high
frequency signals received from the at least one antenna,
20 wherein the low frequency resonance circuit and the mixing element are coupled for providing information of the resonance frequency in a high frequency response from the transponder.
- 25 2. The transponder of any preceding claim, wherein said sensing element is connected in parallel with said low frequency resonant circuit.
3. The transponder of any preceding claim, wherein said sensing element is capacitive, resistive or inductive.
30
4. The transponder of any preceding claim, wherein said low frequency resonant circuit is an RLC circuit.
5. The transponder of any preceding claim, wherein said analogue
35 core comprises said mixing entity.
6. The transponder of any preceding claim, wherein said mixing entity is an element selected from the group consisting of diode, MEMS compo-

nent, ferroelectric element, paraelectric element or micromechanical resonator.

7. The transponder of any preceding claim, wherein said analogue and digital core are coupled in parallel.

8. The transponder of any preceding claim, wherein said converter means are one or several rectifiers.

9. The transponder of any preceding claim, wherein said converter means are an RF to DC converter.

10. The transponder of any preceding claim, wherein the logical functions include at least one function selected from the group consisting of anti-collision scheme, listen, talk, send, receive, read or write procedures defined by the protocol.

11. A wireless sensor system comprising
-a number of transponder in accordance with claim 1, and
-at least one reading device configured to communicate with said transponders.

12. A method for wireless sensing comprising
-sending high frequency signals and digital commands to a transponder with a reading device,
-identifying digitally said transponder,
-obtaining analogically sensor data from said transponder with said reading device.

13. A method according to claim 12, comprising requesting identification code from the transponder with a reading device.

14. A method according to claim 12 or 13, comprising
-transmitting two continuous signal waves at essentially close frequencies from said reading device to said transponder,

- generating a voltage across a mixing entity in said transponder
- generating intermodulation products of the two frequencies with said mixing entity,
- reflecting back current from a low frequency resonance circuit to said
- 5 mixing entity,
- mixing said reflected current with said input frequencies,
- measuring the response and solving sensor output with said reading device.

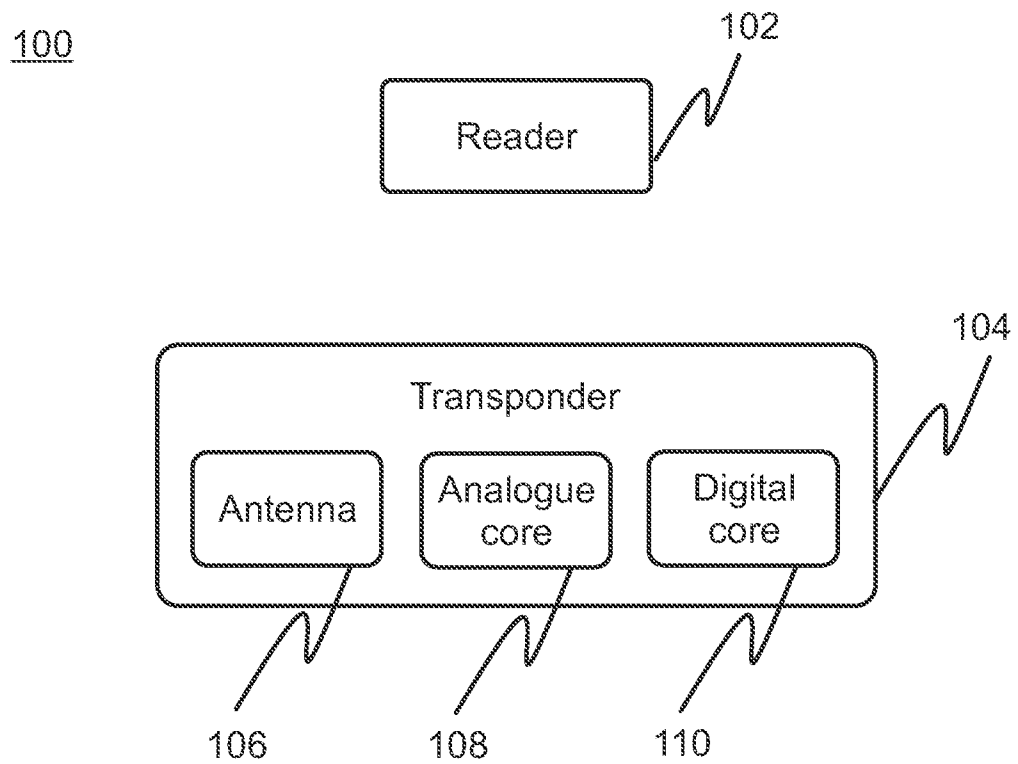


Figure 1

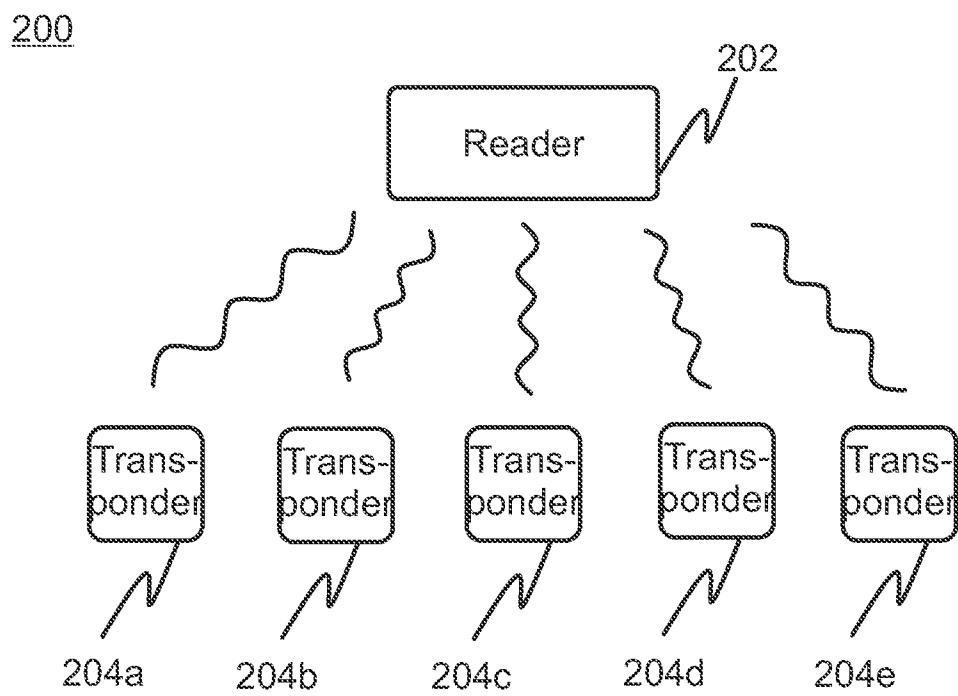


Figure 2

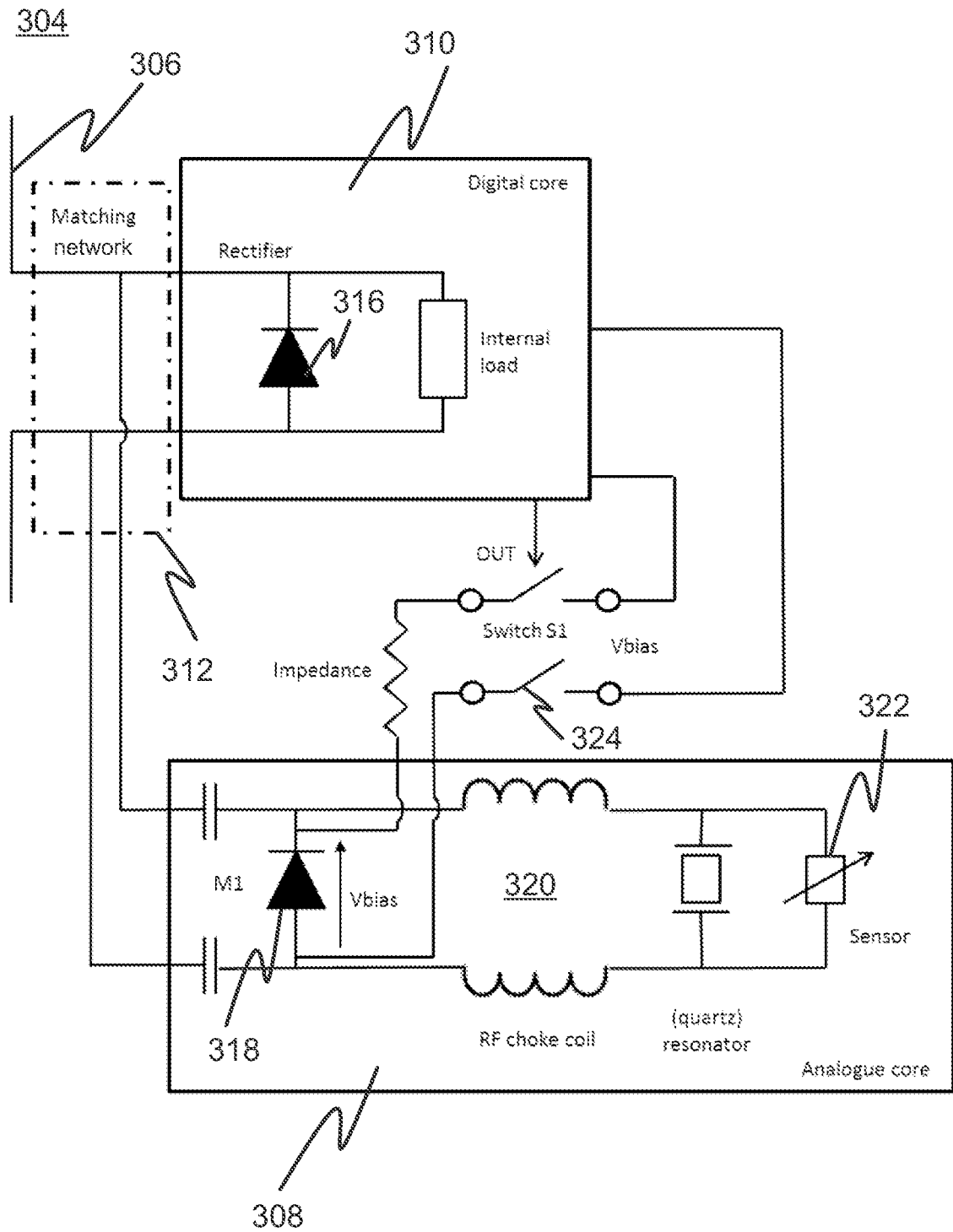


Figure 3

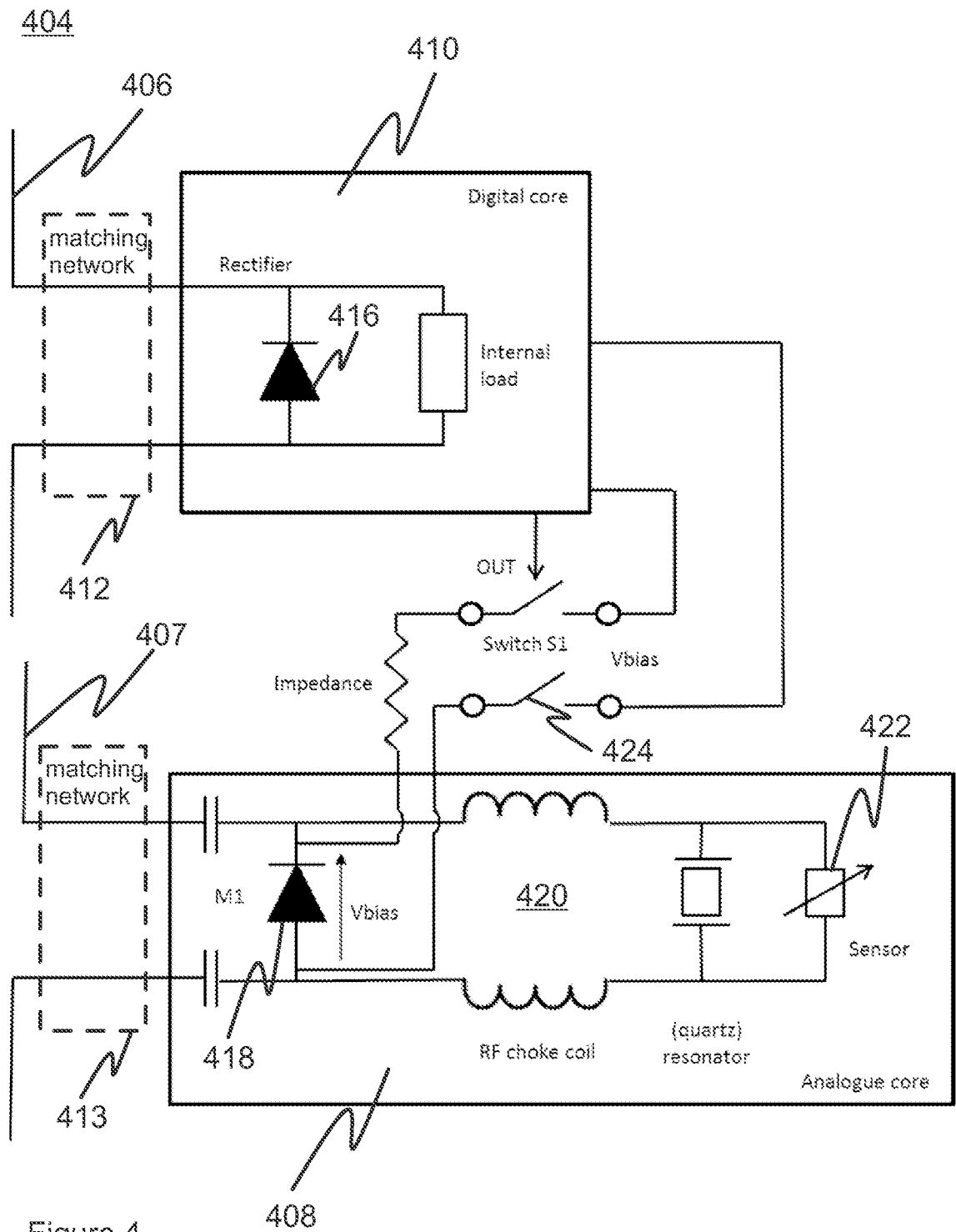


Figure 4

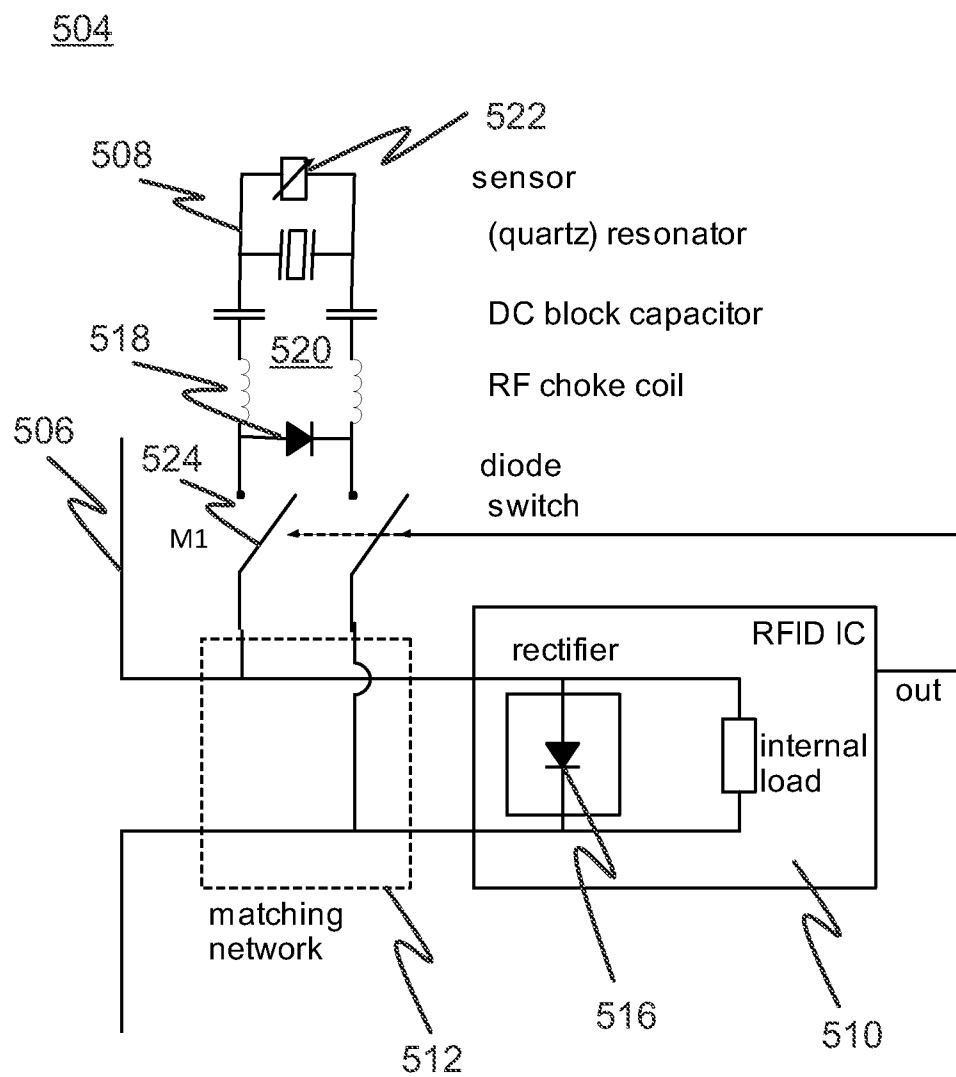


Figure 5

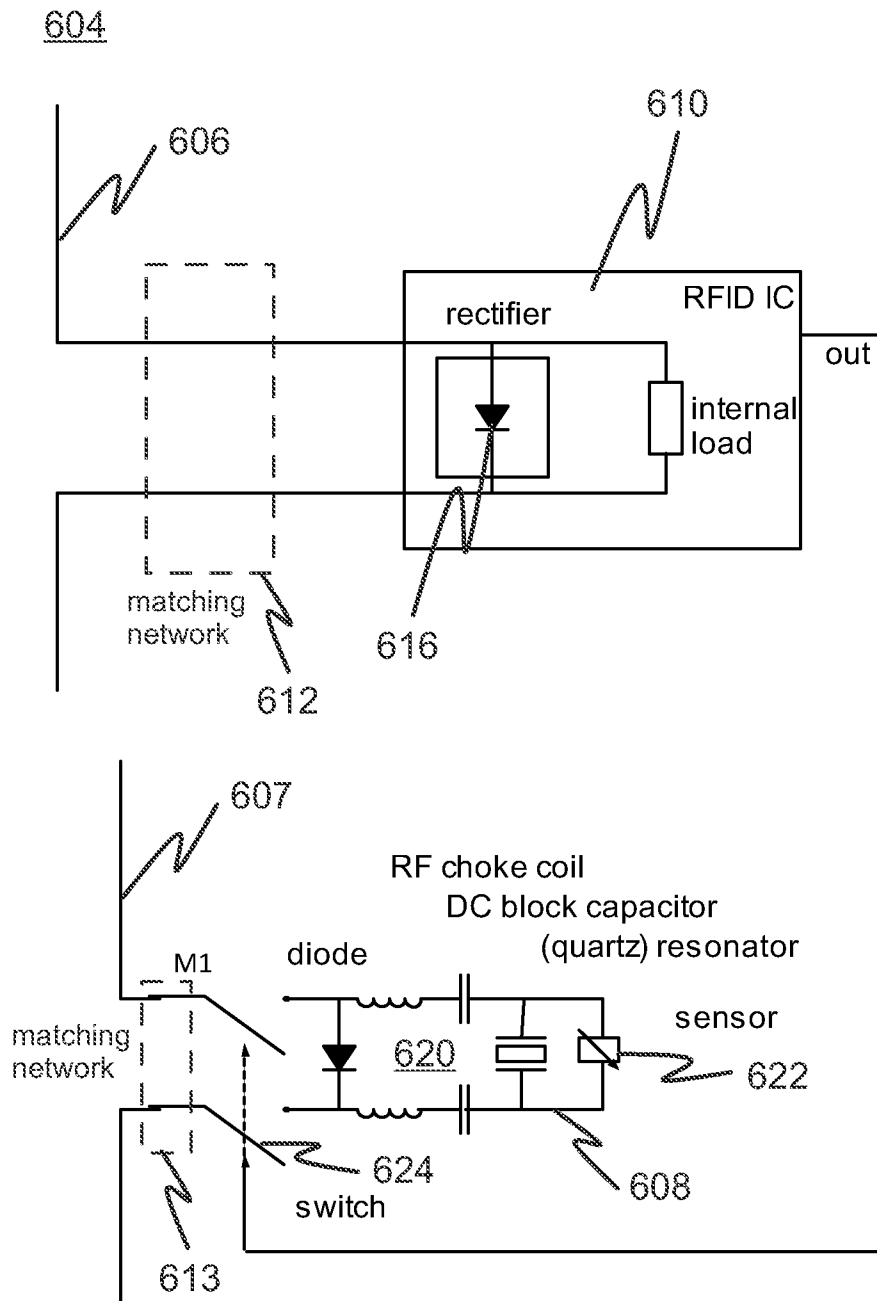


Figure 6

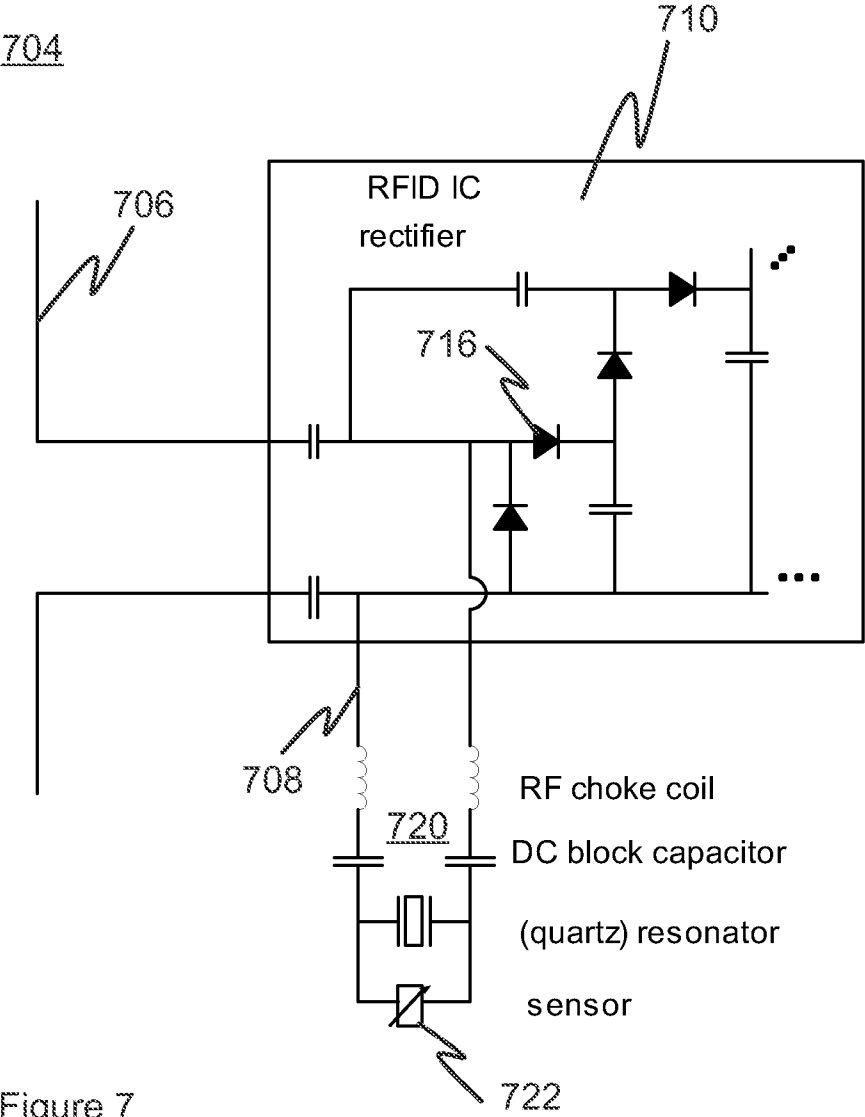


Figure 7

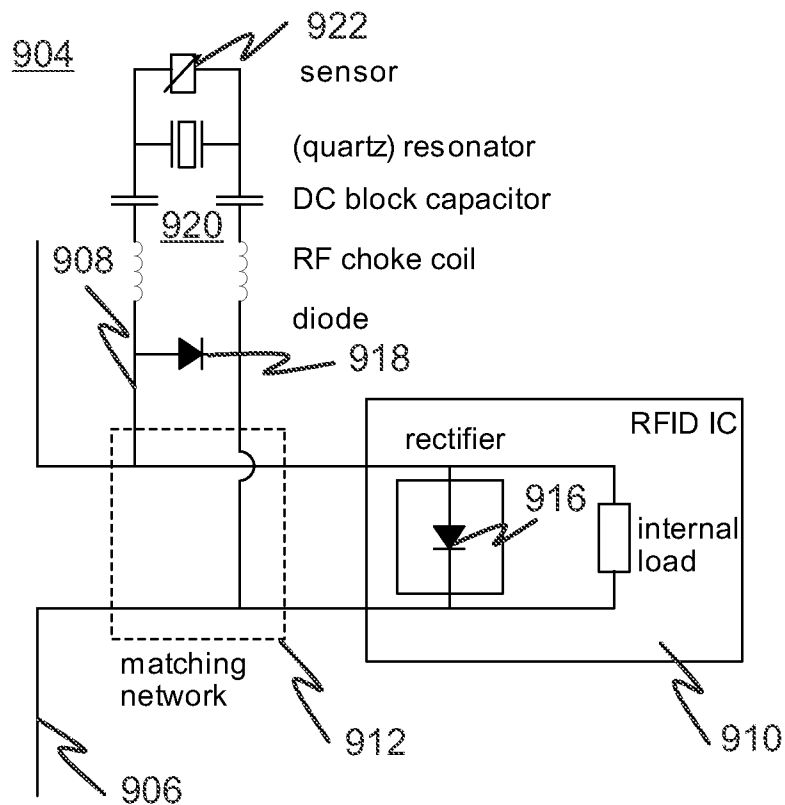


Figure 9

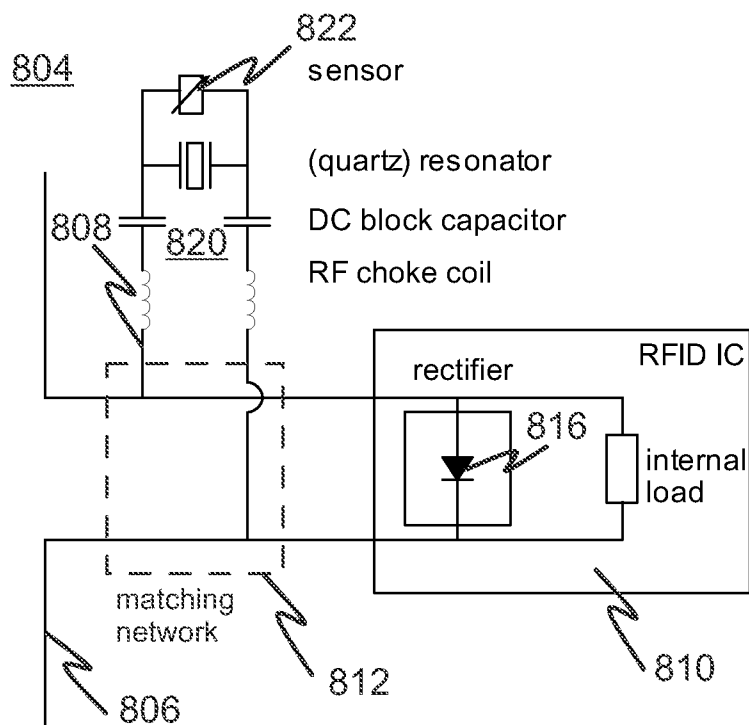


Figure 8

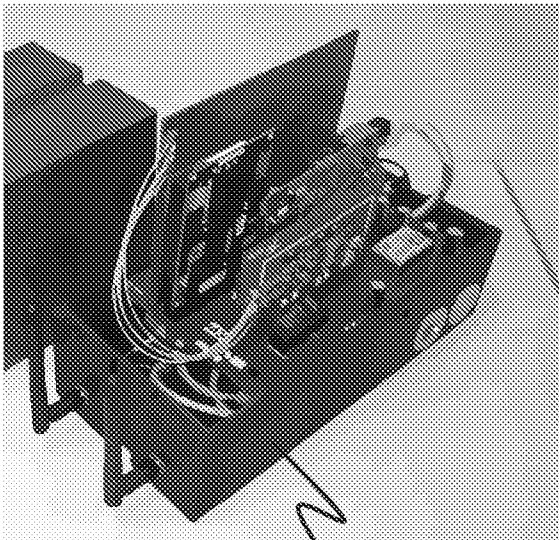


Figure 10

1002

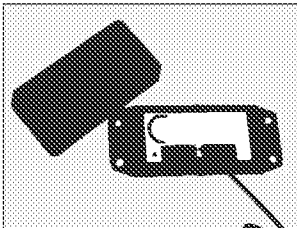


Figure 11

1004

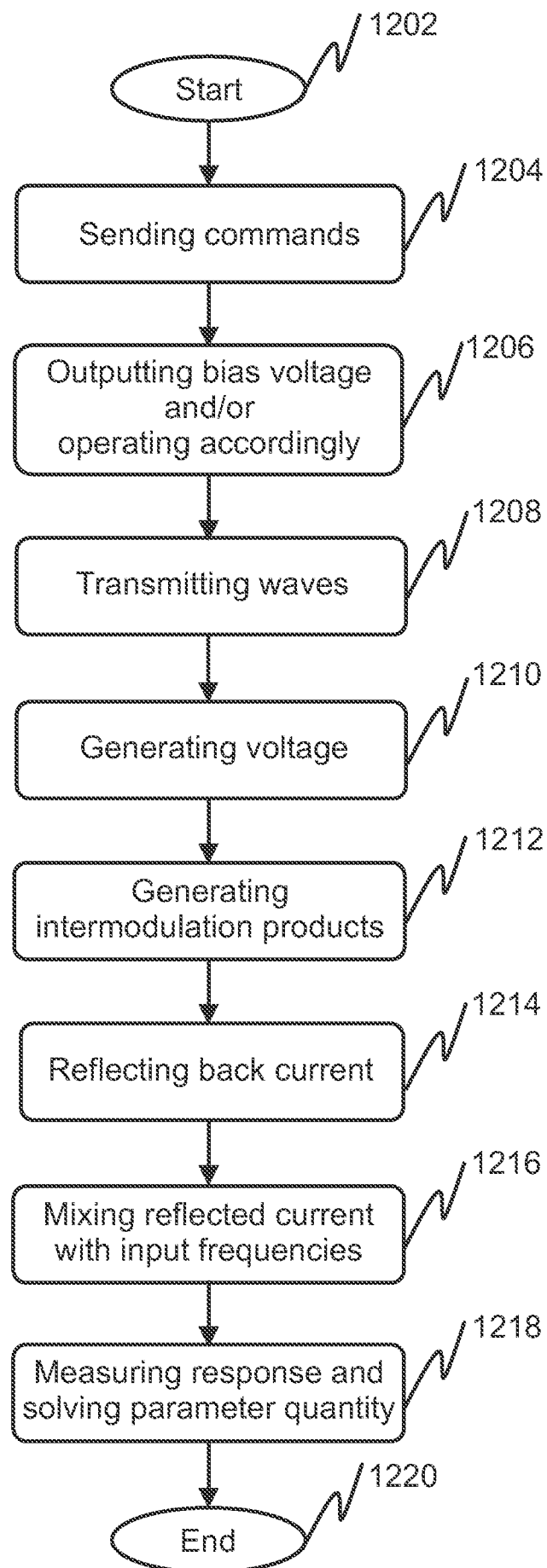
1200

Figure 12

INTERNATIONAL SEARCH REPORT

International application No
PCT/FI2015/050927

A. CLASSIFICATION OF SUBJECT MATTER
INV. G06K19/07
ADD.

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)
G06K H04B G01H

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)

EP0-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2013/175073 A1 (TEKNOLOGIAN TUTKIMUSKESKUS VTT [FI]) 28 November 2013 (2013-11-28)	11
Y	figure 1 page 5, line 22 - page 6, line 18 page 13, lines 23-31 -----	1-10, 12-14
X	WO 2005/074157 A1 (TOPPAN PRINTING CO LTD [JP]; AGENCY SCIENCE TECH & RES [SG]; YEOH WOOI) 11 August 2005 (2005-08-11)	11
Y	figure 1 page 6, lines 10-18 page 8, line 19 - page 9, line 1 -----	1-10, 12-14
A	GB 2 308 947 A (I D SYSTEMS LTD [GB]) 9 July 1997 (1997-07-09) figures 1,2 page 6, line 5 - page 10, line 3 ----- -/--	1,12



Further documents are listed in the continuation of Box C.



See patent family annex.

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INTERNATIONAL SEARCH REPORT

International application No
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