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Pressure based wireless sensor and applications thereof

Abstract

A radio frequency identification (RFID) tag includes an antenna, an analog front end, a processing circuit, and memory. The analog front end includes a power circuit, a tuning circuit, a transmitter, and a receiver. The power circuit is operably coupled to convert a radio frequency (RF) signal into a power supply voltage. The tuning circuit, when enabled, adjusts an RF characteristic of the analog front end to tune power harvesting from the RF signal. The transmitter is operably coupled to transmit a response signal to the RFID reader via the antenna. The receiver is operably coupled to receive a command signal from the RFID reader, wherein the command signal is contained within a portion of the RF signal. The processing circuit is operable to interpret the command signal and generate the response signal.

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continuation-in-part parent-doc US 14150392 20140108 US 9825608 20171121 child-doc US 15217816

continuation-in-part parent-doc US 13467925 20120509 US 10224902 20190305 child-doc US 14256877

continuation-in-part parent-doc US 13209420 20110814 US 8749319 20140610 child-doc US 14256877

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continuation-in-part parent-doc US 13209425 20110814 US 9048819 20150602 child-doc US 13467925

continuation-in-part parent-doc US 12462331 20090801 US 8081043 20111220 child-doc US 13209420

continuation-in-part parent-doc US 12462331 20090801 US 8081043 20111220 child-doc US 13209425

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us-provisional-application US 62196036 20150723

us-provisional-application US 62163143 20150518

us-provisional-application US 62057187 20140929

us-provisional-application US 62057186 20140929

us-provisional-application US 61934935 20140203

us-provisional-application US 61929017 20140118

us-provisional-application US 61896102 20131027

us-provisional-application US 61875599 20130909

us-provisional-application US 61871167 20130828

us-provisional-application US 61833265 20130610

us-provisional-application US 61833167 20130610

us-provisional-application US 61833150 20130610

us-provisional-application US 61814241 20130420

us-provisional-application US 61485732 20110513

us-provisional-application US 61428170 20101229

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Field of Classification Search

USPC: None

References Cited

U.S. PATENT DOCUMENTS

Patent No.	Issued Date	Patentee Name	U.S. Cl.	CPC
4724427	12/1987	Carroll	N/A	N/A
5073781	12/1990	Stickelbrocks	N/A	N/A
5103222	12/1991	Hogen Esch et al.	N/A	N/A
5301358	12/1993	Gaskill et al.	N/A	N/A
5491715	12/1995	Flaxl	N/A	N/A
5680064	12/1996	Masaki et al.	N/A	N/A
5856809	12/1998	Schoepfer	N/A	N/A
5872476	12/1998	Mihara et al.	N/A	N/A
5953642	12/1998	Feldtkeller et al.	N/A	N/A
5959899	12/1998	Sredanovic	N/A	N/A
5969542	12/1998	Maley et al.	N/A	N/A
6002290	12/1998	Avery et al.	N/A	N/A
6133777	12/1999	Savelli	N/A	N/A
6140924	12/1999	Chia et al.	N/A	N/A
6400206	12/2001	Kim et al.	N/A	N/A
6433582	12/2001	Hirano	N/A	N/A
6477062	12/2001	Wagner et al.	N/A	N/A
6477092	12/2001	Takano	N/A	N/A
6529127	12/2002	Townsend et al.	N/A	N/A
6650227	12/2002	Bradin	N/A	N/A
6703920	12/2003	Zimmer	N/A	N/A
6838924	12/2004	Davies, Jr.	N/A	N/A
6838951	12/2004	Nieri et al.	N/A	N/A
6856173	12/2004	Chun	N/A	N/A
6862432	12/2004	Kim	N/A	N/A
6870461	12/2004	Fischer et al.	N/A	N/A
6888459	12/2004	Stilp	N/A	N/A
6889905	12/2004	Shigemasa et al.	N/A	N/A
6940467	12/2004	Fischer et al.	N/A	N/A
6963226	12/2004	Chiang	N/A	N/A
7023817	12/2005	Kuffner et al.	N/A	N/A
7071730	12/2005	Cordoba	N/A	N/A
7079034	12/2005	Stilp	N/A	N/A
7088246	12/2005	Fukuoka	N/A	N/A
7123057	12/2005	Wang et al.	N/A	N/A

7132946	12/2005	Waldner et al.	N/A	N/A
7167090	12/2006	Mandal et al.	N/A	N/A
7215043	12/2006	Tsai et al.	N/A	N/A
7317378	12/2007	Jarvis et al.	N/A	N/A
7347379	12/2007	Ward et al.	N/A	N/A
7423472	12/2007	Hirose et al.	N/A	N/A
7439860	12/2007	Andresky	N/A	N/A
7443199	12/2007	da Fonte Dias et al.	N/A	N/A
7449917	12/2007	Cheon	N/A	N/A
7479886	12/2008	Burr	N/A	N/A
7528725	12/2008	Stewart	N/A	N/A
7535362	12/2008	Moser et al.	N/A	N/A
7551058	12/2008	Johnson et al.	N/A	N/A
7583179	12/2008	Wu et al.	N/A	N/A
7583942	12/2008	Ihara	N/A	N/A
7592961	12/2008	Thober et al.	N/A	N/A
7609090	12/2008	Srivastava et al.	N/A	N/A
7629880	12/2008	Stilp et al.	N/A	N/A
7768308	12/2009	Maede et al.	N/A	N/A
7775083	12/2009	Potyrailo et al.	N/A	N/A
7826297	12/2009	Takeda et al.	N/A	N/A
7880594	12/2010	Breed et al.	N/A	N/A
7948810	12/2010	Tang et al.	N/A	N/A
8120984	12/2011	Huang et al.	N/A	N/A
8174383	12/2011	Chung et al.	N/A	N/A
8249500	12/2011	Wilson	N/A	N/A
8723551	12/2013	Cho	N/A	N/A
8751846	12/2013	Yu et al.	N/A	N/A
8952792	12/2014	Srinivas	N/A	N/A
9087282	12/2014	Hyde et al.	N/A	N/A
9117128	12/2014	Mats et al.	N/A	N/A
9165171	12/2014	Murdoch et al.	N/A	N/A
9418263	12/2015	Butler et al.	N/A	N/A
9789738	12/2016	Rokhsaz	N/A	N/A
2003/0132893	12/2002	Forster et al.	N/A	N/A
2003/0174099	12/2002	Bauer	N/A	N/A
2003/0234631	12/2002	Schulman	N/A	N/A
2004/0070500	12/2003	Pratt et al.	N/A	N/A
2005/0024287	12/2004	Jo et al.	N/A	N/A
2005/0181750	12/2004	Pinks	N/A	N/A
2005/0215219	12/2004	Khorram	N/A	N/A
2006/0202821	12/2005	Cohen	73/146	G06K 19/0723
2006/0256691	12/2005	Miura	N/A	N/A
2006/0290484	12/2005	Bauchot	N/A	N/A
2006/0290496	12/2005	Peeters	340/572.1	G01D 21/00
2007/0026826	12/2006	Wilson	N/A	N/A
2007/0052603	12/2006	Nyalamadugu	343/742	H01Q 7/00
2007/0095903	12/2006	Suenbuel	235/383	H04L 67/52
2007/0156312	12/2006	Breed	N/A	N/A

2008/0055092	12/2007	Burr	340/693.1	H01Q 1/248
2008/0136619	12/2007	Moran	N/A	N/A
2008/0194200	12/2007	Keen	N/A	N/A
2010/0019907	12/2009	Shanks	N/A	N/A
2010/0207754	12/2009	Shostak	N/A	N/A
2012/0176240	12/2011	Athalye et al.	N/A	N/A
2013/0293354	12/2012	Vemagiri et al.	N/A	N/A

FOREIGN PATENT DOCUMENTS

Patent No.	Application Date	Country	CPC
626692	12/1991	AU	N/A
10151856	12/2002	DE	N/A
603081132	12/2006	DE	N/A
0407848	12/1990	EP	N/A
0568067	12/1992	EP	N/A
0801358	12/1996	EP	N/A
0615136	12/1998	EP	N/A
1691320	12/2006	EP	N/A
1960947	12/2009	EP	N/A
2321726	12/1997	GB	N/A
2004019055	12/2003	WO	N/A

OTHER PUBLICATIONS

Belk; An etched antenna for autoclaveable RFID tags; 1996 Symposium on Antenna Technology and Applied Electromagnetics; Montreal, QC, Canada; 1996; pp. 183-186. cited by applicant

Butler et al.; Multiple Radio Frequency Network Node RFID Tag; Specification for U.S. Appl. No. 60/803,612; EFSWeb; TEGO-0003-P60; for U.S. Pat. No. 9,418,263. cited by applicant

Chow, et al.; New Voltage Level Shifting Circuits for High Performance CMOS Interface Applications; WSEAS Transactions on Circuits and Systems; Jun. 2004; No. 4, vol. 3; pp. 975-979. cited by applicant

Epcglobal, Inc.; EPC™ Radio-Frequency Identity Protocols Class-1 Generation-2 UHF RFID Protocol for Communications at 860 MHz-960 MHz; Version 1.0.4; Sep. 8, 2004; pp. 1-88. cited by applicant

Heller, et al.; Session I: Custom and Semi-Custom Design Techniques; WAM 1.3: Cascode Voltage Switch Logic: A Differential CMOS logic Family. cited by applicant

Kaiser et al.; A Low Transponder IC for High Performance Identification Systems; IEEE Custom Integrated Circuits Conference; 1994; pp. 335-338. cited by applicant

Landt; The history of RFID; IEEE Potentials; Oct.-Nov. 2005; vol. 24, No. 4; pp. 8-11. cited by applicant

Lee, et al.; MicroID™ 13.56 MHz RFID System Design Guide; 2001; 164 PGS. cited by applicant

Mandal; Far Field RF Power Extraction Circuits and Systems; MIT; 2004; 199 pgs. cited by applicant

Rao et al.; Antenna Design for UHF RFID Tags: A Review and a Practical Application; IEEE Transactions on Antennas and Propagation; vol. 53, No. 12; pp. 3870-3876; Dec. 2005. cited by applicant

Serneels, et al.; A High speed, Low Voltage to High Voltage Level Shifter in Standard 1.2V 0.13µm CMOS; 2006 13th IEEE International Conference on Electronics, Circuits and Systems; Dec. 10-13, 2006; pp. 668-671. cited by applicant

Turner; Wireless, A Treatise on the Theory and Practice of High-Frequency Electric Signaling;

1931. cited by applicant

U.S. War Department; Technical Manual 11-455; Radio Fundamentals; 1944. cited by applicant
Uyemura; CMOS Logic Circuit Design; 2001. cited by applicant
Want; An Introduction to RFID Technology; IEEE Pervasive Computing; Jan.-Mar. 2006; vol. 5, No. 1; pp. 25-33. cited by applicant

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Background/Summary

CROSS REFERENCE TO RELATED PATENTS (1) The present U.S. Utility Patent Application claims priority pursuant to 35 U.S.C. § 120 as a continuation of U.S. Utility application Ser. No. 17/102,245, entitled "PRESSURE BASED WIRELESS SENSOR AND APPLICATIONS THEREOF", filed Nov. 23, 2020, issuing as U.S. Pat. Ser. No. 11,446,969 on Sep. 20, 2022, which is a continuation of U.S. Utility application Ser. No. 16/017,848, entitled "PRESSURE BASED WIRELESS SENSOR AND APPLICATIONS THEREOF", filed Jun. 25, 2018, issued as U.S. Pat. No. 10,843,510 on Nov. 24, 2020, which is a continuation of U.S. Utility application Ser. No. 15/784,484, entitled "PRESSURE BASED WIRELESS SENSOR AND APPLICATIONS THEREOF," filed Oct. 16, 2017, issued as U.S. Pat. No. 10,005,324 on Jun. 26, 2018, which is a continuation of U.S. Utility application Ser. No. 15/348,365, entitled "PRESSURE BASED WIRELESS SENSOR AND APPLICATIONS THEREOF", filed Nov. 10, 2016, issued as U.S. Pat. No. 9,789,738 on Oct. 17, 2017, which is a continuation-in-part of U.S. Utility application Ser. No. 15/157,723, entitled, "PRESSURE BASED WIRELESS SENSOR AND APPLICATIONS THEREOF", filed on May 18, 2016, now abandoned, which claims priority pursuant to 35 U.S.C. § 119(e) to U.S. Provisional Application No. 62/163,143, entitled "RFID TAGS AND SENSORS", filed May 18, 2015, all of which are hereby incorporated herein by reference in their entirety and made part of the present U.S. Utility Patent Application for all purposes. (2) U.S. Utility patent application Ser. No. 15/348,365 also claims priority pursuant to 35 U.S.C. § 120 as a continuation-in-part of U.S. Utility application Ser. No. 14/869,940, entitled "RADIO FREQUENCY IDENTIFICATION (RFID) TAG(S) and SENSOR(S)", filed Sep. 29, 2015, issued as U.S. Pat. No. 9,607,188 on Mar. 28, 2017, which claims priority pursuant to 35 U.S.C. § 119(e) to U.S. Provisional Application No. 62/057,186, entitled "RADIO FREQUENCY IDENTIFICATION (RFID) TAGS AND SENSORS", filed Sep. 29, 2014 and U.S. Provisional Application No. 62/057,187, entitled "METHOD AND APPARATUS FOR IMPEDANCE MATCHING USING DITHERING", filed Sep. 29, 2014, all of which are hereby incorporated herein by reference in their entirety and made part of the present U.S. Utility Patent Application for all purposes. (3) U.S. Utility patent application Ser. No. 15/157,723 also claims priority pursuant to 35 U. S.C. § 120 as a continuation-in-part of U.S. Utility application Ser. No. 14/869,940, entitled "RADIO FREQUENCY IDENTIFICATION (RFID) TAG(S) and SENSOR(S)", filed Sep. 29, 2015, issued as U.S. Pat. No. 9,607,188 on Mar. 28, 2017, which claims priority pursuant to 35 U.S.C. § 119(e) to U.S. Provisional Application No. 62/057,186, entitled "RADIO FREQUENCY IDENTIFICATION (RFID) TAGS AND SENSORS", filed Sep. 29, 2014 and U.S. Provisional Application No. 62/057,187, entitled "METHOD AND APPARATUS FOR IMPEDANCE MATCHING USING DITHERING", filed Sep. 29, 2014, all of which are hereby incorporated herein by reference in their entirety and made part of the present U.S. Utility Patent Application for all purposes (4) U.S. Utility patent application Ser. No. 16/017,848 further claims priority pursuant

to 35 U.S.C. § 120 as a continuation-in-part of U.S. Utility application Ser. No. 15/217,816, entitled "COMPUTING DEVICE FOR PROCESSING ENVIRONMENTAL SENSED CONDITIONS," filed Jul. 22, 2016, issued as U.S. Pat. No. 10,715,209 on Jul. 14, 2020, which claims priority pursuant to 35 U.S.C. § 119(e) to U.S. Provisional Application No. 62/196,036, entitled "PASSIVE RFID SOFTWARE DEFINED RADIO SYSTEM", filed Jul. 23, 2015, all of which are hereby incorporated herein by reference in their entirety and made part of the present U.S. Utility Patent Application for all purposes. (5) U.S. Utility patent application Ser. No. 15/217,816 also claims priority pursuant to 35 U.S.C. § 120 as a continuation-in-part of U.S. Utility application Ser. No. 14/150,392, entitled "METHOD AND APPARATUS FOR DETECTING RF FIELD STRENGTH", filed Jan. 8, 2014, now U.S. Pat. No. 9,825,608, issued on Nov. 21, 2017, which is a divisional of U.S. Utility application Ser. No. 13/209,420, entitled "METHOD AND APPARATUS FOR DETECTING RF FIELD STRENGTH", filed Aug. 14, 2011, now U.S. Pat. No. 8,749,319, issued on Jun. 10, 2014, which claims priority pursuant to 35 U.S.C. § 119(e) to U.S. Provisional Application No. 61/428,170, entitled "METHOD AND APPARATUS FOR VARYING AN IMPEDANCE", filed Dec. 29, 2010 and U.S. Provisional Application No. 61/485,732, entitled "METHOD AND APPARATUS FOR SENSING ENVIRONMENTAL CONDITIONS USING AN RFID TAG", filed May 13, 2011, all of which are hereby incorporated herein by reference in their entirety and made part of the present U.S. Utility Patent Application for all purposes. (6) U.S. Utility application Ser. No. 13/209,420 also claims priority pursuant to 35 U.S.C. § 120 as a continuation-in-part of U.S. Utility application Ser. No. 12/462,331, entitled "METHOD AND APPARATUS FOR VARYING AN IMPEDANCE", filed Aug. 1, 2009, now U.S. Pat. No. 8,081,043, issued on Dec. 20, 2011, which is a divisional of U.S. Utility application Ser. No. 11/601,085, entitled "METHOD AND APPARATUS FOR VARYING AN IMPEDANCE", filed Nov. 18, 2006, now U.S. Pat. No. 7,586,385, issued on Sep. 8, 2009, all of which are hereby incorporated herein by reference in their entirety and made part of the present U.S. Utility Patent Application for all purposes. (7) U.S. Utility patent application Ser. No. 15/217,816 also claims priority pursuant to 35 U.S.C. § 120 as a continuation-in-part of U.S. Utility application Ser. No. 14/256,877, entitled "METHOD AND APPARATUS FOR SENSING ENVIRONMENT USING A WIRELESS PASSIVE SENSOR", filed Apr. 18, 2014, now U.S. Pat. No. 9,785,807, issued on Oct. 10, 2017, which claims priority pursuant to 35 U.S.C. § 119(e) to U.S. Provisional Application No. 61/814,241, entitled "RFID ENVIRONMENTAL SENSOR", filed Apr. 20, 2013; U.S. Provisional Application No. 61/833,150, entitled "RESONANT ANTENNA", filed Jun. 10, 2013; U.S. Provisional Application No. 61/833,167, entitled "RFID TAG", filed Jun. 10, 2013; U.S. Provisional Application No. 61/833,265, entitled "RFID TAG", filed Jun. 10, 2013; U.S. Provisional Application No. 61/871,167, entitled "RESONANT ANTENNA", filed Aug. 28, 2013; U.S. Provisional Application No. 61/875,599, entitled "CMF ACCURATE SENSOR", filed Sep. 9, 2013; U.S. Provisional Application No. 61/896,102, entitled "RESONANT ANTENNA", filed Oct. 27, 2013; U.S. Provisional Application No. 61/929,017, entitled "RFID ENVIRONMENTAL SENSOR", filed Jan. 18, 2014; U.S. Provisional Application No. 61/934,935, entitled "RFID ENVIRONMENTAL SENSOR", filed Feb. 3, 2014; all of which are hereby incorporated herein by reference in their entirety and made part of the present U.S. Utility Patent Application for all purposes. (8) U.S. Utility application Ser. No. 14/256,877 also claims priority pursuant to 35 U.S.C. § 120 as a continuation-in-part of U.S. Utility application Ser. No. 13/209,420, entitled "METHOD AND APPARATUS FOR DETECTING RF FIELD STRENGTH", filed Aug. 14, 2011, now U.S. Pat. No. 8,749,319, issued on Jun. 10, 2014, which claims priority pursuant to 35 U.S.C. § 119(e) to U.S. Provisional Application No. 61/428,170, entitled "METHOD AND APPARATUS FOR VARYING AN IMPEDANCE", filed Dec. 29, 2010 and U.S. Provisional Application No. 61/485,732, entitled "METHOD AND APPARATUS FOR SENSING ENVIRONMENTAL CONDITIONS USING AN RFID TAG", filed May 13, 2011, all of which are hereby incorporated herein by reference in their entirety and made part of the present U.S. Utility Patent Application for

all purposes. (9) U.S. Utility application Ser. No. 13/209,420 also claims priority pursuant to 35 U.S.C. § 120 as a continuation-in-part of U.S. Utility application Ser. No. 12/462,331, entitled "METHOD AND APPARATUS FOR VARYING AN IMPEDANCE", filed Aug. 1, 2009, now U.S. Pat. No. 8,081,043, issued on Dec. 20, 2011, which is a divisional of U.S. Utility application Ser. No. 11/601,085, entitled "METHOD AND APPARATUS FOR VARYING AN IMPEDANCE", filed Nov. 18, 2006, now U.S. Pat. No. 7,586,385, issued on Sep. 8, 2009, all of which are hereby incorporated herein by reference in their entirety and made part of the present U.S. Utility Patent Application for all purposes. (10) U.S. Utility application Ser. No. 14/256,877 also claims priority pursuant to 35 U.S.C. § 120 as a continuation-in-part of U.S. Utility application Ser. No. 13/209,425, entitled "METHOD AND APPARATUS FOR DETECTING RF FIELD STRENGTH", filed Aug. 14, 2011, now U.S. Pat. No. 9,048,819, issued on Jun. 2, 2015, which claims priority pursuant to 35 U.S.C. § 119(e) to U.S. Provisional Application No. 61/428,170, entitled "METHOD AND APPARATUS FOR VARYING AN IMPEDANCE", filed Dec. 29, 2010 and U.S. Provisional Application No. 61/485,732, entitled "METHOD AND APPARATUS FOR SENSING ENVIRONMENTAL CONDITIONS USING AN RFID TAG", filed May 13, 2011, all of which are hereby incorporated herein by reference in their entirety and made part of the present U.S. Utility Patent Application for all purposes. (11) U.S. Utility application Ser. No. 13/209,425 also claims priority pursuant to 35 U.S.C. § 120 as a continuation-in-part of U.S. Utility application Ser. No. 12/462,331, entitled "METHOD AND APPARATUS FOR VARYING AN IMPEDANCE", filed Aug. 1, 2009, now U.S. Pat. No. 8,081,043, issued on Dec. 20, 2011, which is a divisional of U.S. Utility application Ser. No. 11/601,085, entitled "METHOD AND APPARATUS FOR VARYING AN IMPEDANCE", filed Nov. 18, 2006, now U.S. Pat. No. 7,586,385, issued on Sep. 8, 2009, all of which are hereby incorporated herein by reference in their entirety and made part of the present U.S. Utility Patent Application for all purposes. (12) U.S. Utility application Ser. No. 14/256,877 also claims priority pursuant to 35 U.S.C. § 120 as a continuation-in-part of U.S. Utility application Ser. No. 13/467,925, entitled "ROLL-TO-ROLL PRODUCTION OF RFID TAGS", filed May 9, 2012, now U.S. Pat. No. 10,224,902, issued on Mar. 5, 2019, which is a continuation-in-part of U.S. Utility application Ser. No. 13/209,425, entitled "METHOD AND APPARATUS FOR DETECTING RF FIELD STRENGTH", filed Aug. 14, 2011, now U.S. Pat. No. 9,048,819, issued on Jun. 2, 2015, which claims priority pursuant to 35 U.S.C. § 119(e) to U.S. Provisional Application No. 61/428,170, entitled "METHOD AND APPARATUS FOR VARYING AN IMPEDANCE", filed Dec. 29, 2010 and U.S. Provisional Application No. 61/485,732, entitled "METHOD AND APPARATUS FOR SENSING ENVIRONMENTAL CONDITIONS USING AN RFID TAG", filed May 13, 2011, all of which are hereby incorporated herein by reference in their entirety and made part of the present U.S. Utility Patent Application for all purposes. (13) U.S. Utility application Ser. No. 13/209,425 also claims priority pursuant to 35 U.S.C. § 120 as a continuation-in-part of U.S. Utility application Ser. No. 12/462,331, entitled "METHOD AND APPARATUS FOR VARYING AN IMPEDANCE", filed Aug. 1, 2009, now U.S. Pat. No. 8,081,043, issued on Dec. 20, 2011, which is a divisional of U.S. Utility application Ser. No. 11/601,085, entitled "METHOD AND APPARATUS FOR VARYING AN IMPEDANCE", filed Nov. 18, 2006, now U.S. Pat. No. 7,586,385, issued on Sep. 8, 2009, all of which are hereby incorporated herein by reference in their entirety and made part of the present U.S. Utility Patent Application for all purposes.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT
(1) Not applicable
INCORPORATION-BY-REFERENCE OF MATERIAL SUBMITTED ON A COMPACT DISC
(2) Not applicable
BACKGROUND OF THE INVENTION
Technical Field of the Invention

(3) This invention relates generally to wireless communications and more particularly to wireless sensors and applications thereof.

Description of Related Art

(4) Wireless communication systems are known to include wireless transceivers that communication directly and/or over a wireless communication infrastructure. In direct wireless communications, a first wireless transceiver includes baseband processing circuitry and a transmitter to convert data into a wireless signal (e.g., radio frequency (RF), infrared (IR), ultrasound, near field communication (NFC), etc.). Via the transmitter, the first wireless transceiver transmits the wireless signal. When a second wireless transceiver is in range (e.g., is close enough to the first wireless transceiver to receive the wireless signal at a sufficient power level), it receives the wireless signal via a receiver and converts the signal into meaningful information (e.g., voice, data, video, audio, text, etc.) via baseband processing circuitry. The second wireless transceiver may wirelessly communicate back to the first wireless transceiver in a similar manner.

(5) Examples of direct wireless communication (or point-to-point communication) include walkie-talkies, Bluetooth, ZigBee, Radio Frequency Identification (RFID), etc. As a more specific example, when the direct wireless communication is in accordance with RFID, the first wireless transceiver may be an RFID reader and the second wireless transceiver may be an RFID tag.

(6) For wireless communication via a wireless communication infrastructure, a first wireless communication device transmits a wireless signal to a base station or access point, which conveys the signal to a wide area network (WAN) and/or to a local area network (LAN). The signal traverses the WAN and/or LAN to a second base station or access point that is connected to a second wireless communication device. The second base station or access point sends the signal to the second wireless communication device. Examples of wireless communication via an infrastructure include cellular telephone, IEEE 802.11, public safety systems, etc.

(7) In many situations, direct wireless communication is used to gather information that is then communicated to a computer. For example, an RFID reader gathers information from RFID tags via direct wireless communication. At some later point in time (or substantially concurrently), the RFID reader downloads the gathered information to a computer via a direct wireless communication or via a wireless communication infrastructure.

(8) For instance, in automobiles, wireless tire pressure monitoring sensors are used to provide tire pressure information to an automobile's computer. The sensors may indirectly or directly sense tire pressure. For example, indirect sensing calculates tire pressure from measured revolutions of the tire via the sensor. As another example, direct sensing measures the tire pressure from inside the tire. Direct sensing provides a more accurate measure of tire pressure than indirect sensing, but does so at a cost. In particular, direct wireless sensors include a battery and micro-electromechanical semiconductor (MEMS) circuitry to sense the tire pressure.

Description

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING(S)

(1) FIG. **1** is a schematic block diagram of an embodiment of a wireless communication system in accordance with the present invention;

(2) FIG. **2** is a schematic block diagram of an embodiment of a wireless communication system within a vehicle in accordance with the present invention;

(3) FIG. **3** is a schematic block diagram of an embodiment of a wireless data collecting device and a wireless sensor in accordance with the present invention;

(4) FIG. **4** is a schematic block diagram of another embodiment of a wireless sensor in accordance with the present invention;

(5) FIG. **5** is a schematic block diagram of another embodiment of a wireless sensor in accordance

with the present invention;

(6) FIG. **6** is a schematic block diagram of an embodiment of a pressure sensing circuit of a wireless sensor in accordance with the present invention;

(7) FIG. **7** is a schematic block diagram of another embodiment of a pressure sensing circuit of a wireless sensor in accordance with the present invention;

(8) FIG. **8** is a schematic block diagram of another embodiment of a pressure sensing circuit of a wireless sensor in accordance with the present invention;

(9) FIG. **9** is a schematic block diagram of another embodiment of a pressure sensing circuit of a wireless sensor in accordance with the present invention;

(10) FIG. **10** is a schematic block diagram of an example of a wireless sensor receiving an RF signal in accordance with the present invention; and

(11) FIG. **11** is a logic diagram of an embodiment of a method for calibrating a wireless sensor in accordance with the present invention.

DETAILED DESCRIPTION OF THE INVENTION

(12) FIG. **1** is a schematic block diagram of an embodiment of a wireless communication system **10** that includes three categories of devices: data generation **12**, data collecting **14**, and data processing **16**. As shown, the data generation category **12** includes wireless sensors **18-24**. The wireless sensors **18-24** may be implemented in a variety of ways to achieve a variety of data generation functions. For example, a wireless sensor includes a passive RFID topology and a sensing feature to sense one or more environmental conditions (e.g., moisture, temperature, pressure, humidity, altitude, sonic wave (e.g., sound), human contact, surface conditions, tracking, location, etc.) associated with an object (e.g., a box, a personal item (e.g., clothes, diapers, etc.), a pet, an automobile component, an article of manufacture, an item in transit, etc.). As another example, the wireless sensor includes an active RFID topology and a sensing feature. As yet another example, the wireless sensor includes processing circuitry and a transceiver for use with a personal area network (e.g., Bluetooth), a local area network (e.g., Wi-Fi, local wireless area network), and/or a wide area network (e.g., cellular voice and/or data).

(13) The data collecting category **14** includes stationary wireless collecting devices **26** and/or portable wireless data collecting devices **28**. The construct of a wireless data collecting device **26** and/or **28** is at least partially dependent on the data generation devices of category **12**. For example, when a wireless sensor includes an RFID topology, the wireless data collecting device **26** and/or **28** is an RFID reader. As a specific example, the portable wireless data collecting device **28** is a hand-held RFID reader and the stationary wireless collecting device **26** is a RFID reader mounted in a particular location (e.g., on an assembly line of a manufacturing process).

(14) In general, the wireless sensors **18-24** generate data that is wirelessly communicated to the wireless data collecting devices **26** and/or **28**. A wide variety of wireless communication protocols and/or standards may be used. For example, the wireless communication is in accordance with one or more RFID wireless communication standards and/or protocols. As another example, the wireless communication is in accordance with Bluetooth, ZigBee, IEEE 802.11, etc.

(15) The data processing category **16** includes one or more computing devices **30**. The computing device **30** may be a personal computer, a tablet computer, a laptop, a mainframe computer, and/or a server. The computing device **30** communicates with the wireless data collecting devices via a wired and/or wireless local area network, wide area network, or point-to-point network.

(16) As an example, the wireless communication system **10** is deployed in a factory that assembles a product from multiple components in multiple stages occurring in multiple locations within the factory. Each of the components includes a wireless sensor that identifies the component and may further generate data regarding one or more environmental conditions of the component. In some locations within the factory, stationary wireless data collecting devices are positioned to communicate with the wireless sensors in their proximal area. In other locations of the factory, employees use the portable wireless data collecting devices **28** to communication with the wireless

sensors in their proximal area.

(17) As the wireless data collecting devices **26** and **28** communicate with the wireless sensors **18-24**, they collect data from the sensors and relay the data to the computing device **30**. The computing device processes the data to determine a variety of information regarding the assembly of the products, defects, efficiency, etc.

(18) While the categories **12-16** of the wireless communication system are shown to have separate devices, a device may span multiple categories. For example, a data collecting device includes functionality to process at least some of the data it collects. As another example, a wireless sensor includes functionality to store and/or interpret the data it is collecting.

(19) FIG. **2** is a schematic block diagram of an embodiment of a wireless communication system within a vehicle. The wireless communication system includes a plurality of wireless sensors **20**, one or more wireless data collecting devices **26**, and a computing device **30**. In an example embodiment, the wireless sensors **20** are passive sensors having an RFID topology that are positioned within tires of the vehicle; the wireless data collecting device **26** is an RFID reader, or multiple RFID readers; and the computing device **30** is the on-board computer of the vehicle.

(20) In an example of operation, the wireless data collecting device **26** transmits a radio frequency (RF) signal to a wireless sensor **20** in accordance with one or more RFID communication protocols. The wireless sensor **20** converts the RF signal into a DC supply voltage that is used to power the other components of the wireless sensor, including a pressure sensing circuit. The pressure sensing circuit measures pressure within its respective tire, which is communicated back to the wireless data collecting device **26**.

(21) The wireless data collecting device **26** communicates with the other wireless sensors **20** in the same way to collect tire pressure measurements of the other tires. The wireless data collecting device **26** provides the tire pressure measurements to the computing device **30**, which processes the data. For instance, the computing device may indicate that a tire pressure is too low, too high, or within an acceptable range. Note that a tire may include more than one sensor such multiple pressure measurements per tire are taken and processed.

(22) FIG. **3** is a schematic block diagram of another embodiment of a wireless data collecting device **26-28** and a wireless sensor **18-24**. The wireless sensor **18-24** includes a power harvesting circuit **32**, a processing module **34**, memory **36**, a receiver section **38**, a transmitter section **40**, an antenna structure **42**, a power detection circuit **56**, a pressure sensing circuit **58**, and a tuning circuit **60**. The wireless data collecting device includes an antenna structure **44**, a transmitter **46**, a receiver **48**, a transmit/receive splitter or switch (T/R), a processing module **50**, memory **52**, and an interface **54**. The interface **54** includes firmware (e.g., software and hardware) to communicate with the computing device **30** via a wired and/or wireless LAN and/or WAN.

(23) In an example of operation, the wireless sensor is a passive RFID tag and the wireless data collecting device is an RFID reader. The passive RFID tag is associated with an object and an object identifier is stored in the memory **36** of the wireless sensor. For the RFID reader to communicate with the passive RFID tag, the tag first generates a power supply voltage (or multiple power supply voltages) from the RF (radio frequency) signal **43** transmitted from the RFID reader. For example, the RF signal **43** is a continuous wave signal and uses amplitude shift keying (ASK) or other amplitude-based modulation scheme to convey data.

(24) The power harvesting circuit **32** receives the RF signal **43** via the antenna **42** and converts it into one or more supply voltages (Vs). The supply voltage(s) power the other components (e.g., **34-40**, **56**) so that they perform their specific tasks. For instance, the receiver **38** is operable to convert an inbound message received from the RFID reader into a baseband signal that it provides to the processing module **34**. The processing module **34** processes the baseband signal and, when appropriate, generates a response that is subsequently transmitted via the antenna **42** by the transmitter **40**. For example, the inbound message instructs the wireless sensor to provide a respond with a pressure measurement and the stored ID of the object.

(25) To obtain a pressure measurement, the pressure sensing circuit **58** senses the pressure within an area (e.g., within a tire of an automobile). For example, as the pressure sensing circuit **58** is subjected to different pressures (e.g., force per area measured in pounds per square inch or other units), its electrical characteristics change. For instance, a capacitance, an inductance, an impedance, a resonant frequency, or other characteristic changes (e.g., increases or decreases).

(26) The electrical characteristics change of the pressure sensing circuit **58** causes a change in an RF characteristic of the combination of the antenna **42**, the tuning circuit **60**, and the pressure sensing circuit **58**. Note that an RF characteristic includes an impedance (e.g., an input impedance) at a frequency (e.g., carrier frequency of the RF signal **43**), a resonant frequency (e.g., of the turning circuit and/or antenna), a quality factor (e.g., of the antenna), and/or a gain. As a specific example, the resonant frequency has changed from a desired resonant frequency (e.g., matching the carrier frequency of the RF signal **43**) as result of the sensed pressure.

(27) The processing module **34** detects a variance of the one or more RF characteristics from a desired value (e.g., the resonant frequency changes from a desired frequency that corresponds to the carrier frequency of the RF signal **43**). When the processing module detects the variance, it adjusts the tuning circuit to substantially re-establish the desired value of the one or more RF characteristics. For example, the tuning circuit **60** includes an inductor and a capacitor, one of which is adjusted to change the resonant frequency back to the desired value.

(28) The processing module **34** determines the amount of adjustment of the tuning circuit **60** and converts the amount of adjustment into a digital value. The digital value is representative of the pressure sensed by the pressure sensing circuit **58**. The processing module **34** generates a message regarding the adjusting of the tuning circuit (e.g., the message includes the digital value or an actual pressure measurement if the processing module performs a digital value to pressure measurement conversion function). The transmitter transmits the message to the data collecting device via the antenna **42** or another antenna (not shown in FIG. **3**).

(29) Before the processing module processes the sensed environmental condition, it may perform a power level adjustment. For example, the power detection circuit **56** detects a power level of the received RF signal **43**. In one embodiment, the processing module interprets the power level and communicates with the RFID reader to adjust the power level of the RF signal **43** to a desired level (e.g., optimal for accuracy in detecting the environmental condition). In another embodiment, the processing module includes the received power level data with the environmental sensed data it sends to the RFID reader so that the reader can factor the power level into the determination of the extent of the environmental condition.

(30) The processing module **34** may be further operable to perform a calibration function when the pressure in which the wireless sensor is known (e.g., in a room at a certain altitude, in a calibration chamber having a set pressure, etc.). For example, the processing module **34** receives a calibration request from a data collecting device. In response, the processing module adjusts the tuning circuit to establish the desired value of the RF characteristic(s) (e.g., resonant frequency, input impedance, quality factor, gain, etc.). The processing module then records a level of the adjusting of the tuning circuit to represent a pressure calibration of the wireless sensor (e.g., records a digital value). The processing module may communicate the calibration value to the data collecting device as part of the calibration process or send it along with the digital value of a pressure measurement.

(31) FIG. **4** is a schematic block diagram of another embodiment of a wireless sensor **18-24** that includes the power harvesting circuit **32**, the processing module **34**, memory **36**, the receiver section **38**, the transmitter section **40**, a first antenna structure **42**, a second antenna structure **45**, one or more power detection circuits **56**, a pressure sensing circuit **58**, a first tuning circuit **60-1**, and a second tuning circuit **60-2**. Each of the first and second antenna structures **42** and **45** include an antenna (e.g., monopole, dipole, helical, etc.) and may further include impedance matching circuitry, filtering circuitry, and/or one or more additional antennas for beamforming, diversity, and/or other antenna array configurations and/or applications.

(32) In this embodiment, the pressure sensing is separated from the power harvesting and communication. For instance, the pressure sensing circuit **58** is operably coupled to the first antenna structure **42**, where operably coupled means, in addition to as otherwise defined herein, in close physical proximity to affect RF characteristics of the antenna **42** and/or tuning circuit **60-1** and/or electrically connected to the antenna and/or tuning circuit. The pressure sensing circuit **58**, the processing module **34**, and the tuning circuit **60-1** function as described herein to generate a digital representation of a pressure measurement.

(33) The pressure sensing side of the wireless sensor may further include a separate power detection circuit **56** to provide power measurements to the processing module regarding the RF signal received via antenna **42**. The processing module **34** may use the power information to interpret the RF characteristic changes or may provide a digital representation of received power of the antenna **42** to the data collection device. For example, the processing module **34** calibrates pressure sensing based on a particular input power and a known pressure level. When a pressure measurement is taken and the input power deviates from the particular input power of calibration, the processing module **34** either factors that into the pressure sensing measurement, requests a transmit power adjustment by the data collecting device, and/or provides a digital representation of the received input power and a digital representation of the pressure measurement to the data collecting device.

(34) The second antenna structure **45** supports the separate power harvesting and communication. On this side of the wireless sensor, the power harvesting circuit **32**, the power detection circuit **56** (which is optional for this side of the wireless sensor), the second tuning circuit **60-2**, the receiver **38**, the transmitter **40**, and the processing module **34** function to optimize the generation of power and communication with the data collecting device. For instance, the processing module **34** adjusts the tuning circuit **60-2** to align its resonant frequency with the frequency of the RF signal **43** allowing for more efficient power harvesting.

(35) With the separation of sensing from power harvesting and communication, the first antenna structure **42** may be located in an area that has less reception of the RF signal than the second antenna structure **45**. For example, the first antenna structure **42** and the pressure sensing circuit are positioned on a printed circuit board that is mounted within a tire where the steel rim and the steel cabling of the tire limit reception of the RF signal **43** by the antenna **42**. The second antenna **45** is located outside of the tire (e.g., along the stem of the tire or elsewhere) and thus the rim and the tire do not limit its reception of the RF signal.

(36) FIG. **5** is a schematic block diagram of another embodiment of a wireless sensor **18-24** that is similar to the wireless sensor of FIG. **4** with the addition of a temperature sensor **65**. When the wireless sensor is powered up (e.g., the power harvesting circuit **32** is producing a power supply voltage), the temperature sensor **65** is enabled to measure temperature of its environment. The temperature sensor **65** may have a variety of implementations. For example, the temperature sensor **65** has a thermocouple topology to produce a voltage representative of temperature. As another example, the temperature sensor **65** includes a temperature sensing diode. As another example, the temperature sensor **65** includes circuitry that, as temperature varies, causes an RF characteristic of the antenna and/or tuning circuit to vary.

(37) FIG. **6** is a schematic block diagram of an embodiment of a pressure sensing circuit **58** that includes a metallic diaphragm **58-1** and capacitive plates **58-2** and **58-3**, which form a variable capacitance circuit. Capacitive plate **58-2** with the diaphragm **58-1** form a first capacitance C**1** and capacitive plate **58-3** with the diaphragm **58-1** form a second capacitance C**2**. The total capacitance of the pressure sensing circuit **58** is the series combination of C**1** and C**2**. The first capacitive plate **58-2** is coupled to a first antenna element of antenna **42** (which is shown as a dipole antenna) and the second capacitive plate **58-3** is coupled to a second antenna element of the antenna **42**.

(38) The first capacitive plate **58-2**, the second capacitive plate **58-3**, and the diaphragm **58-1** are sized and spaced to provide specific capacitance values for C**1** and C**2**. The specific capacitance

values are based on the carrier frequency of the RF signal and a desired amount of change of the one or more RF characteristics of the front-end of the sensor **18-24**. For example, at a carrier frequency of 900 MHz, the input impedance of the front-end is 50 Ohms, and a desired change is about 25%, then the impedance of the series combination at 900 MHz is about 12.5 Ohms (e.g., 25% of 50 Ohms) and the series capacitance is about 14 pF.

(39) When the diaphragm **58-1** is compressed, the total capacitance increases, which causes a change in the one or more RF characteristics of the front-end (e.g., impedance). When the antenna **42** receives an RF signal (with the diaphragm compressed), the power detection circuit **56** and power harvesting circuit function as previously described. The processing module **34**, which includes a detection circuit **35** and a controller **37**, receives a power indication **33** (e.g., the input power, the supply voltage, a supply current, input voltage, etc.) that corresponds to the input power of the RF signal. The detection circuit **35** adjusts the varactor of the tuning circuit **60**, which further includes an inductor, to change the one or more RF characteristics. When the power indication **33** indicates a maximum, or near maximum, power level (voltage, and/or current without saturation), of the front-end of the sensor (e.g., the antenna **4**, the tuning circuit **60**, and/or the pressure sensing circuit **58**) is in resonance, or near resonance, with the carrier frequency of the RF signal. The controller **37** determines the amount that the tuning circuit was adjusted and created a digital representation thereof. The digital representation may be stored in memory **36** and/or transmitted to a data collecting device **26-28**.

(40) FIG. **7** is a schematic block diagram of another embodiment of a pressure sensing circuit **58** that includes a tuning loop **58-5** and a diaphragm **58-4**. The tuning loop **58-5** is coupled to the antenna elements of the antenna **42**. The diaphragm **58-4** is a metal plate that, as it is compressed towards the tuning loop **58-5**, decreases the inductance of the tuning loop **58-5**. A change in the inductance of the tuning loop **58-5** causes a change in the one or more RF characteristics of the front-end. As such, changes in the inductance corresponds to varying pressures applied to the diagram.

(41) FIG. **8** is a schematic block diagram of another embodiment of a pressure sensing circuit **58** that is similar to the pressure sensing circuit of FIG. **6** with a puck diaphragm **58-6** replacing the diaphragm **58-1**. The puck diaphragm **58-6** is comprised of a metal material that includes a hermetically sealed core. The core may be a vacuum core, a gas filled core (e.g., a gas with low expansion-contraction over temperature), a dry nitrogen filed core, a gasless core, etc. As pressure is applied to the puck diaphragm **58-6**, the total capacitance of the pressure sensing circuit is reduced, which causes a change in the one or more RF characteristics of the front-end. In an embodiment, the bottom surface of the puck (e.g., the surface towards the plates **58-2** and **58-3**) is thinner than the side walls and top surface (as orientated in the figure) such that it is the surface that primarily moves in response to pressure.

(42) FIG. **9** is a schematic block diagram of another embodiment of a pressure sensing circuit **58** that is similar to the pressure sensing circuit of FIG. **7** with a puck diaphragm **58-6** replacing the diaphragm **58-4**. The puck diaphragm **58-6** is comprised of a metal material and includes a vacuum core. As pressure is applied to the puck diaphragm **58-6**, the inductance of the tuning loop **58-5** is increased, which causes a change in the one or more RF characteristics of the front-end.

(43) FIG. **10** is a schematic block diagram of an example of a wireless sensor **18-24** receiving an RF signal **43**. A data collecting device transmits the RF signal **43** at a given power level, which may be received by the wireless sense at a received power level ranging from a minimum input power to a maximum input power. In an embodiment, the RF signal **43** is a continuous wave at a given frequency (fc).

(44) In many instances, it is desirable to have the input power level at a particular level (e.g., the minimum level or other level). For example, the RF characteristic of the antenna and tuning circuit are dependent on the input power level. As such, the input power level needs to be accounted for to accurately tune the tuning circuit. In one embodiment, the input power is accounted for by the

wireless sensor communicating with the data collection device to lower the transmit power of the RF signal such that the wireless sensor receives it at the desire input power level. In another embodiment, the wireless sensor determines the input power level and provides an indication of the input power level along with the tuning circuit adjustment to the data collecting device.

(45) FIG. **11** is a logic diagram of an embodiment of a method for calibrating a wireless sensor in a known environment with known environmental conditions (e.g., moisture, temperature, pressure, etc.). The method begins at step **100** where the power harvesting circuit converts the continuous wave signal (e.g., the RF signal **43**) into a power supply voltage(s). The method continues at step **102** where a determination is made as to whether there is sufficient power to power the wireless sensor. For example, a determination is made as to whether the power supply voltage has reached a desired voltage level. If not, the method repeats at step **100**.

(46) When there is sufficient power, the method continues at step **104** where the processing module adjusts the tuning circuit to change a resonant frequency (fr) of the input section of the wireless sensor (e.g., the antenna, the tuning circuit, the pressure sensing circuit, the temperature sensing circuit, and/or other components). Note that, at the start of calibration, the resonant frequency (fr) of the input section of the wireless sensor may be at any frequency within a range of frequencies centered about the carrier frequency of the RF signal (fc).

(47) The method continues at step **106** where a determination is made as to whether the resonant frequency (fr) is substantially aligned with the carrier frequency (fc). For example, alignment may be determined based on an interpretation of power levels, voltage levels, and/or current levels within the wireless sensor. If not, the method repeats at step **104** by further adjusting the tuning circuit (e.g., in the same direction or in an opposition direction). If the frequencies are aligned, the method continues at step **108** where the wireless sensor is calibrated and the settings for the tuning circuit are stored as the calibration settings. The calibration settings may be stored by the wireless sensor, the data collecting device, and/or computing device.

(48) It is noted that terminologies as may be used herein such as bit stream, stream, signal sequence, etc. (or their equivalents) have been used interchangeably to describe digital information whose content corresponds to any of a number of desired types (e.g., data, video, speech, audio, etc., any of which may generally be referred to as 'data').

(49) As may be used herein, the terms "substantially" and "approximately" provides an industry-accepted tolerance for its corresponding term and/or relativity between items. Such an industry-accepted tolerance ranges from less than one percent to fifty percent and corresponds to, but is not limited to, component values, integrated circuit process variations, temperature variations, rise and fall times, and/or thermal noise. Such relativity between items ranges from a difference of a few percent to magnitude differences. As may also be used herein, the term(s) "configured to", "operably coupled to", "coupled to", and/or "coupling" includes direct coupling between items and/or indirect coupling between items via an intervening item (e.g., an item includes, but is not limited to, a component, an element, a circuit, and/or a module) where, for an example of indirect coupling, the intervening item does not modify the information of a signal but may adjust its current level, voltage level, and/or power level. As may further be used herein, inferred coupling (i.e., where one element is coupled to another element by inference) includes direct and indirect coupling between two items in the same manner as "coupled to". As may even further be used herein, the term "configured to", "operable to", "coupled to", or "operably coupled to" indicates that an item includes one or more of power connections, input(s), output(s), etc., to perform, when activated, one or more its corresponding functions and may further include inferred coupling to one or more other items. As may still further be used herein, the term "associated with", includes direct and/or indirect coupling of separate items and/or one item being embedded within another item.

(50) As may be used herein, the term "compares favorably", indicates that a comparison between two or more items, signals, etc., provides a desired relationship. For example, when the desired relationship is that signal 1 has a greater magnitude than signal 2, a favorable comparison may be

achieved when the magnitude of signal 1 is greater than that of signal 2 or when the magnitude of signal 2 is less than that of signal 1. As may be used herein, the term "compares unfavorably", indicates that a comparison between two or more items, signals, etc., fails to provide the desired relationship.

(51) As may also be used herein, the terms "processing module", "processing circuit", "processor", and/or "processing unit" may be a single processing device or a plurality of processing devices. Such a processing device may be a microprocessor, micro-controller, digital signal processor, microcomputer, central processing unit, field programmable gate array, programmable logic device, state machine, logic circuitry, analog circuitry, digital circuitry, and/or any device that manipulates signals (analog and/or digital) based on hard coding of the circuitry and/or operational instructions. The processing module, module, processing circuit, and/or processing unit may be, or further include, memory and/or an integrated memory element, which may be a single memory device, a plurality of memory devices, and/or embedded circuitry of another processing module, module, processing circuit, and/or processing unit. Such a memory device may be a read-only memory, random access memory, volatile memory, non-volatile memory, static memory, dynamic memory, flash memory, cache memory, and/or any device that stores digital information. Note that if the processing module, module, processing circuit, and/or processing unit includes more than one processing device, the processing devices may be centrally located (e.g., directly coupled together via a wired and/or wireless bus structure) or may be distributedly located (e.g., cloud computing via indirect coupling via a local area network and/or a wide area network). Further note that if the processing module, module, processing circuit, and/or processing unit implements one or more of its functions via a state machine, analog circuitry, digital circuitry, and/or logic circuitry, the memory and/or memory element storing the corresponding operational instructions may be embedded within, or external to, the circuitry comprising the state machine, analog circuitry, digital circuitry, and/or logic circuitry. Still further note that, the memory element may store, and the processing module, module, processing circuit, and/or processing unit executes, hard coded and/or operational instructions corresponding to at least some of the steps and/or functions illustrated in one or more of the Figures. Such a memory device or memory element can be included in an article of manufacture.

(52) One or more embodiments have been described above with the aid of method steps illustrating the performance of specified functions and relationships thereof. The boundaries and sequence of these functional building blocks and method steps have been arbitrarily defined herein for convenience of description. Alternate boundaries and sequences can be defined so long as the specified functions and relationships are appropriately performed. Any such alternate boundaries or sequences are thus within the scope and spirit of the claims. Further, the boundaries of these functional building blocks have been arbitrarily defined for convenience of description. Alternate boundaries could be defined as long as the certain significant functions are appropriately performed. Similarly, flow diagram blocks may also have been arbitrarily defined herein to illustrate certain significant functionality.

(53) To the extent used, the flow diagram block boundaries and sequence could have been defined otherwise and still perform the certain significant functionality. Such alternate definitions of both functional building blocks and flow diagram blocks and sequences are thus within the scope and spirit of the claims. One of average skill in the art will also recognize that the functional building blocks, and other illustrative blocks, modules and components herein, can be implemented as illustrated or by discrete components, application specific integrated circuits, processors executing appropriate software and the like or any combination thereof.

(54) In addition, a flow diagram may include a "start" and/or "continue" indication. The "start" and "continue" indications reflect that the steps presented can optionally be incorporated in or otherwise used in conjunction with other routines. In this context, "start" indicates the beginning of the first step presented and may be preceded by other activities not specifically shown. Further, the

"continue" indication reflects that the steps presented may be performed multiple times and/or may be succeeded by other activities not specifically shown. Further, while a flow diagram indicates a particular ordering of steps, other orderings are likewise possible provided that the principles of causality are maintained.

(55) The one or more embodiments are used herein to illustrate one or more aspects, one or more features, one or more concepts, and/or one or more examples. A physical embodiment of an apparatus, an article of manufacture, a machine, and/or of a process may include one or more of the aspects, features, concepts, examples, etc. described with reference to one or more of the embodiments discussed herein. Further, from figure to figure, the embodiments may incorporate the same or similarly named functions, steps, modules, etc. that may use the same or different reference numbers and, as such, the functions, steps, modules, etc. may be the same or similar functions, steps, modules, etc. or different ones.

(56) While the transistors in the above described figure(s) is/are shown as field effect transistors (FETs), as one of ordinary skill in the art will appreciate, the transistors may be implemented using any type of transistor structure including, but not limited to, bipolar, metal oxide semiconductor field effect transistors (MOSFET), N-well transistors, P-well transistors, enhancement mode, depletion mode, and zero voltage threshold (VT) transistors.

(57) Unless specifically stated to the contra, signals to, from, and/or between elements in a figure of any of the figures presented herein may be analog or digital, continuous time or discrete time, and single-ended or differential. For instance, if a signal path is shown as a single-ended path, it also represents a differential signal path. Similarly, if a signal path is shown as a differential path, it also represents a single-ended signal path. While one or more particular architectures are described herein, other architectures can likewise be implemented that use one or more data buses not expressly shown, direct connectivity between elements, and/or indirect coupling between other elements as recognized by one of average skill in the art.

(58) The term "module" is used in the description of one or more of the embodiments. A module implements one or more functions via a device such as a processor or other processing device or other hardware that may include or operate in association with a memory that stores operational instructions. A module may operate independently and/or in conjunction with software and/or firmware. As also used herein, a module may contain one or more sub-modules, each of which may be one or more modules.

(59) While particular combinations of various functions and features of the one or more embodiments have been expressly described herein, other combinations of these features and functions are likewise possible. The present disclosure is not limited by the particular examples disclosed herein and expressly incorporates these other combinations.

Claims

1. A passive radio frequency (RF) circuit comprises: antenna circuitry including an antenna and a tuning circuit, wherein the antenna circuitry is operably coupled to: receive an inbound RF signal via an inbound propagating electromagnetic wave; and transmit an outbound RF signal via an outbound propagating electromagnetic wave; a power harvesting circuit operably coupled to generate a supply voltage from the inbound RF signal; a temperature sensor operable to, when the supply voltage is generated, generate a digital signal that represents a temperature; a processing module operable to, when the supply voltage is generated, process the digital signal to produce a digital representation of the temperature; and an RF transmitter operable to, when the supply voltage is generated, transmit, via the antenna circuitry, the outbound RF signal that includes the digital representation of the temperature.

2. The passive RF circuit of claim 1, wherein the temperature sensor is further operable to: generate the digital signal as a representation of an electrical characteristic of the temperature sensor,

wherein, as the temperature changes, the electrical characteristic of the temperature sensor changes.

3. The passive RF circuit of claim 1, wherein the processing module is further operable to: interpret the digital signal to establish a value of the electrical characteristic; and processing the value of the electrical characteristic to produce the digital representation of the temperature.

4. The passive RF circuit of claim 1 further comprises: as the temperature changes, an electrical characteristic of the temperature sensor changes; the change of the electrical characteristic causes a change in an RF characteristic of antenna circuitry; and the processing module is further operable to process the change of the RF characteristic of the antenna circuitry as the digital signal that represents a temperature.

5. The passive RF circuit of claim 4, wherein the processing module is further operable to processing the change of the RF characteristic by: detecting a variance of the RF characteristic from a desired value; and processing the variance to generate the digital representation of the temperature.

6. The passive RF circuit of claim 1 further comprises: the processing module generating a sense temperature command in response to a message of inbound RF signal; and in response to the sense temperature command, the temperature sensor generates the digital signal that represents a temperature.

7. The passive RF circuit of claim 1 further comprises: memory operable to store the digital representation of the temperature.

8. The passive RF circuit of claim 1, wherein the processing module is further operable to: receive the digital signal that represents a known temperature; produce the digital representation of the known temperature from the digital signal; and unitize the digital representation of the known temperature for calibration.

9. The passive RF circuit of claim 1, wherein the processing module is further operable to produce the digital representation of the temperature by one of: converting the digital signal into a coded value; and converting the digital signal or the coded value into a temperature value.

10. The passive RF circuit of claim 1 further comprises: the processing module is further operable to generate a temperature request in accordance with a request of the inbound RF signal; and the temperature sensor generate the digital signal that represents a temperature in response to the temperature request.

11. The passive RF circuit of claim 1 further comprises: a moisture sensor operable to, when the supply voltage is generated, generate a second signal that represents a moisture level; and the processing module operable to, when the supply voltage is generated, process the second signal to produce a second digital representation of the moisture level.

12. The passive RF circuit of claim 11, wherein the processing module is further operable to: generate a third digital representation for humidity based on the digital representation of the temperature and the second digital representation of the moisture level.

13. A radio frequency (RF) circuit comprises: antenna circuitry including an antenna and a tuning circuit, wherein the antenna circuitry is operably coupled to: receive an inbound RF signal via an inbound propagating electromagnetic wave; and transmit an outbound RF signal via an outbound propagating electromagnetic wave; a temperature sensor operable to generate a digital signal that represents a temperature; a processing module operable to process the digital signal to produce a digital representation of the temperature; and an RF transmitter operable to transmit, via the antenna circuitry, the outbound RF signal that includes the digital representation of the temperature.

14. The RF circuit of claim 13, wherein the temperature sensor is further operable to: generate the digital signal as a representation of an electrical characteristic of the temperature sensor, wherein, as the temperature changes, the electrical characteristic of the temperature sensor changes.

15. The RF circuit of claim 13, wherein the processing module is further operable to: interpret the digital signal to establish a value of the electrical characteristic; and processing the value of the electrical characteristic to produce the digital representation of the temperature.

16. The RF circuit of claim 13 further comprises: as the temperature changes, an electrical characteristic of the temperature sensor changes; the change of the electrical characteristic causes a change in an RF characteristic of antenna circuitry; and the processing module is further operable to process the change of the RF characteristic of the antenna circuitry as the digital signal that represents a temperature.

17. The RF circuit of claim 16, wherein the processing module is further operable to processing the change of the RF characteristic by: detecting a variance of the RF characteristic from a desired value; and processing the variance to generate the digital representation of the temperature.

18. The RF circuit of claim 13 further comprises: the processing module generating a sense temperature command in response to a message of inbound RF signal; and in response to the sense temperature command, the temperature sensor generates the digital signal that represents a temperature.

19. The RF circuit of claim 13 further comprises: memory operable to store the digital representation of the temperature.

20. The RF circuit of claim 13, wherein the processing module is further operable to: receive the digital signal that represents a known temperature; produce the digital representation of the known temperature from the digital signal; and unitize the digital representation of the known temperature for calibration.

21. The RF circuit of claim 13, wherein the processing module is further operable to produce the digital representation of the temperature by one of: converting the digital signal into a coded value; and converting the digital signal or the coded value into a temperature value.

22. The RF circuit of claim 13 further comprises: the processing module is further operable to generate a temperature request in accordance with a request of the inbound RF signal; and the temperature sensor generate the digital signal that represents a temperature in response to the temperature request.

23. The RF circuit of claim 13 further comprises: a moisture sensor operable to generate a second signal that represents a moisture level; and the processing module operable to process the second signal to produce a second digital representation of the moisture level.

24. The RF circuit of claim 23, wherein the processing module is further operable to: generate a third digital representation for humidity based on the digital representation of the temperature and the second digital representation of the moisture level.