METHODOLOGY FOR POCKET-FORMING

Applicant: DvineWave Inc., San Ramon, CA (US)
Inventor: Michael A. Leabman, San Ramon, CA (US)
Assignee: DvineWave Inc., San Ramon, CA (US)

Related U.S. Application Data

ABSTRACT
The present invention describes a methodology for wireless power transmission based on pocket-forming. This methodology may include one transmitter and at least one or more receivers, being the transmitter the source of energy and the receiver the device that is desired to charge or power. Both devices, the transmitter and receiver, may communicate to each other via a wireless protocol. By communicating to each other, the transmitter may identify and locate the device to which the receiver is connected and thereafter aim pockets of energy to the device in order to power it.
METHODOLOGY FOR POCKET-FORMING
CROSS-REFERENCES TO RELATED APPLICATIONS


FIELD OF INVENTION

[0002] The present invention relates to wireless power transmission, and more particularly to a method for wireless power transmission based on a pocket forming.

BACKGROUND OF THE INVENTION

[0003] Portable electronic devices such as smart phones, tablets, notebooks and other electronic devices have become an everyday need in the way we communicate and interact with others. The frequent use of these devices may require a significant amount of power, which may easily deplete the batteries attached to these devices. Therefore, a user is frequently needed to plug in the device to a power source, and recharge such device. This may be inconvenient and troublesome if the user forgets to plug in or otherwise charge a device, the device may run out of power and be of no use to the user until the user is again able to charge the device.

[0004] There are many approaches in the literature that have tried to reduce the impact of the changing needs of portable electronic devices. In some cases the devices have rechargeable batteries. However, the aforementioned approach requires a user to carry around extra batteries, and also make sure that the extra set of batteries is charged. Solar-powered battery chargers are also known, however, solar cells are expensive, and a large array of solar cells may be required to charge a battery of any significant capacity. Other approaches involve a mat or pad that allows charging of a device without physically connecting a plug of the device to an electrical outlet, by using electromagnetic signals. In this case, the device still requires to be placed in a certain location for a period of time in order to be charged. Assuming a single source power transmission of electromagnetic (EM) signal, an EM signal gets reduced by a factor of $1/r^2$ inches magnitude over a distance r. Thus, the received power at a large distance from the EM transmitter is a small fraction of the power transmitted.

[0005] To increase the power of the received signal, the transmission power would have to be boosted. Assuming that the transmitted signal has an efficient reception at three centimeters from the EM transmitter, receiving the same signal power over a useful distance of three meters would entail boosting the transmitted power by 10,000 times. Such power transmission is wasteful, as most of the energy would be transmitted and not received by the intended devices, it could be hazardous to living tissue, it would most likely interfere with most electronic devices in the immediate vicinity, and it may be dissipated as heat.

[0006] In yet another approach such as directional power transmission, it would generally require knowing the location of the device to be able to point the signal in the right direction to enhance the power transmission efficiency. However, even when the device is located, efficient transmission is not guaranteed due to reflections and interference of objects in the path or vicinity of the receiving device.

Therefore, a wireless power transmission method solving the aforementioned problems is desired.

SUMMARY OF THE INVENTION

[0007] The present invention provides a methodology for pocket-forming. The methodology includes at least one transmitter and one or more receivers. In one or more aspects of the present invention, the transmitter may include a housing having at least two antenna elements, at least one radio frequency integrated circuit (RFIC), at least one digital signal processor or micro-controller which may be connected to a power source. The housing may also include a communications component. In another aspect of the present invention, a receiver may include a housing having at least one antenna element, one rectifier, one power converter, and one or more communications component.

[0008] The A method for wireless power transmission, comprising:

- generating a communication RF signal from a receiver with identifier information of a chargeable electronic device connected thereto. Broadcasting the identifier RF signal through an antenna of the receiver.
- Interception of the identifier RF signal by an antenna of a power transmitter with a controller. Decoding the identifier RF signal by the controller to ascertain the gain and phase of the identifier RF signal sent by the power receiver including the direction or spatial location of the power receiver. Establishing a power channel or path between the transmitter and receiver from the identifier RF signal information. Transmitting controlled RF power waves from the transmitter to the receiver along the established channel or path. Controlling the phase and amplitude of the RF power waves by the controller to form constructive and destructive interference patterns generating pockets of energy in a 3-dimensional shape from the constructive patterns and generating null-spaces from the destructive patterns to aim the pockets of energy to the receiver in order to charge or power the electronic device. Converging the channels of 3-dimensional pockets of energy at the power receiver antenna for power input to the receiver. Converting the received pockets of energy into DC voltages for charging or powering the electronic device.

The method for pocket-forming starts when the receiver generates a short signal (e.g., RF) through one or more antenna elements. The transmitter, which may have two or more antenna elements, intercepts this signal and sends it to a micro-controller. The micro-controller decodes the signal and identifies the gain and phase from the signal sent by the receiver, and hence determining the direction of the pocket of energy. The latter may form a channel or path between the transmitter and receiver. Once the channel is established, the transmitter may transmit controlled Radio Frequency (RF) waves which may converge in 3D space. These RF waves may be controlled through phase and/or relative amplitude adjustments to form constructive and destructive interference patterns (pocket-forming). Pockets of energy may form at constructive interference patterns and can be 3-dimensional in shape whereas null-spaces may be generated at destructive interference patterns. A receiver may then utilize pockets of energy produced by pocket-forming for charging or powering an electronic device, for example a laptop computer and thus...
effectively providing wireless power transmission. In other situations there can be multiple transmitters and/or multiple receivers for powering various electronic equipment for example smartphones, tablets, music players, toys and others at the same time.

[0010] In yet another aspect of the present invention, an adaptive power focusing technique is disclosed. This technique may be implemented when there may be obstacles interfering the signals between the receiver and the transmitter or for regulating power at one or more receivers. In an embodiment, a receiver and transmitter may use the advantage of having omni-directional antennas, hence allowing the signal to bounce over the walls or ceilings inside a room until establishing a path among them.

[0011] The methodology described in the present invention may provide wireless power transmission while eliminating the use of wires or pads for charging devices which may require tedious procedures such as plugging to a wall outlet, and make the devices unusable during charging. This methodology may also be used to charge or power more than one electronic device. In addition, electronic devices may require less components as the typical wall chargers are not required. In some cases, even batteries may be eliminated as a device is fully powered wirelessly.

[0012] These and other advantages of the present invention may be evident to those skilled in the art, or may become evident upon reading the detailed description of the preferred embodiment, as shown in the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] Embodiments of the present invention are described by way of example with reference to the accompanying figures, which are schematic and are not intended to be drawn to scale. Unless indicated as representing prior art, the figures represent aspects, features and advantages of the present invention. The main aspects, features and advantages of the present invention will be better understood with the following descriptions, claims, and drawings, where:

[0014] FIG. 1 shows a transmitter that can be used for pocket-forming, according to an embodiment of the present invention.

[0015] FIG. 2 shows a receiver that can be used for pocket-forming, according to an embodiment of the present invention.

[0016] FIG. 3 is an exemplary illustration of a method for pocket-forming, according to an embodiment of the present invention.

[0017] FIG. 4 illustrates an adaptive power focusing technique for pocket-forming, according to an embodiment of the present invention.

DETAILED DESCRIPTION OF THE DRAWINGS

[0018] “Pocket-forming” may refer to generating two or more RF waves which converge in 3-d space, forming controlled constructive and destructive interference patterns.

[0019] “Pockets of energy” may refer to areas or regions of space where energy or power may accumulate in the form of constructive interference patterns of RF waves.

[0020] “Null-space” may refer to areas or regions of space where pockets of energy do not form because of destructive interference patterns of RF waves.

[0021] “Transmitter” may refer to a device, including a chip which may generate two or more RF signals, at least one RF signal being phase shifted and gain adjusted with respect to other RF signals, substantially all of which pass through one or more RF antenna such that focused RF signals are directed to a target.

[0022] “Receiver” may refer to a device including at least one antenna element, at least one rectifying circuit and at least one power converter, which may utilize pockets of energy for powering or charging an electronic device.

[0023] “Adaptive pocket-forming” may refer to dynamically adjusting pocket-forming to regulate power on one or more targeted receivers.

DESCRIPTION OF THE DRAWINGS

[0024] In the following detailed description, reference is made to the accompanying drawings, which form a part hereof. In the drawings, which are not to scale or to proportion, similar symbols typically identify similar components, unless context dictates otherwise. The illustrative embodiments described in the detailed description, drawings and claims, are not meant to be limiting. Other embodiments may be used and/or other changes may be made without departing from the spirit or scope of the present invention.

[0025] FIG. 1 shows an example of a transmitter 100 that can be used for pocket-forming. In this embodiment, transmitter 100 may be used to provide wireless power transmission. Transmitter 100 may include a housing 102 having at least two or more antenna elements 104, at least one RF integrated circuit (RFIC) 106, at least one digital signal processor (DSP) or micro-controller 108, and one communications component 110. Housing 102 can be made of any suitable material which may allow for signal or wave transmission and/or reception, for example plastic or hard rubber. Antenna elements 104 may include suitable antenna types for operating in frequency bands such as 900 MHz, 2.5 GHz or 5.8 GHz as these frequency bands conform to Federal Communications Commission (FCC) regulations part 18 (industrial, Scientific and Medical equipment). Antenna elements 104 may include vertical or horizontal polarization, right hand or left hand polarization, elliptical polarization, or other suitable polarizations as well as suitable polarization combinations. Suitable antenna types may include, for example, patch antennas with heights from about ¼ inch to about 6 inches and widths from about ¼ inch to about 6 inches. Micro-controller 108 may then process information sent by a receiver through communications component 110 for determining optimum times and locations for pocket-forming. Communications component 110 may be based on standard wireless communication protocols which may include Bluetooth, Wi-Fi or ZigBee. In addition, communications component 110 may be used to transfer other information such as an identifier for the device or user, battery level, location or other such information. Other communications component 110 may be possible which may include radar, infrared cameras or sound devices for sonar triangulation for determining the device’s position.

[0026] FIG. 2 shows an example of a receiver 200 that can be used for pocket-forming. In this embodiment, receiver 200 may be used for powering or charging an electronic device. Receiver 200 may also include a housing 202 having at least one antenna element 204, one rectifier 206, one power converter 208 and one or more communications component 210 that sends out status information about a rechargeable electronic device or about a device client in RF signals or RF signal bursts including present location information of the
client device. Housing 202 can be made of any suitable material which may allow for signal or wave transmission and/or reception, for example plastic or hard rubber. Housing 202 may be an external hardware that may be added to different electronic equipment, for example in the form of cases, or can be embedded within electronic equipment as well. Antenna element 204 may include suitable antenna types for operating in frequency bands such as those described for transmitter 100 from FIG. 1. Antenna element 204 may include vertical or horizontal polarization, right hand or left hand polarization, elliptical polarization, or other suitable polarizations as well as suitable polarization combinations. Using multiple polarizations can be beneficial in devices where there may not be a preferred orientation during usage or whose orientation may vary continuously through time, for example a smartphone or portable gaming system. On the contrary, for devices with well-defined orientations, for example a two-handed video game controller, there might be a preferred polarization for antennas which may dictate a ratio for the number of antennas of a given polarization.

[0027] Suitable antenna types may include patch antennas with heights from about 1/8 inch to about 6 inches and widths from about 1/8 inch to about 6 inches. Patch antennas may have the advantage that polarization may depend on connectivity, i.e. depending on which side the patch is fed, the polarization may change. This may further prove advantageous as a receiver, such as receiver 200, may dynamically modify its antenna polarization to optimize wireless power transmission. Rectifier 206 may include diodes or resistors, inductors or capacitors to rectify the alternating current (AC) voltage generated by antenna element 204 to direct current (DC) voltage. Rectifier 206 may be placed as close as is technically possible to antenna element 204 to minimize losses. After rectifying AC voltage, DC voltage may be regulated using power converter 208. Power converter 208 can be a DC-DC converter which may help provide a constant voltage output, regardless of input, to an electronic device, or as in this embodiment to a battery 212. Typical output voltages can be from about 5 volts to about 10 volts.

[0028] In some embodiments, power converter 208 may include electronic switched mode DC-DC converters which can provide high efficiency. In such a case, a capacitor (not shown) may be included before power converter 208 to ensure sufficient current is provided for the switching device to operate. When charging an electronic device, for example a phone or laptop computer, initial high currents which can break-down the operation of an electronic switched mode DC-DC converter may be required. In such a case, a capacitor (not shown) may be added at the output of receiver 200 to provide the extra energy required. Afterwards, lower power can be provided, for example 1/6 of the total initial power while having the phone or laptop still build-up charge. Lastly, a communications component 210 may be included in receiver 200 to communicate with a transmitter or to other electronic equipment in RF signals or RF signal bursts with status information and present location information about a rechargeable electronic device or the client device. Such a communications component 210 may be based on standard wireless communication protocols which may include Bluetooth, WiFi or ZigBee similar to communications component 110 from transmitter 100.

[0029] FIG. 3 is an exemplary illustration of the methodology used for pocket forming 300, which may include one transmitter 100 and at least one or more receivers 200. Receiver 200 may communicate with transmitter 100 by generating a short signal (e.g., RF) through antenna elements 204 in order to locate its position with respect to the transmitter 100. In some embodiments, receiver 200 may additionally utilize at least one communications component 210 to communicate with other devices or components. Communications components 210 may enable receiver 200 to communicate using a wireless protocol. As described in FIG. 1 and FIG. 2, the wireless protocol can be a proprietary protocol or use a conventional wireless protocol such as Bluetooth, WiFi, ZigBee, etc. Communications component 210 may then be used to transfer information such as an identifier for the device as well as battery level information, geographic location data, or other information that may be of use for transmitter 100 in determining when to send power to receiver 200, as well as the location to deliver a pocket of energy 304. In other embodiments, adaptive pocket-forming may be used to regulate power on electronic devices.

[0030] Once transmitter 100 identifies and locates receiver 200, a channel or path can be established by knowing the gain and phases coming from receiver 200. Transmitter 100 may start to transmit or broadcast controlled Radio Frequency (RF) waves 302 which may converge in 3-d space by using a minimum of two antenna elements 104. These RF waves may be produced by using an external power source 112 and a local oscillator chip using a suitable piezoelectric material. RF waves 302 may be controlled by RFIC 106 which may include a proprietary chip for adjusting phase and/or relative magnitudes of RF signals which may serve as inputs for antenna elements 104 to form constructive and destructive interference patterns (pocket-forming). Pocket-forming may take advantage of interference to change the directionality of the antenna elements 104 where constructive interference generates a pocket of energy 304 and deconstructive interference generates a null space. Receiver 200 may then utilize pocket of energy 304 produced by pocket-forming for charging or powering an electronic device, for example a laptop computer 306 and therefore effectively providing wireless power transmission.

[0031] FIG. 4 is an exemplary illustration of adaptive pocket-forming 400. In this embodiment, a user 402 may be inside a room and may hold on his hands an electronic device which in this case may be a tablet 404. Tablet 404 may include a receiver 200 either embodied to it or as a separate adapter connected to tablet 404. Receiver 200 may include all the components described in FIG. 2. A transmitter 100 may be hanging on one of the walls of the room right behind user 402, as shown in FIG. 4. Transmitter 100 may also include all the components described in FIG. 1. As user 402 may seem to be obstructing the path between receiver 200 and transmitter 100, RF waves 406 may not be easily aimed to receiver 200 in a linear direction. However, since the short signals generated from receiver 200 may be omni-directional for the type of antenna elements 104 used, these signals may bounce over the walls until they find transmitter 100. Almost instantly, a micro-controller 108 which may reside in transmitter 100, may recalibrate the signals, sent by receiver 200, by adjusting gain and phases and form conjugates taking into account the built-in phases of antenna elements 104. Once calibration is performed, transmitter 100 may focus RF waves 406 in two channels following the path described in FIG. 4, which may be the most efficient path. Subsequently, a pocket of energy 408 may form on tablet 404 while avoiding obstacles such as user 402. The foregoing property may be beneficial in that
wireless power transmission using pocket-forming 300 may inherently be safe as signals may never go through living tissue or other such obstacles.

[0032] While the invention has been shown and described with reference to the embodiments as disclosed herein, other aspects and embodiments may be contemplated. The various aspects and embodiments disclosed herein are for purposes of illustration and are not intended to be limiting, with the true scope and spirit being indicated by the following claims.

Having thus described the invention, we claim:

1. A method for transmitting wireless power, comprising:
generating two or more RF power waves from a transmitter
having at least two RF transmit antennas for transmitting
two separate RF power waves;
forming controlled constructive interference patterns
between the generated RF power waves to form pockets
of energy;
converging the pockets of energy in 3-D space to a targeted
electronic device; and
receiving the converged pockets of energy in a receiver
having at least one antenna for charging or powering a
targeted electronic device from the received pockets of
energy.

2. The method for transmitting wireless power of claim 1,
wherein the forming controlled constructive interference pat-
terns between the generated RF waves further comprising
destructive interference patterns between the generated RF
waves generating a null-space where pocket of energy do not
form.

3. The method for transmitting wireless power of claim 1,
wherein converging the pockets of energy further comprises
adjusting dynamically the pockets of energy to regulate the
power to the targeted electronic device.

4. The method for transmitting wireless power of claim 1,
wherein generating two or more RF power waves comprises
generating two or more RF power waves from at least one RF
integrated circuit with at least one RF power wave being
phase shifted and gain adjusted with respect to the other RF
power waves.

5. The method for transmitting wireless power of claim 4,
wherein generating two or more RF power waves comprises
operating antenna elements with polarization in frequency
bands conforming to FCC regulations such as 900 MHz or 2.5
GHz or 5.8 GHz for transmitting the RF power waves.

6. The method for transmitting wireless power of claim 1,
wherein receiving the pockets of energy in the receiver with at
least one antenna further comprises communicating between
the receiver and transmitter operating on standard wireless
communication protocol signals such as Bluetooth, Wi-Fi or
ZigBee to transfer status information of the targeted elec-
tronic device regarding battery level and target location for
directing desired pockets of energy to the targeted electronic
device.

7. The method for transmitting wireless power of claim 1,
further comprising embedding the receiver in the targeted
electronic device.

8. The method for transmitting wireless power of claim 1,
further comprising attaching electrically the receiver to the
targeted electronic device.

9. The method for transmitting wireless power of claim 1,
wherein converging the pockets of energy in 3-D space to a
targeted electronic device further comprises recalibrating the
pockets of energy by adjusting gain and phases to focus RF
power waves in two channels to follow a path that forms
pockets of energy on the targeted electronic device without
obstacles in the path.

10. The method for transmitting wireless power of claim 6,
wherein converging the pockets of energy in 3-D space to a
targeted electronic device comprises energy pocket-forming
with generally a wireless power transmission level directed
by communication signals to avoid humans or other
obstacles.

11. Wireless power transmission, comprising:
a transmitter for generating two or more RF power waves
having at least two RF transmit antennas;
a controller for forming constructive and destructive inter-
fERENCE patterns from the generated RF power waves;
RF circuitry in the transmitter for generating energy in the
form of constructive interference patterns between the
RF power waves to form pockets of energy;
a targeted electronic device for converging the pockets of
energy in 3-D space; and
a receiver with the RF circuitry and at least one antenna for
receiving the pockets of energy for powering or charging
the targeted electronic device.

12. The wireless power transmission of claim 11, wherein
the transmitter and receiver include communication circuitry
for adjusting dynamically the pockets of energy to regulate
the power or charge to the targeted electronic device.

13. The wireless power transmission of claim 11, wherein
the two RF transmit antennas and one RF receiver antenna are
patch antennas operating in a frequency band of 900 MHz, 2.5
GHz or 5.8 GHz or other frequency bands conforming to FCC
regulations.

14. The wireless power transmission of claim 11, wherein
the transmitter and receiver further include communication
circuitry based on standard wireless communication proto-
cols for transferring information regarding identifier of the
targeted electronic device, battery level and location of the
device to regulate power to one or more targeted electronic
devices.

15. The wireless power transmission of claim 11, wherein
the RF circuitry in transmitter and receiver communicate with
each other and the RF circuitry generate two or more RF
power waves, at least one RF power wave being phase shifted
and gain adjusted with respect to other RF power waves and
the one RF power wave passes through one or more RF
antenna to direct the focused RF power waves in the pockets
of energy to the targeted electronic device.

16. The wireless power transmission of claim 11, wherein
the communication signals between the transmitter and
receiver are standard wireless communication protocols of
Bluetooth, Wi-Fi or ZigBee.

17. The wireless power transmission of claim 13, wherein
the patch antennas are made from any suitable antenna ma-
terial and further include a height from about ¼ inch to about
6 inches in height and include a width from about ¼ inch to 6
inches.

18. The wireless power transmission of claim 11, wherein
the transmitter RF circuitry comprises at least two antenna
104, an RF integrated circuit 106 with at least one digital
signal processor or micro-controller 108 and one communi-
cation circuit 110 and a power source 112.

19. The wireless power transmission of claim 11, wherein
the receiver RF circuitry comprises a antenna 204, a rectifier
206, a converter 208, a communication circuit 210 and a
battery 212 that is charged.
20. A method for wireless power transmission, comprising:
generating a communication RF signal from a receiver with identifier information of a chargeable electronic device connected thereto;
broadcasting the identifier RF signal through an antenna of the receiver;
intercepting the identifier RF signal by an antenna of a power transmitter with a controller;
decoding the identifier RF signal by the controller to ascertain the gain and phase of the identifier RF signal sent by the power receiver including the direction or spatial location of the power receiver;
establishing a power channel or path between the transmitter and receiver from the identifier RF signal information;
transmitting controlled RF power waves from the transmitter to the receiver along the established channel or path;
controlling the phase and amplitude of the RF power waves by the controller to form constructive and destructive interference patterns generating pockets of energy in a 3-dimensional shape from the constructive patterns and generating null-spaces from the destructive patterns to aim the pockets of energy to the receiver in order to charge or power the electronic device;
converging the channels of 3-dimensional pockets of energy at the power receiver antenna for power input to the receiver; and
converting the received pockets of energy into DC voltages for charging or powering the electronic device.

21. The method for wireless power transmission of claim 20, wherein converging 3-dimensional pockets of energy comprises pocket-forming for charging or powering electronic devices wirelessly with multiple transmitters and receivers for charging and powering smartphones, tablets, music players, laptop computers, toys, gaming controls and other similar electronic devices operating on battery power from generally 5 to 10 volts.

22. The method for wireless power transmission of claim 21, further comprising dynamically adjusting pocket-forming to regulate charging or power on one or more of the chargeable electronic devices.

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