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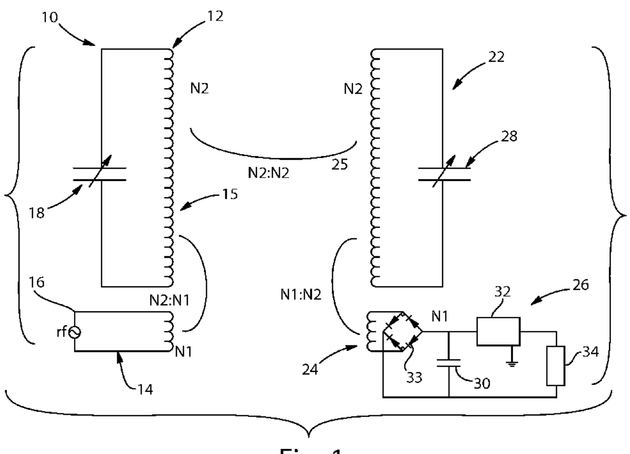

Fig. 1

(57) Abstract: A system for wireless energy transfer includes a circuit for wireless transmission of energy, including a first, tunable resonator circuit including a transmitter coil and a variable capacitance device connected in shunt across the transmitter coil. Also disclosed is a circuit for wireless reception of energy including a tunable second resonator circuit including a receiver coil inductively coupled to the transmitter coil and a variable capacitance device connected in shunt across the receiver coil. Also disclosed is an arrangement for wireless energy transmission and reception that foregoes the necessity for separate circuits for DC rectification at the reception end of the arrangement. Also disclosed a system for wireless energy transfer where the system includes a tunable resonator circuit embedded in a surface such as piece of furniture, counter, etc., *e.g.*, a table.

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WIRELESS POWER TRANSFER USING SEPARATELY TUNABLE RESONATORS

BACKGROUND

This invention relates to wireless power transfer and in particular to techniques that can be adapted for charging of batteries and the like.

Wireless power transfer is known for over 100 years. With the boom of portable electronic devices in the last decade the interest in wireless power transfer for battery charging is growing rapidly.

SUMMARY

To increase wireless power transfer system operating range, a high-Q factor system using self-resonating coils can be used. The problem with self-resonating coils is the difficulty to tune the two coils to the RF source frequency and between one another (this is done by changing the number of windings and distance between the windings and not suitable for automatic feedback control).

For practical applications such as for use in charging household appliance applications, typical short range inductive chargers are limited to several centimeters or even millimeters. High-Q factor resonant systems partially offset the rapid decay of received power vs. distance between transmitter (transmitter) and receiver (receiver), at the cost of high operating voltages across the resonant coils, as the receiver coil voltage swings up wildly when the receiver device is moved closer to the transmitter. High-Q systems have to rectify and regulate voltages in the order of hundreds and even thousands of volts. This can pose a problem for typical low-voltage operated electronic devices operating in this type of environment. High input voltage regulators exist, although they are less efficient, bulky and costly.

Inductive, e.g., battery chargers typically operate over a short spatial range, typically limited to several centimeters or even millimeters. High-Q resonant systems partially offset the rapid decay of received power vs. distance between transmitter (transmitter) and receiver (receiver). While a better Q-factor can occur in the megahertz range, e.g. 5 to 27 MHz, the performance of a typical rectifier circuit in such a range is limited by the maximum operating frequency of semiconductor devices. A conventional rectifier design may not perform satisfactorily at these high frequencies of operation. At such a high frequency, the output voltage waveform of a conventional rectifier may include ringing transients, due to parasitic inductance and capacitance resonances. These transients cause rectification efficiency losses and output signal noise. Moreover, input impedance characteristics of rectifiers change as a function of frequency and load. To reduce the impact, series resonant converters are used to regulate by varying the switching frequency and counteract the reactive impedance variations.

According to an aspect, a circuit includes a resonator circuit for wireless reception of energy, including a receiver coil having a large number of windings N1 and a variable capacitance device connect in shunt across the receiver coil with the receiver coil and the variable capacitor and intrinsic capacitance of the receiver coil forming the resonator circuit and an output coil with a low number of windings N2 compared to the number of windings N1 of the receiver coil, the output coil being inductively coupled to the receiver coil to provide power output from the circuit, with the resonator circuit having a resonant frequency in a range of about 100 kHz to 30 MHz.

The following are embodiments.

The resonator circuit is tuned by the variable capacitance device to a resonant frequency within the range of 100 kHz to 30 MHz. The resonator circuit oscillates at high voltage and produces a strong magnetic field that is coupled to the secondary coil. Inductive coupling of the two coils produces an output voltage at the output coil related to $V_{L(coil)} = V_{in}*Q*N2/N1$. The circuit further includes circuitry to convert an AC voltage across the output coil to a DC voltage. The circuit further includes circuitry to convert an AC voltage across the output coil to a DC voltage, the circuitry including a capacitor connected in shunt across the secondary coil and a DC/DC converter or battery charger coupled to the capacitor. The circuit further includes a rectifier circuit connected to the output coil to convert AC voltage across the output coil to a DC voltage, the circuitry further including a capacitor connected in shunt across the secondary coil and a DC/DC converter coupled in series with the capacitor.

According to an additional aspect, a circuit includes a resonator circuit for wireless transmission of energy, the circuit including a transmitter coil having a large number of windings N1, a variable capacitance device connected in shunt across the transmitter coil with the transmitter coil and the variable capacitor and intrinsic capacitance of the transmitter coil forming the resonator circuit, and an input coil configured to be coupled to an input RF source, with the input coil having a low number of windings N2 compared to the number of windings N1 of the transmitter coil, and the input coil being inductively coupled to the transmitter coil to provide power output from the circuit with the resonator circuit having a resonant frequency in a range of about 100 kHz to 30 MHz.

The following are embodiments.

The resonator circuit is tuned by the variable capacitance device. The resonator circuit oscillates at high voltage and produces a strong magnetic field at the transmitter coil. The circuit further includes an RF source connected to the input coil. Inductive coupling of the transmitter and input coils produces an output voltage at the transmitter coil related to $V_{L(coil)} = V_{in}*Q*N1/N2$ where V_{in} is related to the voltage of the RF source connected to the input coil.

According to an additional aspect, a system for wireless energy transfer includes a circuit for wireless transmission of energy, the circuit including a first resonator circuit including a transmitter coil having a large number of windings N1, a variable capacitance device connected in shunt across the transmitter coil with the transmitter coil and the variable capacitor and intrinsic capacitance of the transmitter coil forming the resonator circuit, an input coil configured to be connected to an input RF source, with the input coil having a low number of windings N2 compared to the number of windings N1 of the transmitter coil, and the input coil being inductively coupled to the transmitter coil to provide power output from the resonator circuit at a resonant frequency in a range of about 100 kHz to 30 MHz, a circuit for wireless reception of energy, the circuit includes a second resonator circuit includes a receiver coil inductively coupled to the transmitter coil, the receiver coil having a large number of windings N3, a variable capacitance device connected in shunt across the receiver coil with the receiver coil and the variable capacitor and intrinsic capacitance of the receiver coil forming the second resonator circuit, an output coil with a low number of windings N2 compared to the number of windings N1 of the receiver coil, the output coil being inductively coupled to the receiver coil to provide power output from the circuit, with the resonator circuit having a resonant frequency in a range of about 100 kHz to 30 MHz.

The following are embodiments.

The second resonator circuit is tuned by the variable capacitance device to a resonant frequency within the range of 100 kHz to 30 MHz. The circuit further includes circuitry to convert an AC voltage across the output coil to a DC voltage.

According to an additional aspect, a system for wireless energy transfer includes a circuit for wireless transmission of energy, configured to be fed by an RF source the circuit for wireless transmission including a first resonator circuit, a circuit for wireless reception of energy, from the first resonator circuit, the circuit for wireless reception including a second resonator circuit, and a circuit disposed between the circuit for wireless transmission of energy and the circuit for wireless reception of energy to inductively couple with the first and second resonator circuits to effectively produce a rectified voltage having a DC component at the circuit for wireless reception of energy.

The following are embodiments.

The circuit to inductively couple includes a tunable passive resonator disposed between the first and second resonator circuits, the tunable passive resonator including a coil having a large number of windings N1, a variable capacitance device connected in shunt across the coil with the coil and the variable capacitor and intrinsic capacitance of the coil forming the tunable resonator circuit, with the first and second resonator circuits in combination with the passive tunable resonator circuit providing at an output of the second resonator circuit a voltage having a DC component. The circuit to inductively couple includes a magnetic field transmitter operating at the first harmonic or higher harmonic of the base transmitter frequency. The first resonator further includes a transmitter coil having a large number of windings N1, a variable capacitance device connected in shunt across the transmitter coil with the transmitter coil and the variable capacitor and intrinsic capacitance of the transmitter coil forming the resonator circuit, an input coil configured to be coupled to an input RF source, with the input coil having a low number of windings N2 compared to the number of windings N1 of the transmitter coil, and the input coil being inductively coupled to the transmitter coil to provide power output from the resonator circuit at a resonant frequency in a range of about 100 kHz to 30 MHz. The second resonator further includes a receiver coil inductively coupled to the transmitter coil, the receiver coil having a large number of windings N3, a variable capacitance device connected in shunt across the receiver coil with the receiver coil and the variable capacitor and intrinsic capacitance of the receiver coil forming the second resonator circuit, an output coil with a low number of windings N2 compared to the number of windings N1 of the receiver coil, the output coil being inductively coupled to the receiver coil to provide power output from the circuit, with the resonator circuit having a resonant frequency in a range of about 100 kHz to 30 MHz

According to an additional aspect, a system for wireless energy transfer includes a table, a circuit embedded in the table for wireless transmission of energy, the circuit includes a first resonator circuit including a transmitter conductor and a variable capacitance device connected in shunt across the transmitter conductor with the transmitter coil and the variable capacitor and intrinsic capacitance of the transmitter coil forming the resonator circuit.

The following are embodiments. The transmitter conductor is coupled to an input RF source to provide power output from the resonator circuit at a resonant frequency in a range of about 100 kHz to 30 MHz.

The details of one or more embodiments of the invention are set forth in the accompanying drawings and the description below. Other features, objects, and advantages of the invention will be apparent from the description and drawings, and from the claims.

DESCRIPTION OF DRAWINGS

FIG. 1 is a schematic of an inductive power link employing separately tunable transmitter/receiver coils.

FIG. 2 is a perspective view of an embodiment of a self-shielding coil pair.

FIG. 3 is a schematic of an inductive power link employing separately tunable transmitter/receiver coils and an intermediate passive resonator.

FIGS. 4A and 4B are diagrammatical illustrations of an effect that can be produced by the arrangement of FIG. 3.

FIG. 5 is diagram of a charging arrangement.

DETAILED DESCRIPTION

Referring now to FIG. 1 a wireless energy transfer arrangement 10 including a transmitter 11 and receiver 21 is shown. The transmitter 11 and receiver 21 include respective ones of tunable resonators 12, 22, respectively, for transmission and reception of wireless power. These tunable resonators 12, 22 are electrically isolated from driver electronics 16 on the transmitter side 11 and from receiver electronics 26, e.g., a rectifier circuit 32 and step-down DC/DC 34 converter on the receiver side 21.

The tunable transmitter resonator 12 includes a coil 15 (a transmitter coil) having a high number of windings N2 and a coil 14 (input coil) with a relatively low number of windings N1 where N2 is about 10 to 1000 times greater than N1. The tunable transmitter resonator 12 also includes a variable capacitance element (variable capacitor) 18 coupled in shunt across the coil 15. The variable capacitance element 18 allows the resonator 12 to be tuned, via an electrically isolated LC circuit (coil 15 and capacitor 18). The coil 15 having the relatively large number of windings N2 compared to coil 14 having windings N1. The tunable transmitter resonator 12 is fed via the input coil 14. The input coil 14 is fed an RF signal from RF source 16.

Typical bandwidth ranges, voltage ranges and power ranges are:

frequency range: 100 kHz to 30 MHz;

voltage range: 5V to 48V;

power range: 1 mW to 100W

Other ranges and sub-ranges within the above ranges, such as 5 to 27 MHz are possible.

The ratio of windings N2/N1 permits a relatively low voltage at the input coil 14 to transfer electrical energy by inductively coupling to the transmitter coil 15 and produce a very high magnetic field at transmitter coil 15. This high magnetic field inductively couples to the receiver resonator 22, as will be discussed shortly. The tunable transmitter 12 thus has a resonant structure operating at a high-voltage, producing a strong magnetic field.

A resonator is provided by use of air-core coils with an air-gap variable capacitor and variable tuning. Other configurations are possible depending on the desired properties including the bandwidth, voltage and power requirements for the tunable transmitter resonator 12. The tunable receiver resonator 22 includes a coil 25 (receiver coil) having a high number of windings N2 and a coil 24 (output coil) having a relatively low number of windings N1, where N2 is about 10 to 1000 times greater than N1. The tunable receiver resonator 22 also includes a variable capacitance element (variable capacitor) 28 coupled in shunt across the coil 25. The variable capacitance element 28 allows the resonator 22 to be tuned, via an electrically isolated LC circuit (coil 25 and capacitor 28). The coil 25 having the relatively large number of windings N2 compared to coil 24 having windings N1 permits the receiver resonator (coil 26 and capacitor 28) to efficiently couple via inductive coupling for coil 25 into the relatively high magnetic field produced by the transmitter resonator 12, producing a relatively high voltage at the coil 25. The coil 25 is inductively coupled to the coil 24.

In some embodiments, the coil 24 is magnetically shielded from the coil 15 so as not to allow significant inductive coupling between coil 15 in the transmitter and coil 24 in the receiver. Such magnetic shielding could be accomplished in various ways including placing the secondary coil within a region defined by and confined by the primary coil 25 on the receiver 21. One such arrangement to magnetically shield the coil 24 in the receiver is illustrated in FIG. 2.

Referring now to FIG. 2 a structure 40 carrying two coils that can be used as part of the tunable resonators 12, 22 (FIG. 1) is shown. The structure 40 includes a band 42 or a disc having a first coil (illustratively 25 in FIG. 1) comprised of N2 windings of a continuous, electrically isolated conductor 44 disposed on an outer surface 42a of the band 42. The structure 40 also includes a second coil (illustratively 24 in FIG. 1) comprised of N1 windings (where N2>>N1) of a continuous, electrically isolated conductor 46 disposed on an inner surface 42b of the band 42. This structure 40 permits, e.g., tunable resonator 22 (FIG. 1) having the first coil 25 disposed on the outer surface 42a of the band 42 to at least partially shield the second coil 24 from a field produced by other coils that might couple to the structure 40, such as coil 15 from tunable resonators 12 (FIG. 1) while permitting such a field to couple to coil 25 of the structure 40.

The tunable receiver resonator 22 receives energy via inductive coupling from the tunable transmitter resonator 12 and the tunable receiver resonator 22 inductively couples that energy to the coil 24. An output voltage at the coil proportional to the ratio N1/N2 is produced. This voltage is much lower than the voltage induced across coil 25 from tunable resonator 12. This lower AC voltage at the coil 24 is rectified by a full wave rectifier 33 to produce a DC voltage. The capacitor 30 smoothes/filters this DC voltage and the DC/DC converter 32, converts the DC voltage to a desired value according to input voltage requirements of a subsequent device such as a load 34. As the load 34 draws current from the DC/DC converter circuit 32, the voltage at the output of the coil 25 does not drop, but causes the DC/DC converter to increase current drawn through the coil 25. The separately tunable resonators for both transmission and reception increase the operating range of the arrangement and improve the manufacturability of the arrangement in comparison to self-resonator coils that rely in intrinsic coil capacitance. The inclusion of a variable capacitor permits precise tuning and thus selection of the resonant frequency of the resonator. The inclusion of the secondary coils 14, 24 for transmission and reception respectively, reduces the voltage requirement at the RF source 16, as well as the voltage requirements of the processing circuits, e.g., capacitor 30, rectifier 33 and DC/DC converter 32 at the receiver.

Because the power output is connected to the coil 24 having a low number of windings N2, the ratio between output voltage and resonator voltage is controlled by the ratio of the number of windings of the two coils, as:

$$VL_{(coil)} = Vin * Q * N2/N1$$

Where Q is the quality factor of the resonator and N2 and N1 are respectively the number of windings for the coils 25 and 24. For example, if Q=10, N1=100 and N2=10, the coil voltage will be the same as the input voltage, convenient to rectify and regulate. Another advantage of this arrangement is the ability to tune transmitter and receiver resonators 12, 22 separately to the oscillator/driver RF power source frequency rather than tuning the source to the resonator. This can enable tuning multiple receivers separately while powered by a single transmitter. Tuning can be performed manually with a variable capacitor, or automatically using a voltage-controlled capacitor, such as reverse-biased semiconductor junction.

In an example, tunable AM-radio antenna resonators usable in a range of 550 kHz to 1600 kHz are used for the coil arrangement of Fig. 1. The transmitter coil is powered by an RF oscillator set at 1MHz sinusoidal signal via 10W Power Amplifier driver. The receiver coil can be displaced, e.g., 24" away. The two resonators are tuned to the oscillator frequency and feature Q-factors of 10 each.

Referring now to FIG. 3, an alternative enhancement uses a tunable passive resonator 62 comprising coil 64 and variable capacitor 68 with the resonator 62 disposed between the transmitter 11 of FIG. 1, and a receiver 21' similar to that of receiver 21 of FIG. 1 without the rectifier circuit. Here the tunable passive resonator 62 boosts received power and range by tuning the passive resonator 62 around the resonant frequency and providing phase control to bias a waveform on the receiver 11' side to effectively rectify the RF signal coupled to the receiver 11'. The tunable passive resonator 62 enables resonant wireless power transfer systems to operate in the high radio frequency range and provide AC to DC power conversion without a rectifier circuit. The technique is applicable to alternating current to direct current conversion, as well as RF to DC (radio frequency to direct current) conversion using resonant circuits for transmission, conditioning and reception of wireless power.

The resonator 62 is a LC tank circuit with resonant frequency f, driven by rectangular pulse oscillator and a power switch or amplifier. A passive LC repeater is tuned to the first harmonic 2f of the resonant frequency f. The two frequencies are mixed in the receiver to produce an essentially asymmetrical DC component in the output without a rectifier circuit. DC power is produced from AC source by mixing the two signals f and 2f to produce a signal having a sum output voltage along with a DC component. The two voltages with different frequency can be produced from the same AC or RF power source, using the base frequency f and the first harmonic 2f.

By controlling the phase shift between the two voltages, a higher amplitude positive or negative DC component can be produced at the output. Signals at the two frequencies are mixed at the power source or transmitted separately and mixed at the receiver. By using resonant circuits for transmitter and receiver, amplification of the output voltage can be achieved. That is, by mixing the two sinusoidal waveforms, f and 2f (as illustrated in FIGS. 4A, 4B) an asymmetrical waveform with a DC component is produced. For example, mixing a frequency f with the first harmonic 2f with equal amplitudes can produce a sum with positive (FIG. 4A) or negative (FIG. 4B) high-amplitude, half-waves, depending on the phase shift between the two voltages. For instance, in FIG. 4A, a 270° phase shift between the two source voltages results in positive peaks 69a whereas in FIG. 4B a 90° phase shift between the two source voltages results in negative peaks 69b. Either the preponderance of the positive or negative peaks 69a, 69b can be used to directly charge a battery without the user of traditional rectifier and filter circuitry.

Referring now to FIG. 5, in a practical application, a single-wire transmitter conductor 70 forms a loop disposed about a periphery of a structure such as a table 72, as shown. The transmitter inductor 70 (corresponding to coil 15 in FIG. 1) is coupled in parallel with a tuning capacitor 74 (corresponding to capacitor 18 in FIG. 1) at two ends of the conductor. The receiver can be positioned within the area enclosed by the conductor 72 and about 1 m up or down from the surface of the table 72. Such a single wire loop is fed via an RF source, (not shown) as discussed above, and could deliver power over a relatively large area providing sufficient power for charging of low-rate intermittent-usage devices 78, such as household care appliances, e.g., cell phones, electric shavers, electric toothbrushes, etc. or other appliances with low average charging rate.

This arrangement permits RF transmission that can charge multiple devices (and the emissions can be under acceptable limits, such as those established by for example the International Commission on Non-Ionizing Radiation Protection). With this arrangement, e.g., around 100 mW each (typically 30 mW needed) could be received by multiple devices over several cubic meters of space and resonant repeaters enhance power for small devices. In this arrangement the loop around the table provides a large surface area where devices having tunable receiver resonators (22 or 22') can be positioned freely.

A number of embodiments of the invention have been described. Nevertheless, it will be understood that various modifications may be made without departing from the spirit and scope of the invention. For example, instead of the passive resonator a magnetic field transmitter operating at the first harmonic or higher harmonic of the base transmitter frequency can be used to provide effective rectification, as discussed above. Accordingly, other embodiments are within the scope of the following claims.

CLAIMS

What is claimed :

1. A circuit comprising:

a resonator circuit for wireless reception of energy, comprising:

a receiver coil having a large number of windings N1;

a variable capacitance device connect in shunt across the receiver coil with the receiver coil and the variable capacitor and intrinsic capacitance of the receiver coil forming the resonator circuit;

an output coil with a low number of windings N2 compared to the number of windings N1 of the receiver coil, the output coil being inductively coupled to the receiver coil to provide power output from the circuit, with the resonator circuit having a resonant frequency in a range of about 100 kHz to 30 MHz.

2. The circuit of claim 1 wherein the resonator circuit is tuned by the variable capacitance device to a resonant frequency within the range of 100 kHz to 30 MHz.

3. The circuit of claim 1 or claim 2 wherein the resonator circuit oscillates at high voltage and produces a strong magnetic field that is coupled to the secondary coil.

4. The circuit of any one of the preceding claims wherein inductive coupling of the two coils produces an output voltage at the output coil related to $V_{L(coil)} = V_{in}*Q*N2/N1$.

5. The circuit of any one of the preceding claims further comprising:

circuitry to convert an AC voltage across the output coil to a DC voltage.

6. The circuit of any one of the preceding claims further comprising:

circuitry to convert an AC voltage across the output coil to a DC voltage, the circuitry comprising:

a capacitor connected in shunt across the secondary coil; and

a DC/DC converter or battery charger coupled to the capacitor.

7. The circuit of any one of the preceding claims further comprising:

a rectifier circuit connected to the output coil to convert AC voltage across the output coil to a DC voltage, the circuitry further comprising:

a capacitor connected in shunt across the secondary coil; and

a DC/DC converter coupled with the capacitor.

8. A circuit comprising:

a resonator circuit for wireless transmission of energy, the circuit comprising:

a transmitter coil having a large number of windings N1;

a variable capacitance device connected in shunt across the transmitter coil with the transmitter coil and the variable capacitor and intrinsic capacitance of the transmitter coil forming the resonator circuit;

an input coil configured to be coupled to an input RF source, with the input coil having a low number of windings N2 compared to the number of windings N1 of the transmitter coil, and the input coil being inductively coupled to the transmitter coil to provide power output from the circuit with the resonator circuit having a resonant frequency in a range of about 100 kHz to 30 MHz.

9. The circuit of claim 8 wherein the resonator circuit is tuned by the variable capacitance device.

10. The circuit of claim 8 or claim 9 wherein the resonator circuit oscillates at high voltage and produces a strong magnetic field at the transmitter coil.

11. The circuit of any one of claims 8-10 further comprising an RF source connected to the input coil.

12. The circuit of any one of claims 8-11 wherein inductive coupling of the transmitter and input coils produces an output voltage at the transmitter coil related to

$V_{L(coil)} = V_{in}*Q*N1/N2$ where V_{in} is related to the voltage of the RF source connected to the input coil.

13. A system for wireless energy transfer, the system comprises:

a circuit for wireless transmission of energy, the circuit comprises:

a first resonator circuit comprising:

a transmitter coil having a large number of windings N1;

a variable capacitance device connected in shunt across the transmitter coil with the transmitter coil and the variable capacitor and intrinsic capacitance of the transmitter coil forming the resonator circuit;

an input coil configured to be connected to an input RF source, with the input coil having a low number of windings N2 compared to the number of windings N1 of the transmitter coil, and the input coil being inductively coupled to the transmitter coil to provide power output from the resonator circuit at a resonant frequency in a range of about 100 kHz to 30 MHz;

a circuit for wireless reception of energy, the circuit comprises:

a second resonator circuit comprising:

a receiver coil inductively coupled to the transmitter coil, the receiver coil having a large number of windings N3;

a variable capacitance device connected in shunt across the receiver coil with the receiver coil and the variable capacitor and intrinsic capacitance of the receiver coil forming the second resonator circuit;

an output coil with a low number of windings N2 compared to the number of windings N1 of the receiver coil, the output coil being inductively coupled to the receiver coil to provide power output from the circuit, with the resonator circuit having a resonant frequency in a range of about 100 kHz to 30 MHz.

14. The system of claim 13 wherein the second resonator circuit is tuned by the variable capacitance device to a resonant frequency within the range of 100 kHz to 30 MHz.

15. The system of claim 13 or claim 14further comprising:
circuitry to convert an AC voltage across the output coil to a DC voltage.

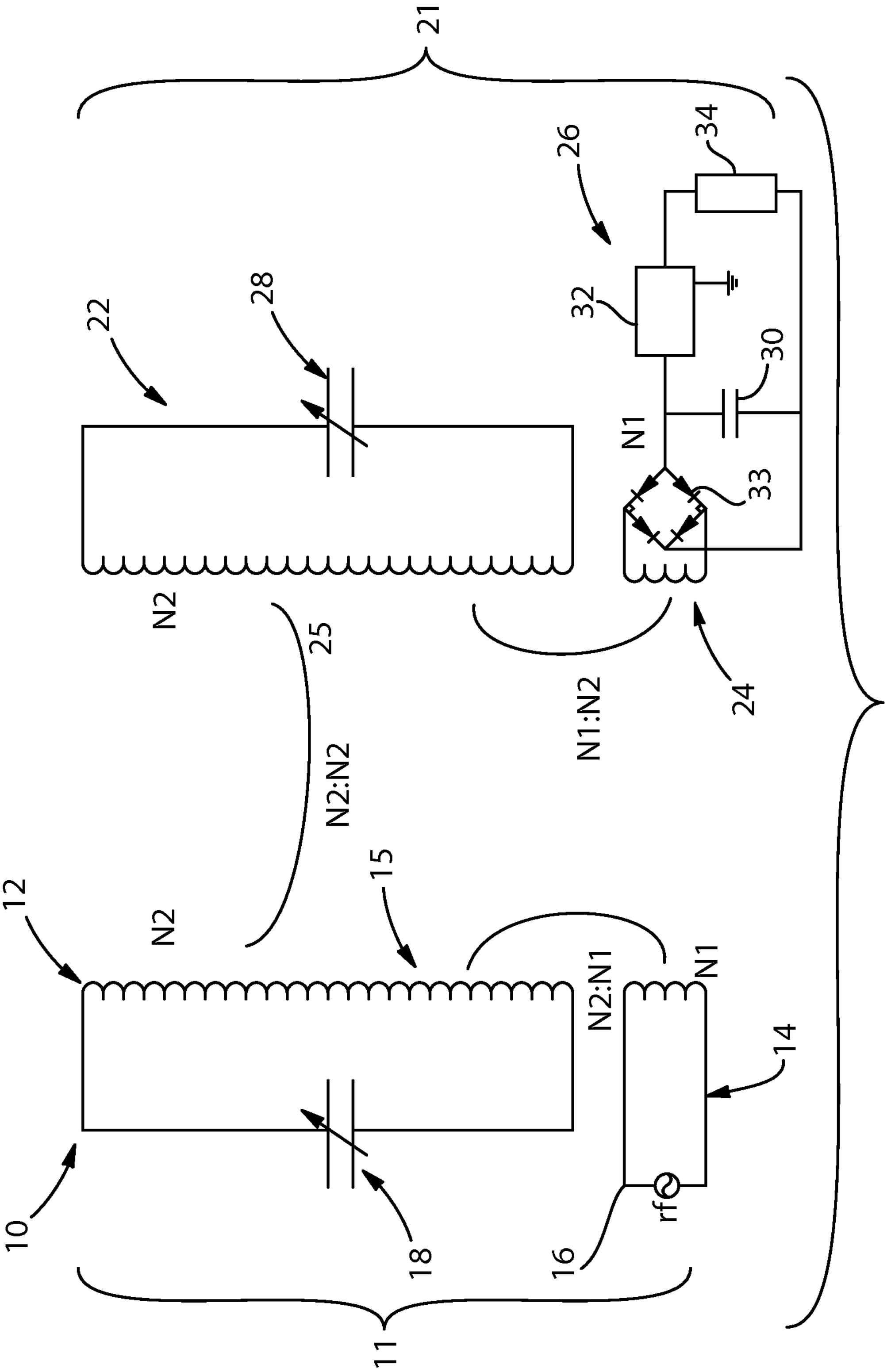
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Fig. 1

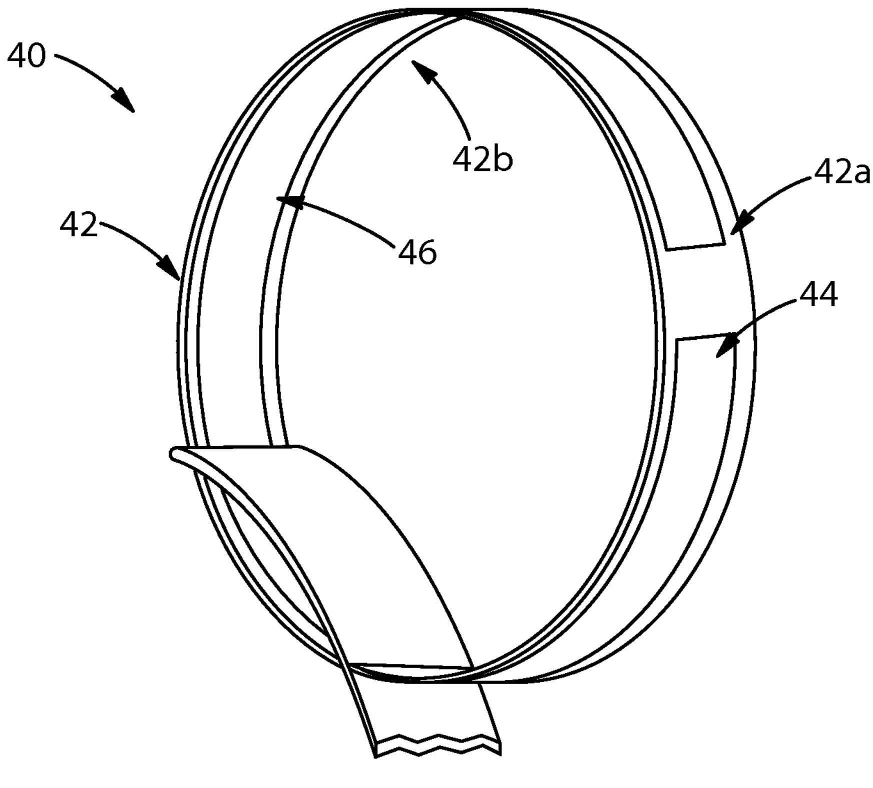

Fig. 2

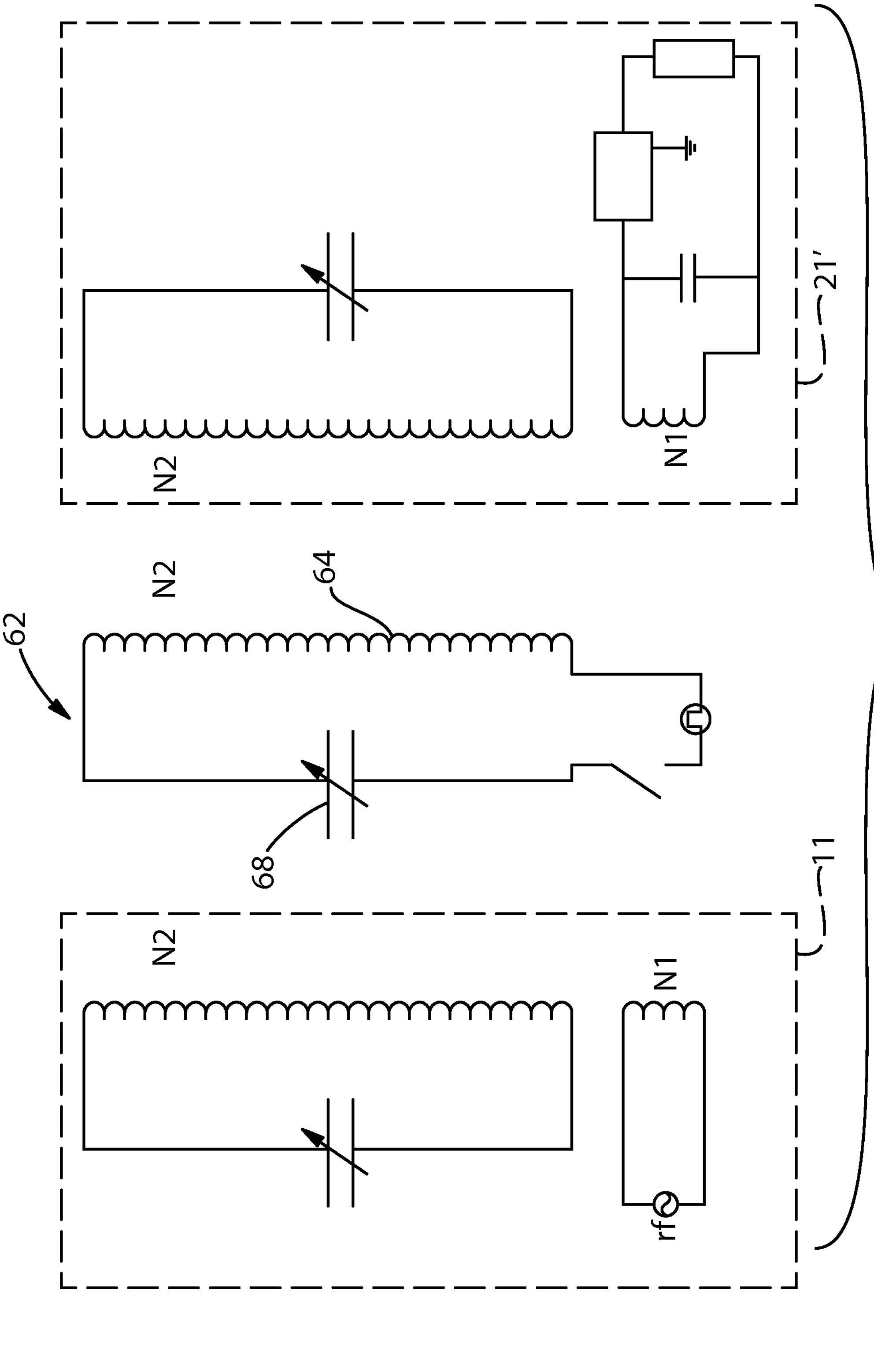

Fig. 3

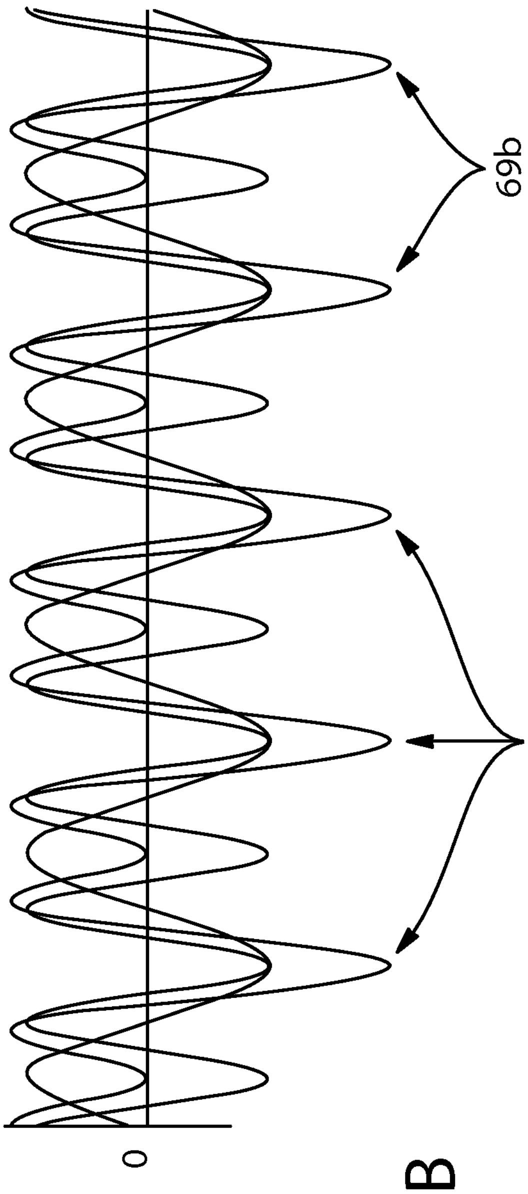

Fig. 4B

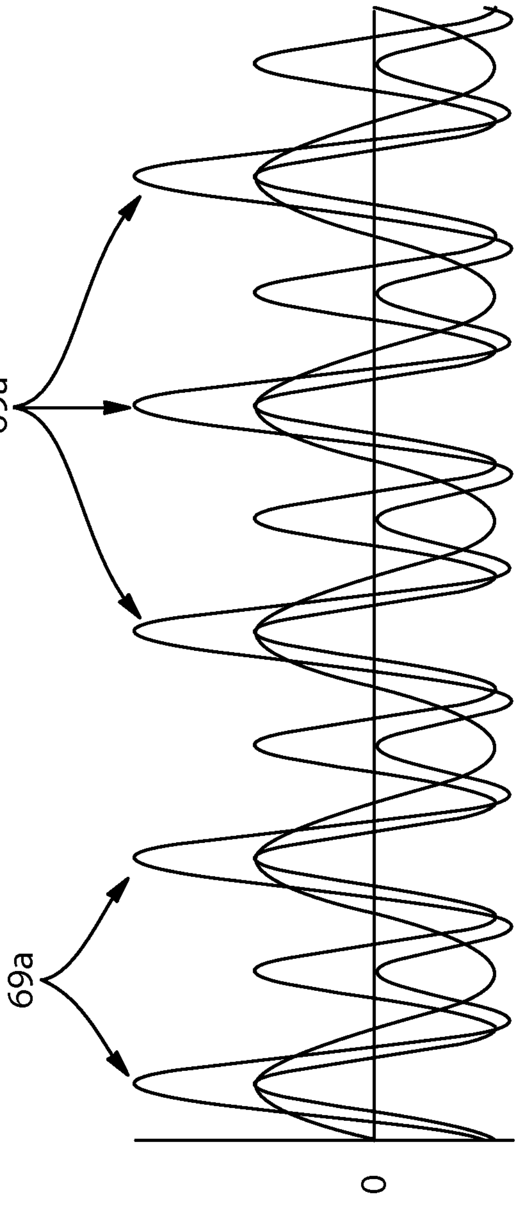

Fig. 4A

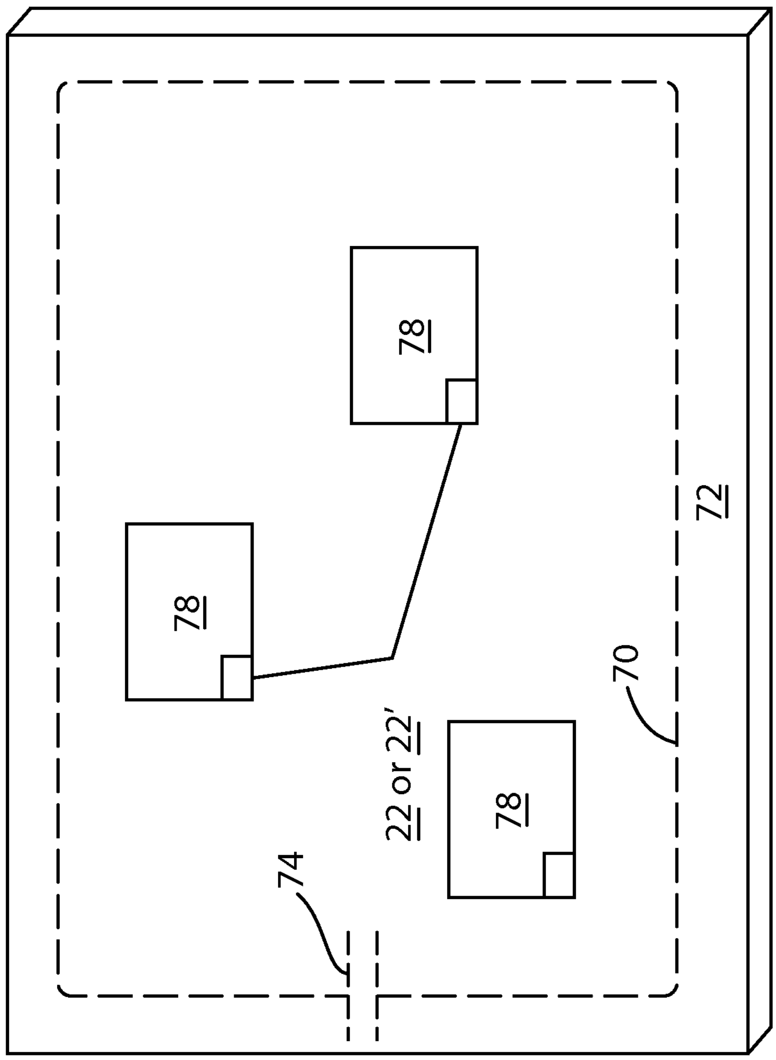

Fig. 5

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2013/025065

A. CLASSIFICATION OF SUBJECT MATTER
INV. H02J7/02
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)
H02J

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2009/023155 A2 (NIGELPOWER LLC [US]) 19 February 2009 (2009-02-19) paragraphs [0020] - [0058]; figures 2-9	1-15
X	US 2010/259109 A1 (SATO KAZUHIRO [JP]) 14 October 2010 (2010-10-14) paragraphs [0071] - [0103]; figures 1-5	1-15
A	US 2010/277120 A1 (COOK NIGEL P [US] ET AL) 4 November 2010 (2010-11-04) the whole document	1-15
A,P	EP 2 530 811 A1 (TOYOTA MOTOR CO LTD [JP]) 5 December 2012 (2012-12-05) the whole document	1-15

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
10 June 2013	10/07/2013

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Hunckler, José

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2013/025065

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2012/014482 A1 (TOYOTA JIDOSHOKKI KK [JP]; TOYOTA MOTOR CO LTD [JP]; SAKODA SHIMPEI [J) 2 February 2012 (2012-02-02) the whole document -----	1-15
A	US 2011/115430 A1 (SAUNAMAEKI ESA ILMARI [FI]) 19 May 2011 (2011-05-19) the whole document -----	1-15

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2013/025065

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2009023155 A2	19-02-2009	CN 101842962 A	22-09-2010
		EP 2176939 A2	21-04-2010
		JP 2010536315 A	25-11-2010
		KR 20100057632 A	31-05-2010
		KR 20130036071 A	09-04-2013
		US 2009051224 A1	26-02-2009
		WO 2009023155 A2	19-02-2009
US 2010259109 A1	14-10-2010	CN 101867229 A	20-10-2010
		JP 2010252468 A	04-11-2010
		US 2010259109 A1	14-10-2010
US 2010277120 A1	04-11-2010	CN 102414953 A	11-04-2012
		EP 2425514 A1	07-03-2012
		JP 2012525816 A	22-10-2012
		KR 20120003953 A	11-01-2012
		TW 201112568 A	01-04-2011
		US 2010277120 A1	04-11-2010
		WO 2010127047 A1	04-11-2010
EP 2530811 A1	05-12-2012	EP 2530811 A1	05-12-2012
		JP 5152446 B2	27-02-2013
		US 2013127242 A1	23-05-2013
		WO 2012073348 A1	07-06-2012
WO 2012014482 A1	02-02-2012	CN 103108768 A	15-05-2013
		DE 112011102539 T5	16-05-2013
		EP 2598363 A1	05-06-2013
		US 2013119930 A1	16-05-2013
		WO 2012014482 A1	02-02-2012
US 2011115430 A1	19-05-2011	US 2011115430 A1	19-05-2011
		WO 2011061388 A1	26-05-2011