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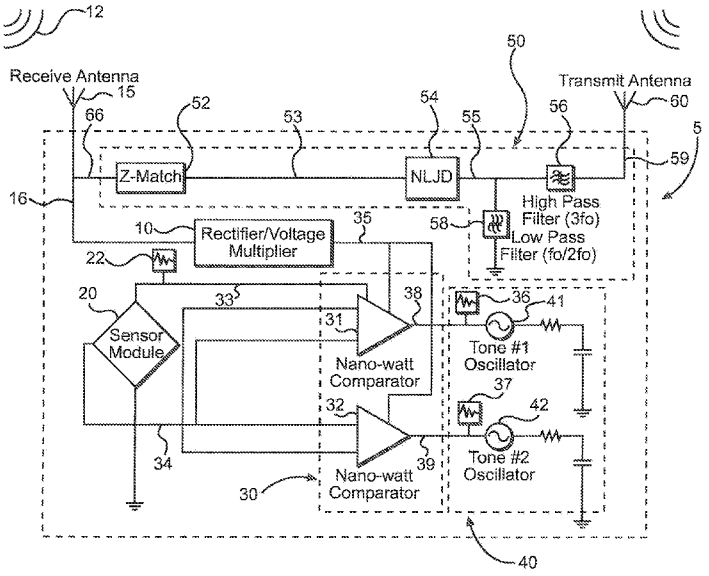


FIG. 1

(57) Abstract: A sensor platform (5) is powered remotely through electromagnetic RF energy (12), When the platform (5) is illuminated with electromagnetic RF energy (12) at a specific frequency (fo), the platform (5) develops sufficient power by using a rectenna (15, 62) to drive onboard components (20, 30, 40, 50) such as a tone generator module (40) and a sensor module (20). The tone generator module (40) on the platform (5) produces a dual- tone, amplitude modulated, third harmonic (3fo) of the incoming RF illuminating frequency and subsequently re-transmits the third harmonic (3fo) to a remote receiver. The remote receiver demodulates the third harmonic (3fo) to recover the original tones. Each tone represents a particular state of the sensor module. The sensor platform (5) can be advantageously used to inspect shipping containers.

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REMOTELY POWERED SENSOR DETECTION PLATFORM

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Patent Application serial number 61/635,503, entitled "Remotely Powered Sensor Detection Platform" filed on April 19, 2012, which is hereby incorporated by reference.

BACKGROUND OF THE INVENTION

Field of the Invention

[0002] The present invention pertains to the art of sensor platforms and, more specifically, sensor platforms which are remotely powered by transmitting energy such as electromagnetic RF energy, to the sensor platforms and receiving the electromagnetic RF energy with antennas mounted on the platforms, particularly rectifying antennas that convert the electromagnetic RF energy into direct electrical current.

Background of the Invention

[0003] Currently, there exist numerous industries that require remote sensors in locations that are not easily accessible in order to conduct business. For example, in the shipping industry, certain shipping containers that are repeatedly moved from place to place benefit from sensors. Specifically, containers that are used to ship food need sensors for sensing the container's temperature in order to determine if the food is spoiling. The sensed information is then transmitted to display equipment used by

shipping workers who can take appropriate action based on the information provided by the sensors. Other shipping containers require the remote detection of hazardous gases or chemicals present inside the shipping containers. Such sensors are needed to detect dangerous substances without risking injury to shipping workers.

[0004] In addition to the above, certain known sensors, such as those based on a Wheatstone-Bridge-based sensing module, are powered through many different types of power sources. For example, sensors may receive power from a hardwired source or from a battery. While hardwired power sources are satisfactory for sensors located in buildings or on stationary platforms, they are susceptible to utility power outages and are not portable. Since hardwired sensors are not portable, they cannot easily be used in the shipping industry. Battery powered sensors are portable and are not affected by power outages. However, batteries do require recharging or replacement and the logistics involved in connection with the replacement of batteries in large numbers, (hundreds or thousands), of remotely powered sensors can be very costly. Furthermore, sensors that are hardwired or require battery replacement cannot be placed in locations which are difficult to access due to the associated cost of traveling to each sensor every time the battery needs to be replaced or the electrical wiring needs to be maintained. Another problem with these types of sensors is that workers need to access the sensors to determine if the sensors are working properly.

[0005] With the above in mind, there exists a need for a remote detector platform which is powered without hardwiring or batteries and functions to scan the environment in which the platform resides. The platform preferably functions without direct physical contact and provides information to associated display equipment used by the workers monitoring

the sensors. The platform preferably also needs to send signals not only containing information about sensed parameters, but also about whether or not the sensor is receiving power and whether or not the sensor is functioning properly.

SUMMARY OF THE INVENTION

[0006] The present invention is directed to a sensor platform powered remotely through electromagnetic RF energy. Specifically, when the platform is illuminated with electromagnetic RF energy at a specific predetermined frequency, the platform develops sufficient power by using a rectenna to drive onboard components, particularly a tone generator and a sensor module. The tone generator on the platform produces a dual-tone, amplitude modulated, third harmonic of the incoming RF frequency and subsequently re-transmits the dual-tone to a remote receiver. The remote receiver demodulates the third harmonic of the incoming RF frequency to recover the original tones. Each tone represents a particular state of the sensor module. In accordance with a preferred embodiment, one tone represents successful illumination and powering of the platform with no positive detection from the sensor and the other tone represents successful illumination and powering of the platform with positive sensor detection.

[0007] The sensor platform is a wirelessly powered, general purpose transponder platform used as a mounting structure for any sensing module, particularly a Wheatstone-Bridge-based sensing module. The sensor platform can be advantageously employed in connection with inspecting shipping containers. Additional objects, features and advantages of the present invention will become more readily apparent from the following

detailed description of preferred embodiments when taken in conjunction with the drawings wherein like reference numerals refer to corresponding parts in the several views.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] Figure 1 is a block diagram of a detection platform with five major circuit modules including a Rectifier and Voltage Module, a Sensor Module, a Comparator Module, a Two Tone Oscillator/Modulator Module, and a Non-Linear Junction Detector (NLJD) within an RF output module, in accordance with a preferred embodiment of the invention;

[0009] Figure 2 is a circuit diagram of the Rectifier and Voltage Module shown in Figure 1;

[0010] Figure 3 is a circuit diagram of the Sensor Module and the Comparator Module (including two Nano-watt Comparators) shown in Figure 1;

[0011] Figure 4 is a circuit diagram of the Two Tone Oscillator/Modulator Module shown in Figure 1, including a Tone #1 Oscillator and a Tone #2 Oscillator; and

[0012] Figure 5 is a circuit diagram of the Non-Linear Junction Device within the RF Output Module shown in Figure 1.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0013] With initial reference to Figure 1, a sensor detection platform for sensing various parameters constructed in accordance with the invention is generally indicated at 5. Sensor detection platform 5 is formed from five

major circuit modules. The first module is a Rectifier/Voltage Multiplier Module 10 that rectifies fundamental incoming electromagnetic RF energy 12 as received by a receiving antenna 15 along a power line 16 to create a DC voltage. Rectifier/Voltage Multiplier Module 10 then multiplies the DC generated voltage to generate an amplified DC voltage, labeled +VPower, that is used to power platform 5. The second module is a Sensor Module 20 for detecting a sensed parameter, such as ambient temperature, and producing an output 22 based on the sensed parameter. The third module is a Comparator Module 30, shown to include two nano-watt comparators 31, 32 powered by the amplified DC voltage. Comparator Module 30 is connected to Sensor Module 20 by connecting lines 33 and 34, which carry output 22 to nano-watt comparators 31, 32. Comparator Module 30 is also connected to Rectifier/Voltage Multiplier Module 10 by power line 35 from which Comparator Module 30 is powered by the amplified DC voltage (+VPower). Nano-watt comparators 31, 32 produce first and second signals at 36, 37 from output 22 of Sensor Module 20. First and second signals 36, 37 travel along communication lines 38 and 39 to the fourth module which is a Two Tone Oscillator/Modulator Module 40 including first and second square wave audio oscillators 41, 42 for producing first and second audio tones based on first and second signals 36, 37 respectively and for loading down Rectifier/Voltage Multiplier Module 10 to cause Rectifier/Voltage Multiplier Module 10 to cause a fluctuation in the incoming RF energy in power line 16. The fifth module is an RF Output Module 50 that includes an impedance matching circuit 52 connected to receiving antenna 15. Circuit 52 is connected by a communication line 53 to a Non-Linear Junction Device (NLJD) constituted by anti-parallel diode pair 54 for receiving the incoming RF energy and producing a dual-tone, amplitude modulated, third

harmonic signal 3fo, based on the fluctuation. Anti-parallel diode pair 54 is connected by a line 55 to a high pass filter 56 and a low pass filter 58. High pass filter 56 is connected via line 59 to a transmitting antenna 60.

[0014] Each module will now be discussed in detail. First, Rectifier/Voltage Multiplier Module 10 is shown in Figure 2 and configured as a series of capacitor/diode connections 62 which in combination with receiving antenna 15 constitute a rectenna. Capacitor/diode connections 62 rectify incoming electromagnetic RF energy 12 entering along power line 16 and multiply (8x) the generated DC voltage present on power line 35. Each pair of diode pairs D1-D4 is preferably a pair of surface mount RF Schottky barrier diodes arranged in a package with three pin connections. The surface mount RF Schottky barrier diodes generally include a metal-semiconductor barrier formed by deposition of a metal layer on a semiconductor substrate. Such Schottky barrier diode pairs are well known and are commercially available. For example, Agilent Technologies produces such a pair of diodes with a part number HSMS2822. As shown, pin 3 from diode pair D1 is connected between capacitors C1 and C2 while capacitor C9 is connected between pins 1 and 2. Diode pairs D2-D4 are connected in an analogous fashion. The values of capacitors C1-C12 and diode pairs D1-D4 are chosen to optimize the amplified DC voltage (+VPower) produced in power line 35 with minimal RF input energy over a specific narrow-band frequency range. Power line 35 carries the amplified DC voltage (+VPower) to Comparator Module 30 as best seen in Figure 3.

[0015] Comparator Module 30 is shown in Figure 3. Comparators 31, 32 of Comparator Module 30 are used to generate a high/low state on first and second signals 36, 37 of Figure 1, based upon output 22 of Sensor Module 20. Each comparator 31, 32 is preferably an ultralow power, single

comparator with a built in reference. Since comparator 32 is preferably the same as comparator 31, only the pin connections of comparator 31 will be described.

[0016] Comparator 31 is shown with eight pin connections 1-8. Pin 1 is a ground connection. Pin 2 is a negative supply but is shown connected to ground since only a single power supply is being used. Pin 3 is a positive or non-inverting comparator input. Preferably, pin 3 can receive a common mode input range from –V to +V of -1.3V with a typical input current of 10pA at 25°C. Pin 4 is a negative or inverting comparator input which also preferably has a common mode input range from –V to +V of -1.3V with a typical input current of 10pA at 25°C. Pin 5 is a hysteresis input with an input voltage range from Vref to Vref-50mV. Pin 6 is a reference output that provides a voltage of 1.182V with respect to V- at pin 2, pin 2 being connected to ground as shown. Pin 7 is a positive supply connection designed to receive a voltage of 2 to 11 volts and is shown connected to power line 35 to receive the amplified DC voltage (+VPower). Such comparators are well known and are commercially available. For example, Linear Technology produces such a comparator with a part number LTC1540.

[0017] When Sensor Module 20, which preferably constitutes a Wheatstone Bridge-Based circuit, has a positive detection, one comparator 31 will swing high on signal 36 and the other comparator 32 will swing low on signal 37. Hysteresis connections at pin 5 are used to develop a "window" of detection/non-detection to prevent wild output swings during near-threshold conditions. Voltage is provided to Wheatstone Bridge-Based Sensor Module 20 either directly from voltage multiplier output on power line 35 or using the reference output at pin 6 of comparator 31 as shown in

Figure 3. It should be noted that a general Wheatstone Bridge based sensor module 20 is shown since any Wheatstone Bridge sensor may be used.

[0018] The next part to be discussed is Two Tone Oscillator/Modulator Module 40 shown in Figure 4. Micro-powered comparators U3, U4 of Two Tone Oscillator/Modulator Module 40 are preferably identical so only comparator U3 will be discussed in detail. Comparator U3 is preferably an ultra low power comparator with 5 pin connections and a "Push-Pull" output. Pin 1 produces an output voltage. Pin 2 is a negative supply. Pin 3 is a non-inverting comparator input. Pin 4 is an inverting comparator input. Pin 5 is a positive power supply. Such comparators are well known and are commercially available. For example, Texas Instruments produces such a comparator with a part number LPV7215.

[0019] Comparator U3 may be configured in many ways but is preferably configured as square wave generator by the placement of resistors R9, R12, R14, and R16 and capacitor C20. Micro-powered comparators U3, U4 of Two Tone Oscillator/Modulator Module 40 are powered from the output of comparators 31, 32 as discussed previously. Each comparator U3, U4 is configured as a free running, square-wave audio oscillator 41, 42, thus collectively forming a two tone generator, with component values for resistors R9, R10, R12-R17, and capacitors C20 and C22 chosen to provide two distinct audio frequencies. The outputs, of these oscillators 41, 42 are capacitively coupled to ground by capacitors C25 and C26 respectively and indirectly modulate incoming electromagnetic RF energy 12 by "loading down" Rectifier/Voltage Multiplier Module 10 through output 35, which causes a fluctuation in the amplitude of predetermined fundamental RF frequency fo applied to anti-parallel diode pair 54, resulting in an amplitude modulated third harmonic 3fo.

[0020] The last part to be discussed is RF Output Module 50 shown in Figure 5. To strengthen third harmonic 3fo, an anti-parallel diode pair 54 is used. Anti-parallel diode pair 54 is preferably similar to diode pairs D1-D4 and is also a pair of surface mount RF Schottky barrier diodes arranged in a package with three pin connections. Pins 1 and 2 are connected to communication line 53 while pin 3 is connected to a line leading to low pass filter 58 and high pass filter 56. High pass filter 56 is a conventional high pass filter that is commercially available. Mini Circuits produces such high pass filters with part numbers HFCN 650 and HFCN 1000 with different frequency cut off points. Similarly, low pass filter 58 is a conventional low pass filter that is commercially available. Mini Circuits produces such low pass filters with part numbers LFCN 490 and LFCN 1000 also with different frequency cut off values. The type of filter used is preferably chosen based on the fundamental RF frequency to be filtered out. Fundamental RF frequency fo applied to anti-parallel diode pair 54 produces strong third harmonic 3fo, which is routed, via high pass filter 56, to an external transmitting antenna 60. Fundamental fo and second 2fo harmonics are bypassed to ground via a low pass filter 58. Because of the loading effect on incoming electromagnetic RF energy 12 caused by engaging one of the square wave oscillators (41, 42), the fundamental RF power (amplitude) applied to anti-parallel diode pair 54 fluctuates at the same rate as the oscillation, i.e audio tone, of the engaged square wave oscillator (41, 42) resulting in amplitude modulated (AM) fundamental fo, AM second harmonic 2fo and subsequently AM third harmonic 3fo. Third harmonic 3fo is transmitted back to the receiver where the audio tones are recovered by demodulating third harmonic 3fo so that the state of detection platform 5 can be determined.

[0021] Although described with reference to preferred embodiments of the invention, it should be readily understood that various changes and/or modifications can be made to the invention without departing from the spirit thereof. For instance, the invention relates to a sensor platform that may be used in any remote environment, not just with shipping containers, such that the invention is applicable to a wide range of commercial applications.

CLAIMS

1. A sensor platform comprising:

a receiving antenna for receiving incoming electromagnetic RF energy;

a sensor module for detecting a sensed parameter;

a modulator module including first and second audio oscillators for producing first and second audio tones;

an output module in electrical communication with the receiving antenna, the sensor module and the modulator module, said output module being configured to produce an amplitude modulated signal incorporating the first and second audio tones; and

a transmitting antenna connected to the output module for transmitting the amplitude modulated signal whereby each audio tone indicates at least one of whether or not the receiving antenna is receiving the incoming electromagnetic RF energy and whether or not the sensor module is detecting the sensed parameter.

2. The sensor platform according to claim 1, wherein the first audio tone indicates that the receiving antenna is receiving the incoming electromagnetic RF energy and the sensor module is detecting the sensed parameter, and the second audio tone indicates that the receiving antenna is receiving the incoming electromagnetic RF energy and the sensor module is not detecting the sensed parameter.

3. The sensor platform according to claim 1, wherein the output module is configure to produce the amplitude modulated signal such that the amplitude modulated signal can be demodulated to reproduce the first and second audio tones to determine whether or not the receiving antenna is receiving the incoming electromagnetic RF energy and whether or not the sensor module is detecting the sensed parameter.

4. The sensor platform according to claim 1, wherein the receiving antenna is configured to receive the incoming electromagnetic RF energy at a predetermined frequency and the output module is configured to produce the amplitude modulated signal at a frequency equal to a third harmonic of the predetermined frequency.

5. The sensor platform according to claim 4, further comprising a rectifier module connected to the receiving antenna for rectifying and amplifying the incoming electromagnetic RF energy to generate an amplified DC voltage.

6. The sensor platform according to claim 5, wherein the first and second audio oscillators are configured to load down the rectifier module to cause the rectifier module to cause a fluctuation in the incoming electromagnetic RF energy and wherein the output module is configured to produce the amplitude modulated signal based on the fluctuation.

7. The sensor platform according to claim 5, wherein the sensor module is powered by the amplified DC voltage and is configured to produce an output based on the sensed parameter.

8. The sensor platform according to claim 7, further comprising a comparator module powered by the amplified DC voltage for producing first and second signals from the output of the sensor module and wherein the first and second audio tones are produced based on the first and second signals respectively.

9. The sensor platform according to claim 8, wherein the output module includes:

a non-linear junction detector configured to receive the fluctuation and create, from the fluctuation, the amplitude modulated signal having the predetermined frequency, a second harmonic of the predetermined frequency, the third harmonic of the predetermined frequency, and higher harmonics of the predetermined frequency;

a low pass filter for filtering out the predetermined frequency and the second harmonic; and

a high pass filter for filtering out the higher harmonics.

10. The sensor platform according to claim 1 wherein the sensor platform is in a shipping container, the sensor module includes a Wheatstone-Bridge type sensor and the sensed parameter is a temperature within the shipping container.

11. A method for detecting a sensed parameter with a sensor platform including a receiving antenna, a sensor module, a first audio oscillator, and a second audio oscillator, said method comprising comprising:

receiving incoming electromagnetic RF energy with the receiving antenna;

detecting a sensed parameter with the sensor module;

producing first and second audio tones with the first and second audio oscillators;

producing an amplitude modulated signal incorporating the first and second audio tones; and

transmitting the amplitude modulated signal thereby indicating, with each audio tone, at least one of whether or not the receiving antenna is receiving the incoming electromagnetic RF energy and whether or not the sensor module is detecting the sensed parameter.

12. The method according to claim 11, further comprising indicating with the first audio tone that the receiving antenna is receiving the incoming electromagnetic RF energy and the sensor module is detecting the sensed parameter, and indicating with the second audio tone that the receiving antenna is receiving the incoming electromagnetic RF energy and the sensor module is not detecting the sensed parameter.

13. The method according to claim 11, wherein receiving the incoming electromagnetic RF energy occurs with the electromagnetic RF energy at a predetermined frequency and producing the amplitude modulated signal occurs at a frequency equal to a third harmonic of the predetermined frequency.

14. The method according to claim 13, further comprising demodulating the amplitude modulated signal to reproduce the first and second audio tones to determine whether or not the receiving antenna is receiving the incoming

electromagnetic RF energy and whether or not the sensor module is detecting the sensed parameter.

15. The method according to claim 13, further comprising rectifying and amplifying the incoming electromagnetic RF energy with a rectifier module to generate an amplified DC voltage.

16. The method according to claim 15, further comprising loading down the rectifier module with the first and second audio oscillators to cause a fluctuation in the incoming electromagnetic RF energy, and generating the amplitude modulated signal based on the fluctuation.

17. The method according to claim 15, further comprising powering the sensor module with the amplified DC voltage and producing an output with the sensor module based on the sensed parameter.

18. The method according to claim 17, further comprising producing first and second signals with a comparator module from the output of the sensor module, wherein producing the first and second audio tones is based on the first and second signals respectively.

19. The method according to claim 18, wherein producing the amplitude modulated signal at the third harmonic includes:

creating an amplitude modulated signal having the predetermined frequency, a second harmonic of the predetermined frequency, the third harmonic of the predetermined frequency, and higher harmonics of the predetermined frequency;

filtering out the predetermined frequency and the second harmonic with a low pass filter; and

filtering out the higher harmonics with a high pass filter.

20. The method according to claim 11, further comprising sensing a temperature of a shipping container, within which the sensor platform is located, with the sensor module.

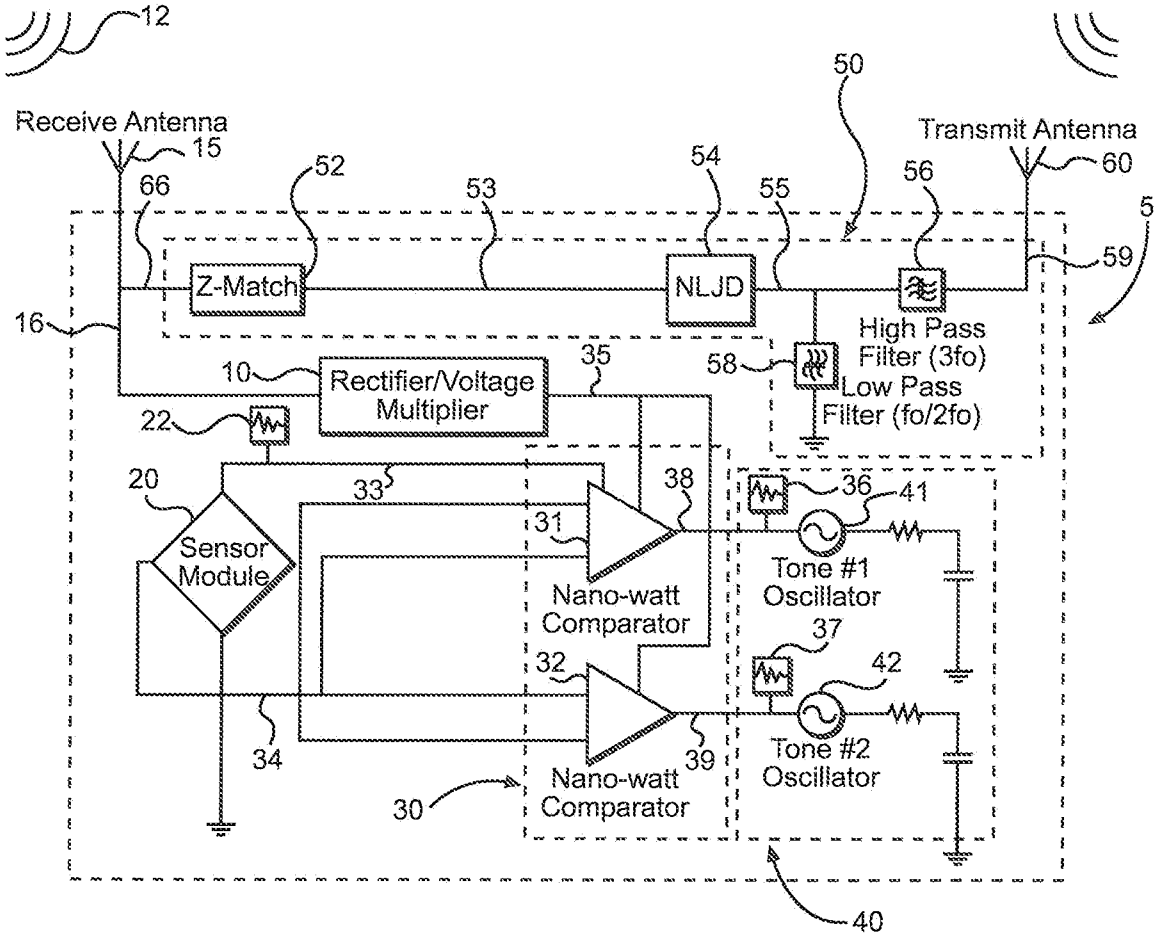

12
Receive Antenna
15
66
52
53
54
55
50
56
Transmit Antenna
60
5
59
Z-Match
NLJD
16
High Pass
Filter (3fo)
58
Low Pass
Filter (fo/2fo)
35
10
Rectifier/Voltage
Multiplier
22
20
33
38
36
41
31
Sensor
Module
Nano-watt
Comparator
Tone #1
Oscillator
37
32
42
34
39
Tone #2
Oscillator
30
Nano-watt
Comparator
40

FIG. 1

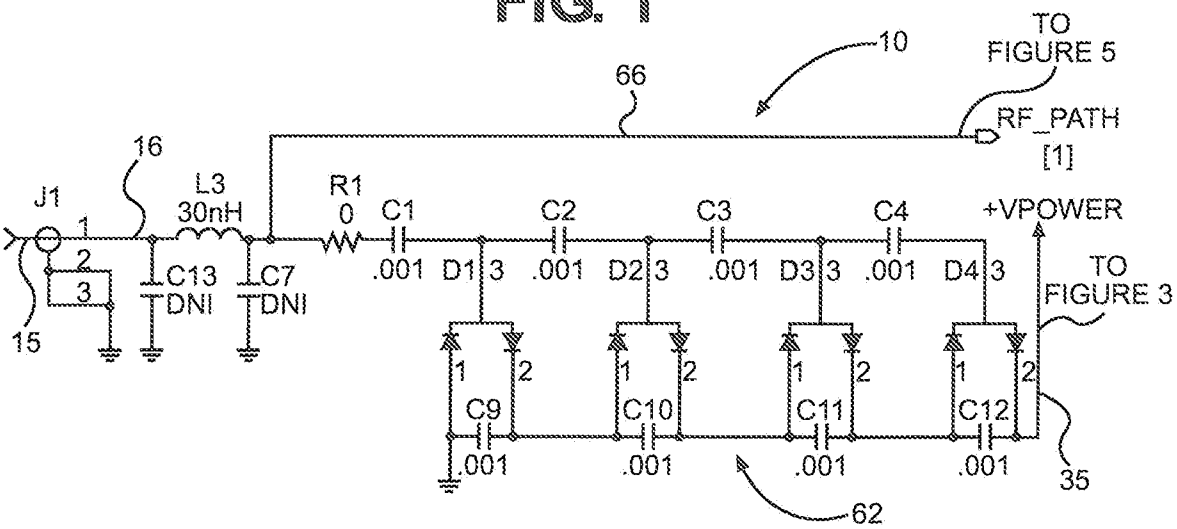

10
TO
FIGURE 5
66
RF_PATH
[1]
16
J1
L3
30nH
R1
0
C1
C2
C3
C4
+VPOWER
1
2
3
15
C13
DNI
C7
DNI
.001
D1
D2
D3
D4
TO
FIGURE 3
C9
C10
C11
C12
35
62

FIG. 2

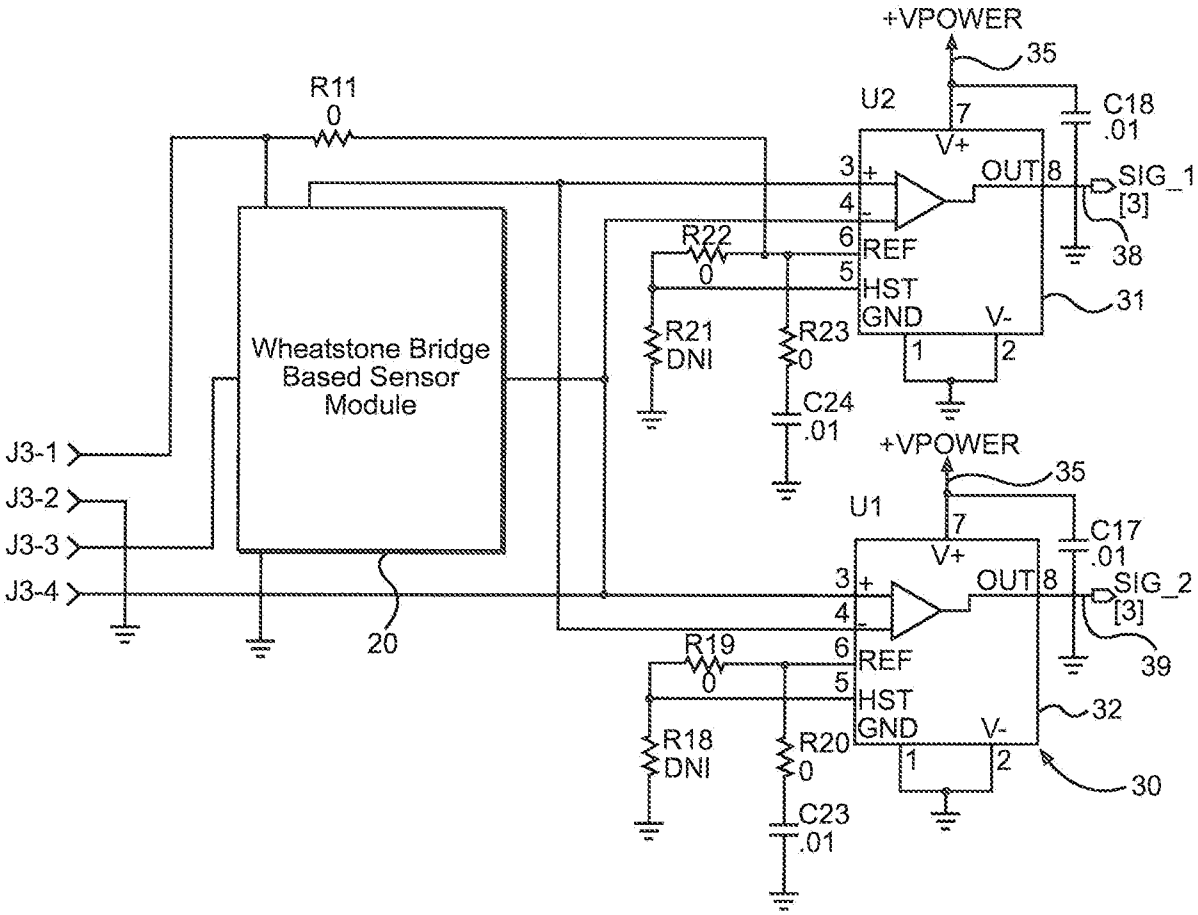

+VPOWER
35
R11
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U2
7
V+
C18
.01
3
+
OUT
8
SIG_1
[3]
4
-
R22
0
6
REF
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HST
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V-
31
R21
DNI
R23
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1
2
C24
.01
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Based Sensor
Module
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J3-2
J3-3
J3-4
+VPOWER
35
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7
V+
C17
.01
3
+
OUT
8
SIG_2
[3]
4
-
20
R19
0
6
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39
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HST
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V-
32
R18
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1
2
30
C23
.01

FIG. 3

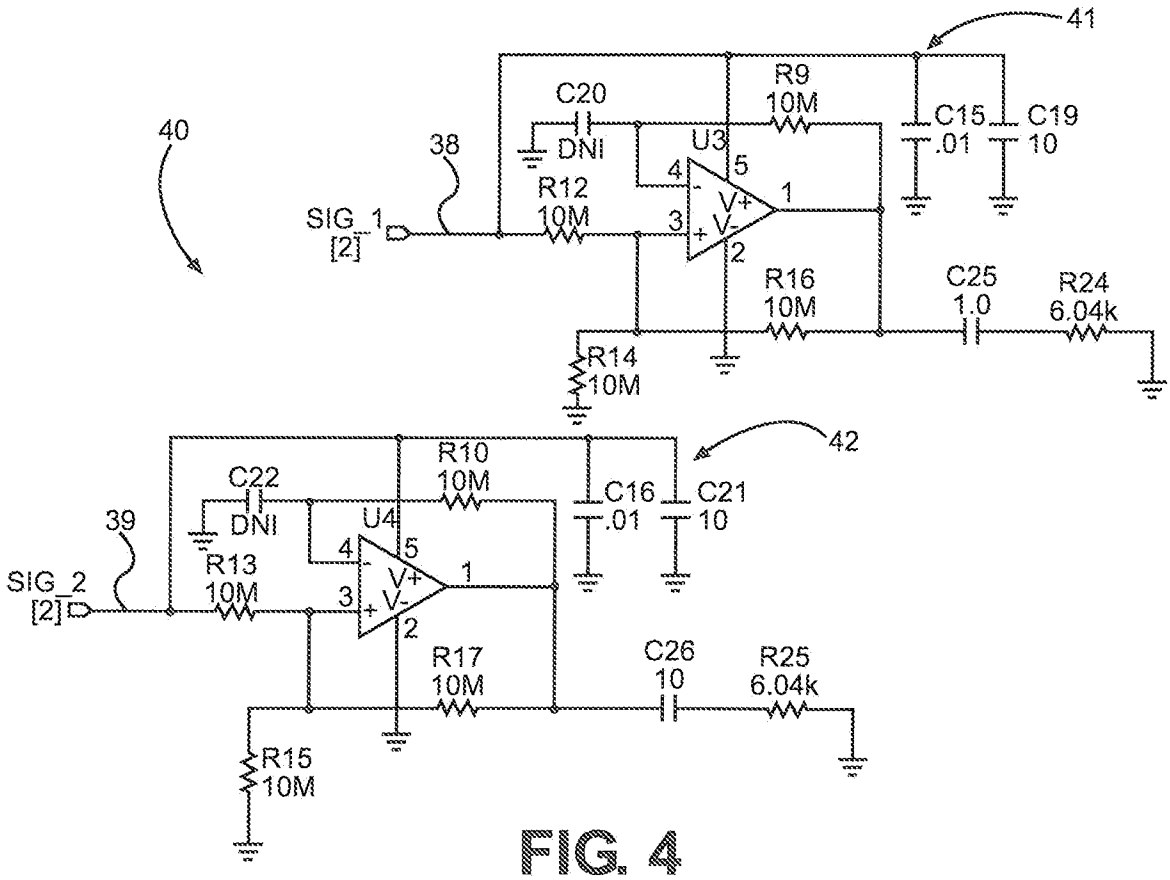

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U3
R9
10M
C15
.01
C19
10
R16
10M
C25
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R24
6.04k
R14
10M
42
39
SIG_2
[2]
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R13
10M
U4
R10
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C21
10
R17
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C26
10
R25
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R15
10M

FIG. 4

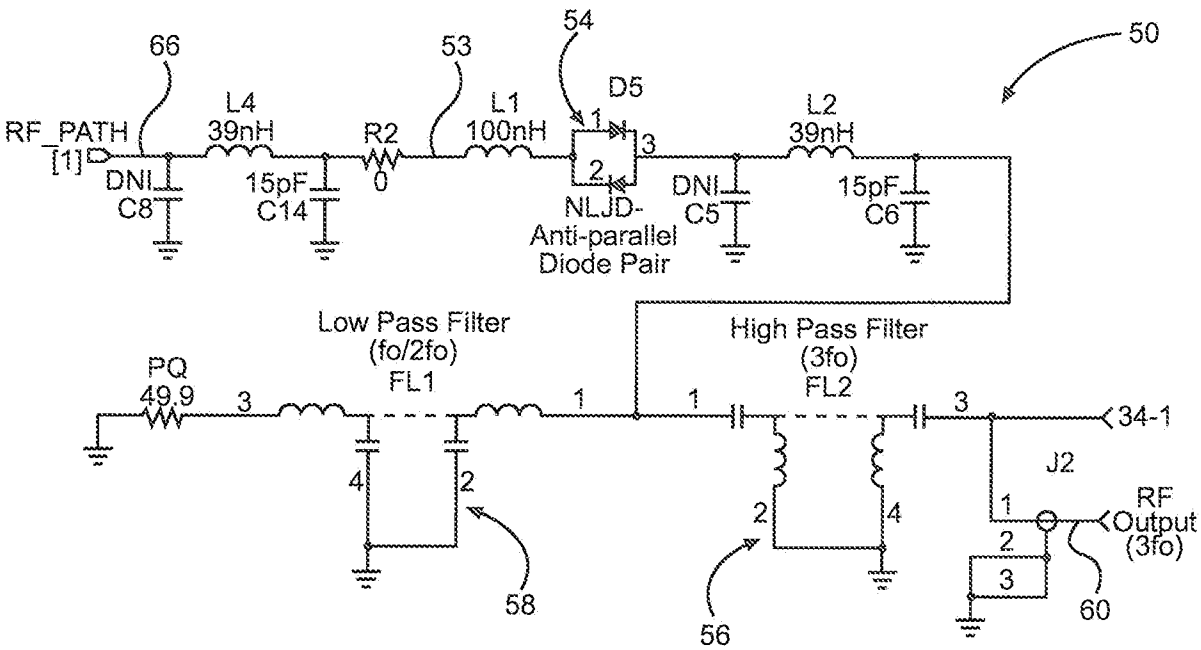

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C8
L4
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15pF
C14
R2
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53
L1
100nH
54
D5
NLJD-
Anti-parallel
Diode Pair
DNI
C5
L2
39nH
15pF
C6
Low Pass Filter
(fo/2fo)
FL1
High Pass Filter
(3fo)
FL2
PQ
49.9
34-1
J2
RF
Output
(3fo)
58
56
60

FIG. 5

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2013/037162

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

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)
EPO-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	US 2004/008112 A1 (CARRENDER CURT [US]) 15 January 2004 (2004-01-15) paragraph [0014] - paragraph [0032]; figure 3	1-20
A	US 3 961 323 A (HARTKORN ALBERT W) 1 June 1976 (1976-06-01) the whole document	1-20
A	WO 87/00665 A1 (GERHART ROLAND T; HILL J CARROLL) 29 January 1987 (1987-01-29) the whole document	1-20

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INTERNATIONAL SEARCH REPORT

Information on patent family members

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