



US009627919B2

(12) **United States Patent**
Radziemski et al.

(10) **Patent No.:** **US 9,627,919 B2**
(45) **Date of Patent:** **Apr. 18, 2017**

(54) **ELECTRO-ACOUSTIC DEVICE CHARGING
AND POWER SUPPLY**

USPC 320/107, 108, 114, 115, 101; 367/135,
367/137, 138, 140, 180
See application file for complete search history.

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(56) **References Cited**

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U.S. PATENT DOCUMENTS

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(*) Notice: Subject to any disclaimer, the term of this
patent is extended or adjusted under 35
U.S.C. 154(b) by 0 days.

4,784,147	A	11/1988	Moshfeghi
5,554,922	A	9/1996	Kunkel
5,659,173	A	8/1997	Putterman et al.
5,889,383	A	3/1999	Teich
6,342,776	B1	1/2002	Taylor et al.
6,798,716	B1	9/2004	Charych
8,082,041	B1	12/2011	Radziemski
8,974,366	B1	3/2015	Radziemski et al.
2012/0299540	A1	11/2012	Perry
2012/0299541	A1	11/2012	Perry
2012/0299542	A1	11/2012	Perry
2012/0300588	A1	11/2012	Perry
2012/0300592	A1	11/2012	Perry
2012/0300593	A1	11/2012	Perry
2013/0241468	A1	9/2013	Moshfeghi
2013/0241474	A1	9/2013	Moshfeghi
2014/0265725	A1	9/2014	Angle et al.
2014/0265727	A1	9/2014	Berte

(Continued)

(21) Appl. No.: **14/671,741**

(22) Filed: **Mar. 27, 2015**

(65) **Prior Publication Data**

US 2015/0280484 A1 Oct. 1, 2015

Related U.S. Application Data

(60) Provisional application No. 61/971,204, filed on Mar.
27, 2014.

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(51) **Int. Cl.**

H01M 10/46	(2006.01)
H02J 7/02	(2016.01)
H02J 7/00	(2006.01)
H02J 50/80	(2016.01)
H02J 50/15	(2016.01)

(52) **U.S. Cl.**

CPC **H02J 7/025** (2013.01); **H02J 7/0042**
(2013.01); **H02J 50/15** (2016.02); **H02J 50/80**
(2016.02)

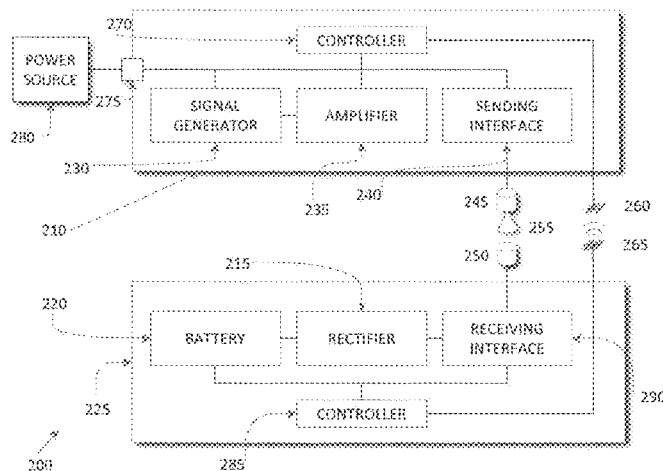
(58) **Field of Classification Search**

CPC .. H02J 7/025; H02J 5/005; H02J 50/00; H02J
7/0042; H02J 7/355

(57) **ABSTRACT**

An electroacoustic portable device charger and direct power adaptor. Ultrasonic transducers transmit acoustic energy which is converted into electrical power for the purposes of charging portable device batteries. Specifically, a wireless personal data device (such as a mobile phone) charging pad is disclosed. Feedback control loop and phased piezo array steer acoustic wavefronts into receiver transducers without the threat of electromagnetic interference. Parameters are monitored to maximize power efficiency and transmission. Device cradles and covers can be retrofitted to accommodate piezo electronics or integrated therein.

20 Claims, 14 Drawing Sheets



(56)

References Cited

U.S. PATENT DOCUMENTS

2014/0265943	A1	9/2014	Angle et al.
2014/0281655	A1	9/2014	Angle et al.

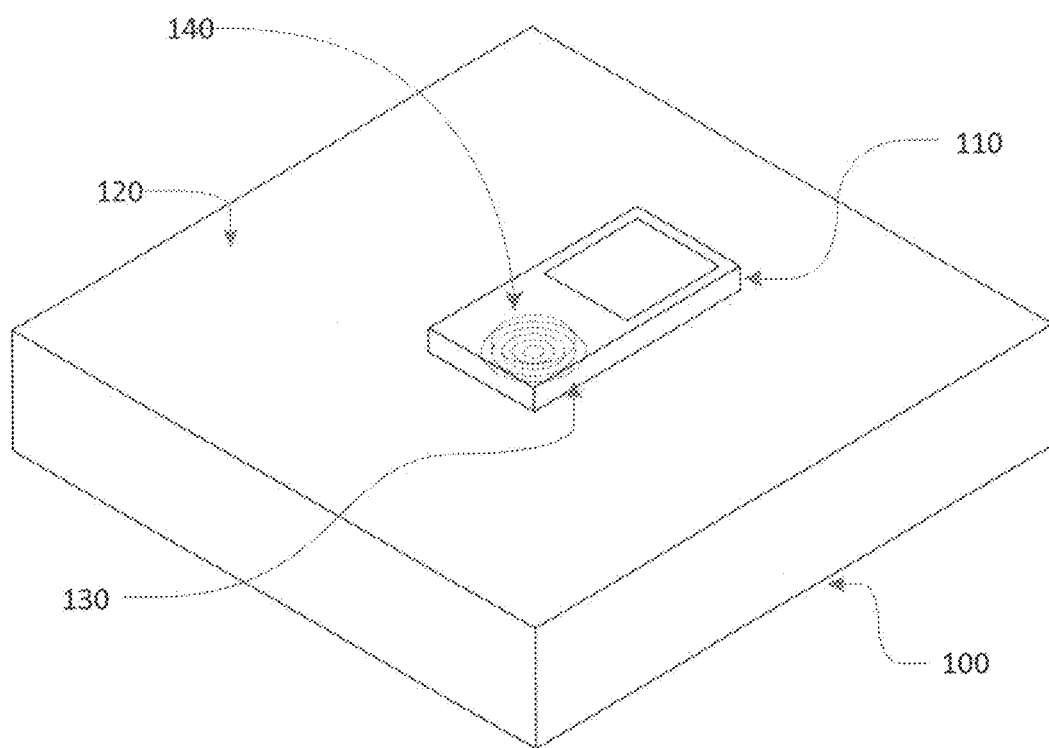


Fig. 1

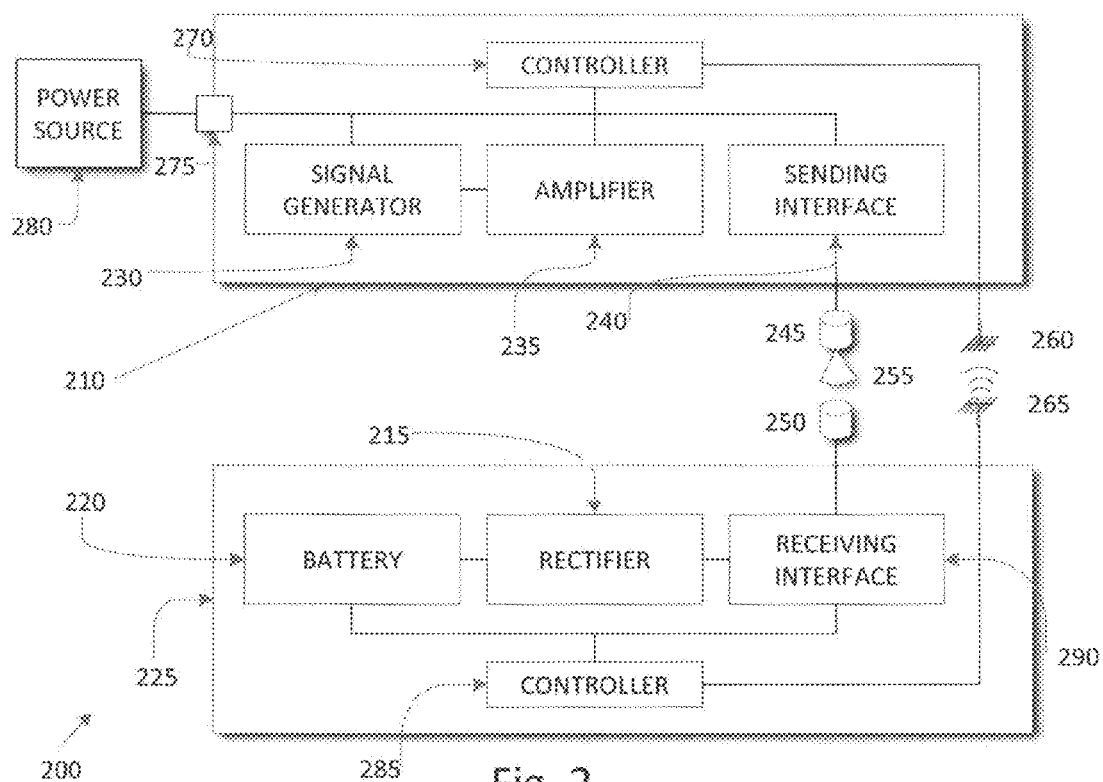


Fig. 2

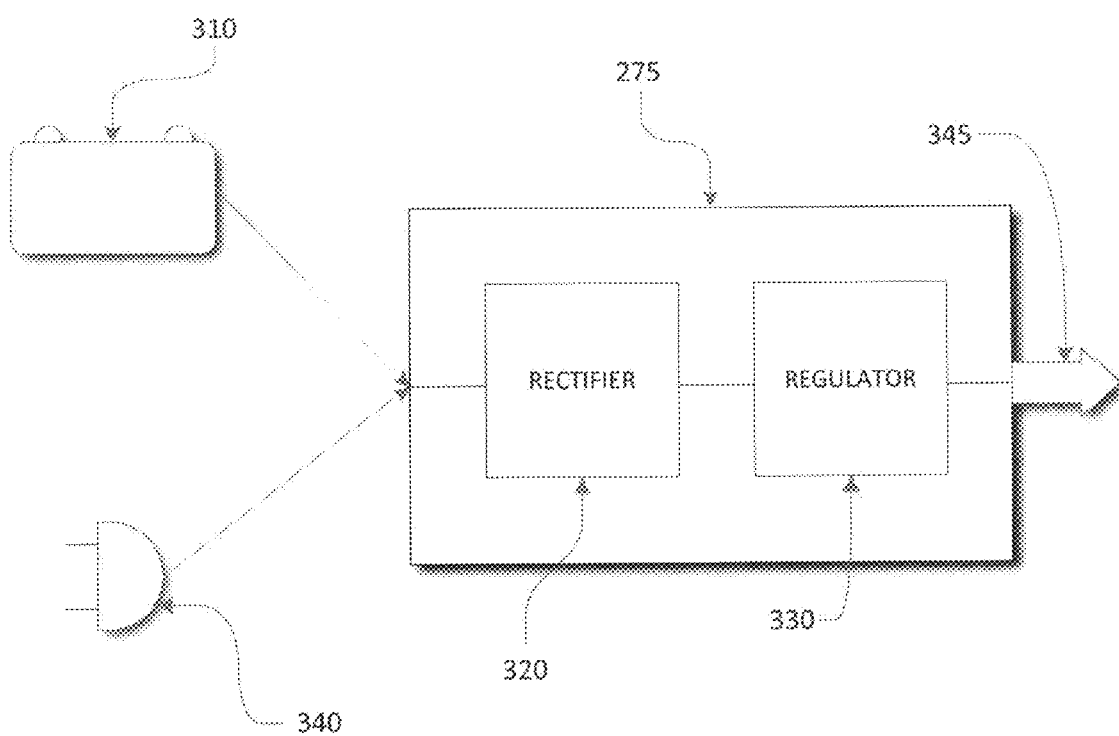


Fig. 3

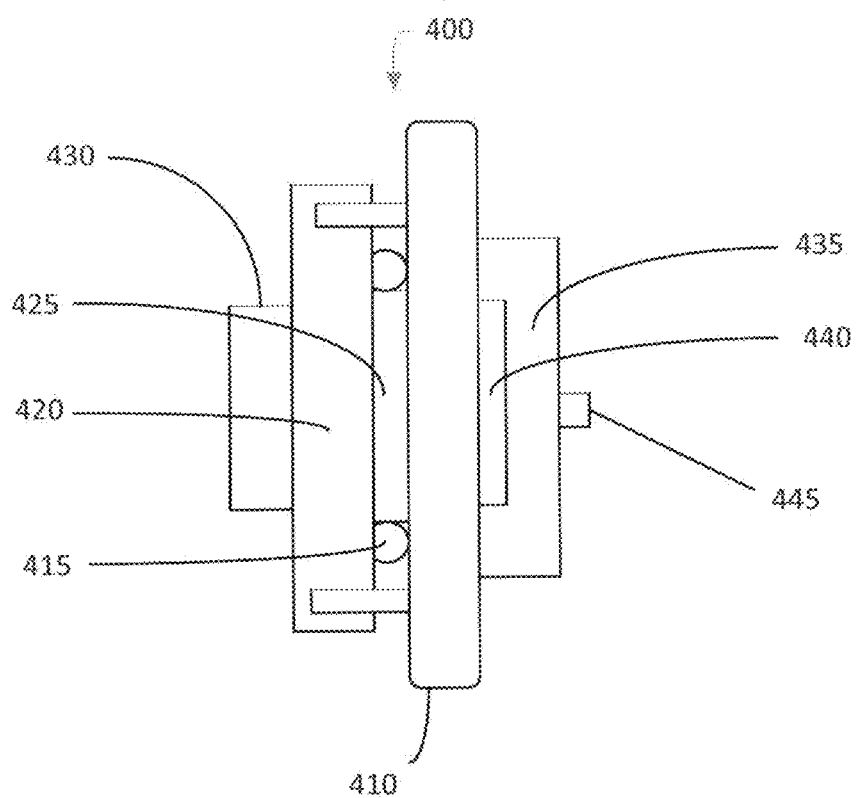


Fig. 4

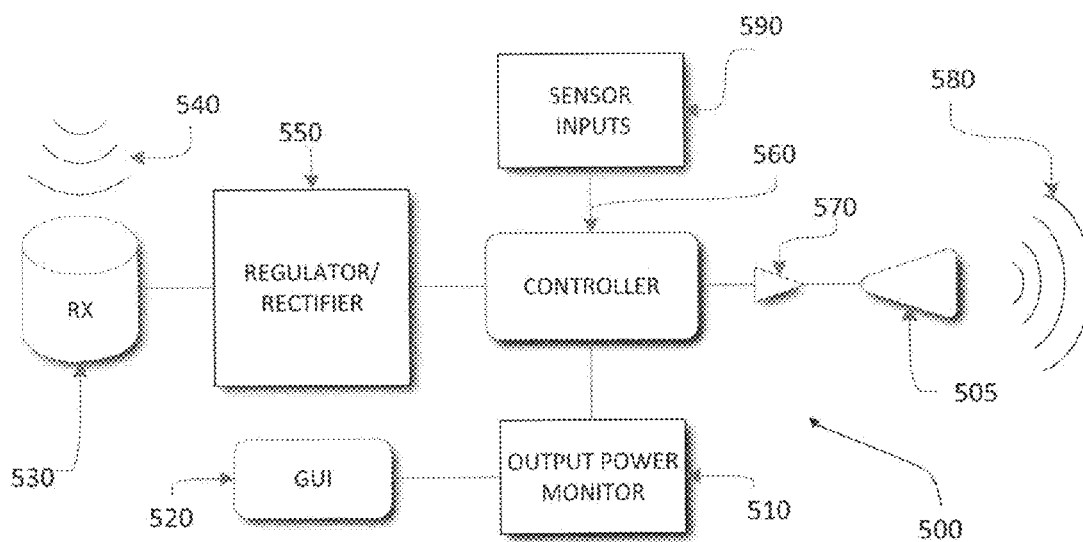


Fig. 5

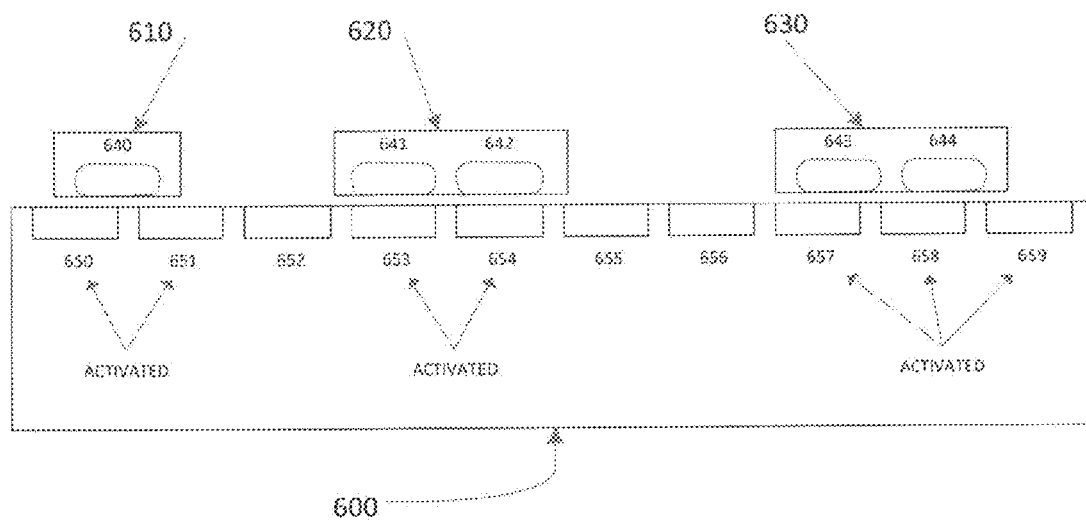


Fig. 6

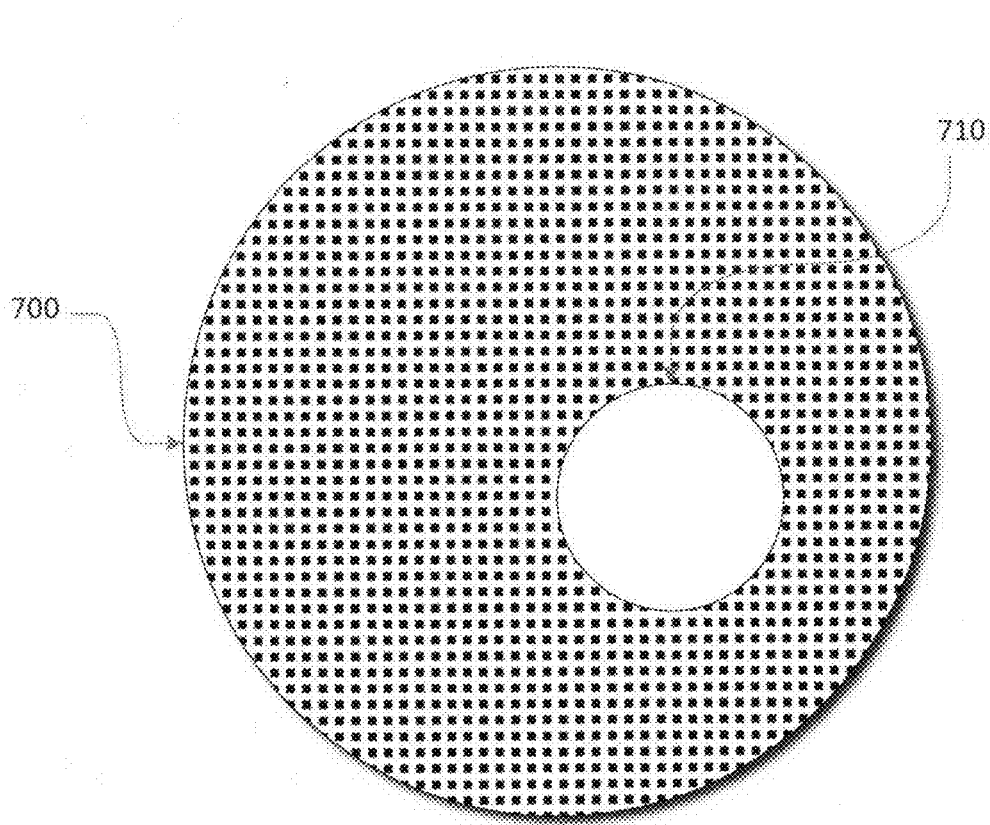


Fig. 7

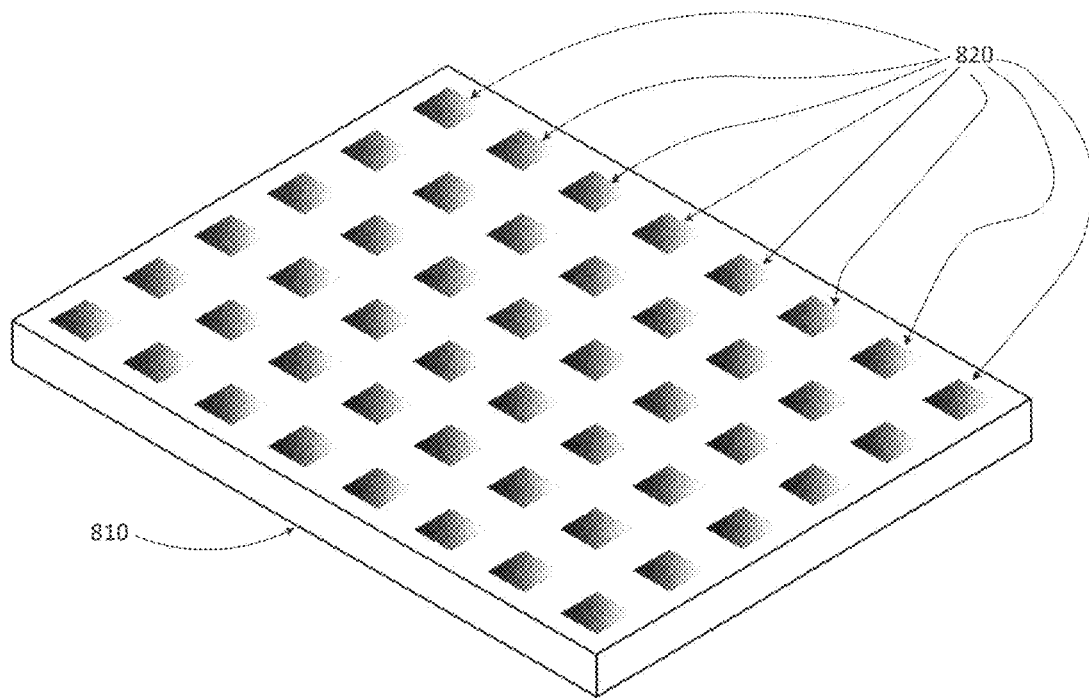


Fig. 8

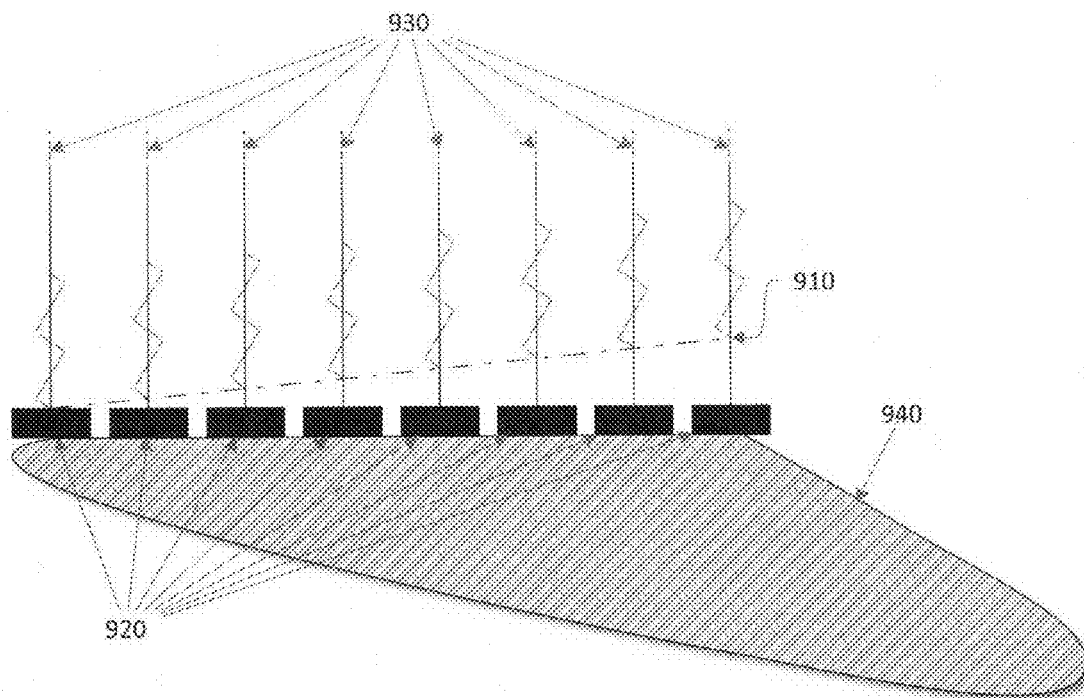


Fig. 9

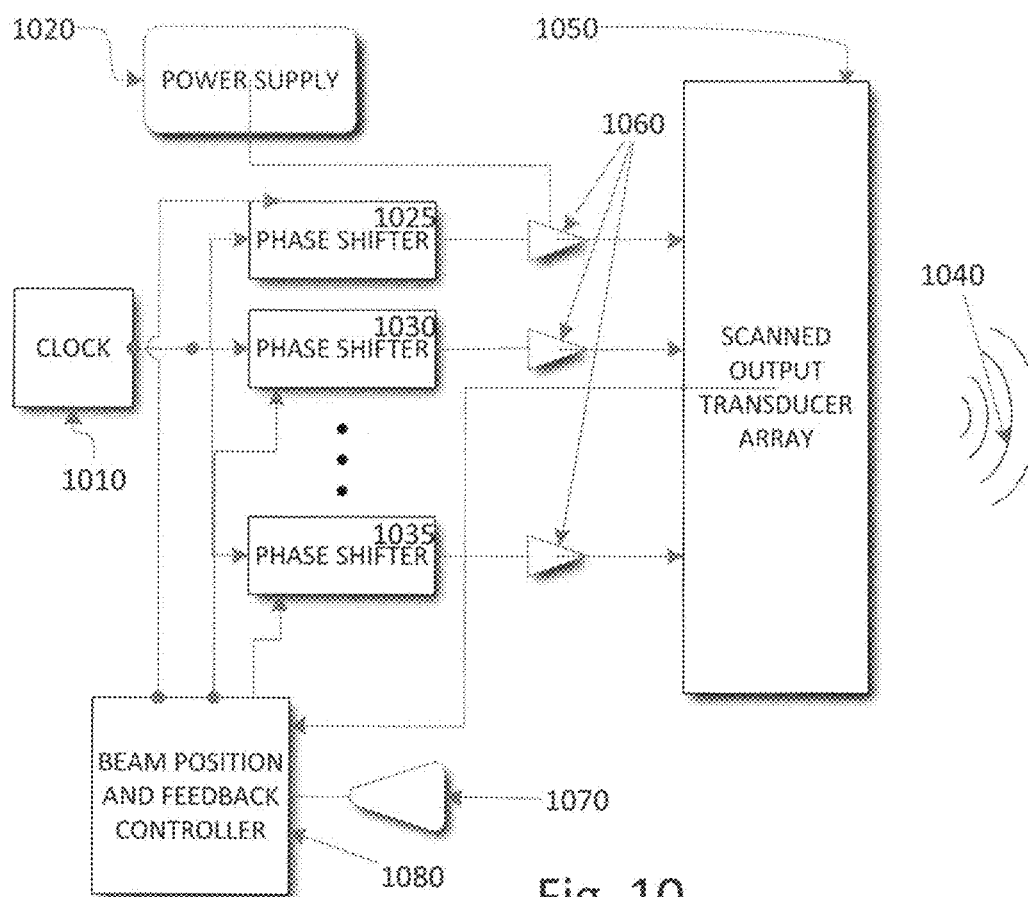


Fig. 10

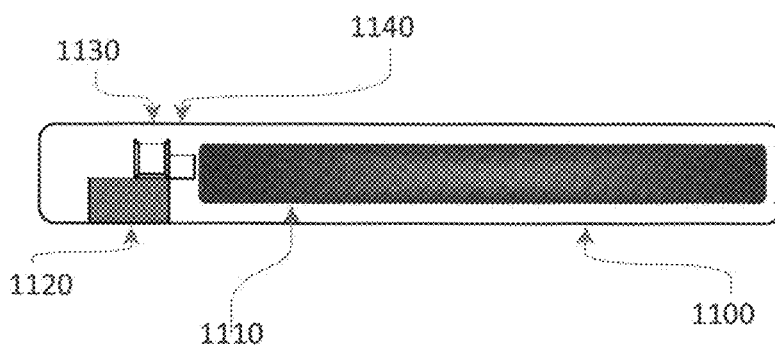


Fig. 11

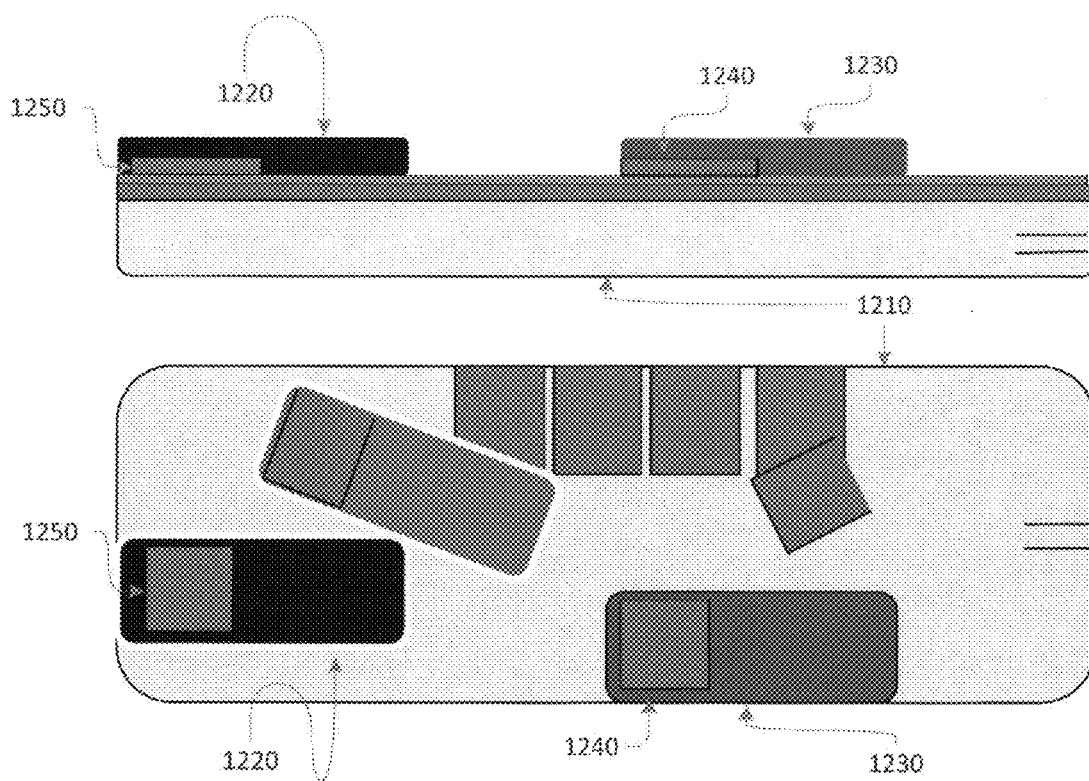


Fig. 12

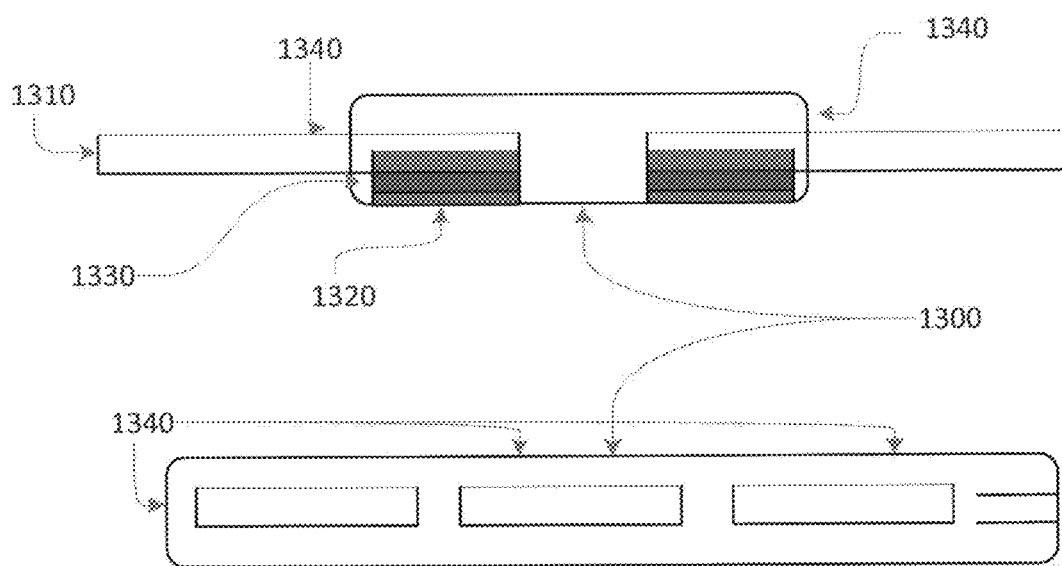


Fig. 13

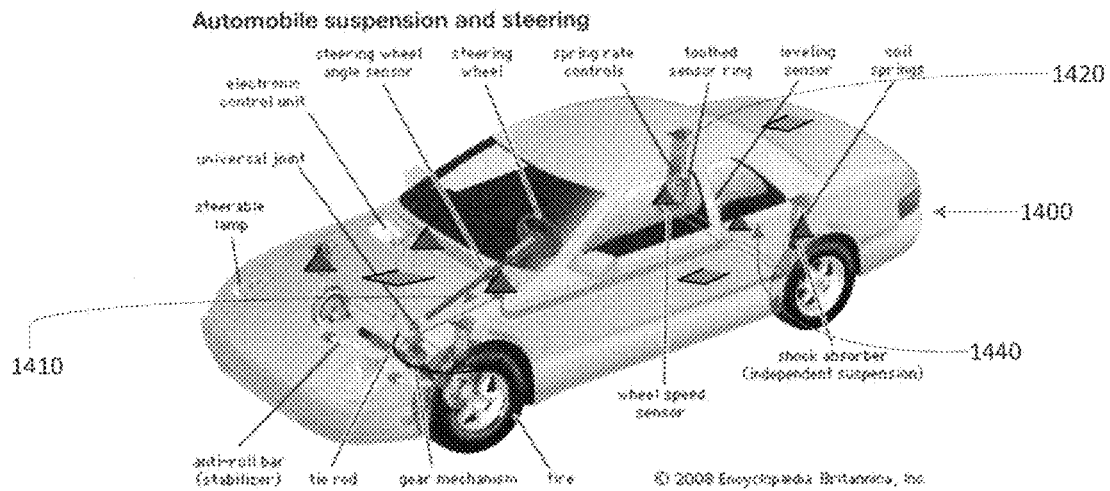


Fig. 14

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ELECTRO-ACOUSTIC DEVICE CHARGING AND POWER SUPPLY

RELATED APPLICATIONS

This application is related and claims priority to U.S. Provisional Application No. 61/971,204 entitled, "Battery Charging or Direct Power Delivery" filed on Mar. 27, 2014, which is hereby incorporated by reference in its entirety.

TECHNICAL FIELD

The present application relates to the transmission of electrical power between electronic devices without the use of wires. More specifically, the present application pertains to the transmission of electrical power between electronic devices using ultrasound so as to directly power an electrical device or component or to charge a battery thereof.

BACKGROUND

Portable devices such as mobile phones, laptop computers, tablets, and other communication device primarily rely on electrical battery energy to operate and conduct communications. Electrical batteries store chemical energy and deliver electrical energy through an electrochemical conversion process. Electrical batteries may be non-rechargeable or rechargeable. Although some portable devices may use non-rechargeable batteries, the vast majority depend on rechargeable batteries.

To recharge, conventional power transfer into portable devices requires these devices to be plugged into an electrical outlet. Although wireless data transmission is commonplace, wireless power transmission is not, except at extremely low power levels and not in an effective form for many applications. One impediment to wireless power transmission is the diffusion and diffraction of electromagnetic waves which is the conventional wireless transmission of electrical power. Consequently, this spreads out the available energy so that only a tiny fraction is available at the receiving end.

Nevertheless, manufacturers have begun producing wireless battery charging stations. They operate under the principle of electromagnetic (EM) induction. electromagnetic induction is well known in the art and involves coupling the magnetic field generated by an external coil with an implanted coil (Schuder, 1960; Van Schuylenbergh and Puers, 2009). As the name connotes, wireless charging pads recharge portable device batteries and forego the necessity of connecting wires.

Other disclosures, e.g., patent Pub. No. US 2013/0241468 A1 (Moshfeghi, 2013) disclose battery charging using an array of transducers and a power combiner connected to a battery charger. These systems are costly and difficult to manufacture and maintain and have other operational limits with respect to the power and frequency range of their operation, which make them non-ideal for some applications as discussed below.

With the proliferation of wireless devices, electromagnetic interference amongst devices will become an increasing problem with electromagnetic induction charging. In general, electromagnetic waves are incoherent and tend to spread out spatially while propagating. Electromagnetic systems also depend on a progressively crowded frequency space shared with other devices. Both electromagnetic stray fields (noise) from diffusion and bandwidth encroachment

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can interfere with the operation of nearby devices that are sensitive to such interference.

Although a useful method, electromagnetic induction charging has other limitations. To achieve sufficient power at the receiver, the power level at the transmitter becomes impractically high. Additionally, to focus a useable amount of energy to the transmitter requires physically large antennas. This is due to the focusing antennas having to be many times larger than the wavelength of the transmitted radiation. Furthermore, there is difficulty of controlling the impedance matching as a function of transmitter and receiver alignment. That in turn reduces the efficiency of transmission, leading to heating of the electronic devices themselves, causing, in some cases, their failure. There are also issues relating to safety and electromagnetic interference to other electronic devices.

Therefore, there exists a need for an electric power charging system using directional power propagation without the threat of electromagnetic interference and bandwidth infringement of other devices. The present disclosure contemplates such new and useful battery recharging stations, practical methods for the application thereof and remedying the above and/or other associated problems.

Further limitations and disadvantages of conventional and traditional approaches will become apparent to one of skill in the art, through comparison of such systems with some aspects of the present invention as set forth in the present disclosure and claims.

SUMMARY

The following description and drawings set forth certain illustrative implementations of the disclosure in detail, which are indicative of several exemplary ways in which the various principles of the disclosure may be carried out. The illustrative examples, however, are not exhaustive of the many possible embodiments of the disclosure. Other objects, advantages and novel features of the disclosure will be set forth in the following detailed description of the disclosure when considered in conjunction with the drawings.

Aspects of the present disclosure are directed to a charging system for batteries or providing direct power to applications using ultrasonic waves to transfer energy between transmitting and receiving transducers. In one aspect, a transducer is connected to a battery-driven controller that modulates the power provided to the transmitter. In another aspect, the power may be supplied by other means, for example from an electrical power outlet fixed in a home or any other location. The controller can receive several feedback signals wirelessly from the device being charged in order to regulate the transmitter power and frequency, to stabilize the power provided at an adequate level, and provide peak power as necessary. Feedback communication may be provided by electromagnetic induction, ultrasound, or other methods. In an alternate aspect, the controller can be preprogrammed for a particular delivery protocol. According to another aspect, wavefront steering is provided by an ultrasonic phased array and feedback control loop.

Yet another aspect is directed to system for delivering energy to power or charge an electrical source, comprising an electrical power supply; a transmitting ultrasound transducer that takes electrical energy from said electrical power supply and transmits an ultrasound energy wavefront in a determined direction; a receiving ultrasound transducer, coupled to said transmitting ultrasound transducer through an acoustic coupling medium, that receives said ultrasound energy wavefront and generates a generated electrical output

through transduction in said receiving ultrasound transducer; an electronic signal conditioning circuit receiving said generated electrical output and outputting a conditioned electrical output; a controller for controlling an amount of conditioned electrical output to generate a controlled electrical output; and a battery unit receiving said controlled electrical output so as to charge said battery with electrical energy derived from said controlled electrical output.

IN THE DRAWINGS

FIG. 1 illustrates an exemplary electro-acoustic power pad;

FIG. 2 depicts an exemplary abstraction of an electroacoustic charging system comprising electroacoustic power pad and portable device electroacoustic receiver;

FIG. 3 illustrates an exemplary adaptive power supply to an electroacoustic charging system;

FIG. 4 illustrates an exemplary electroacoustic transducer mechanical alignment stage;

FIG. 5 illustrates an exemplary receiver module an electroacoustic charging system;

FIG. 6 demonstrates the selective activation of an exemplary transducer array of an electroacoustic charging system;

FIG. 7 is the top down view of an exemplary transducer array of an electroacoustic charging system;

FIG. 8 projects an isometric view of an exemplary two dimensional ultrasonic transducer array of an electroacoustic power pad for the purposes of charging in a non-mechanical alignment environment;

FIG. 9 depicts an exemplary temporal abstraction of the side view of 2-dimensional electroacoustic phased array and corresponding wavefront steering for non-mechanical alignment;

FIG. 10 illustrates an abstraction circuit used to produce electrical signals delivered to 2-dimensional electroacoustic phased arrays;

FIG. 11 illustrates the side view of an exemplary electroacoustic charging cover circumscribing a generic portable device;

FIG. 12 depicts top and side views of an exemplary electroacoustic charging system comprising electroacoustic power pad and portable devices;

FIG. 13 depicts top and side views of an exemplary electroacoustic charging system comprising electroacoustic power pad and portable devices according to an alternate embodiment; and

FIG. 14 illustrates in-situ autonomous sensor charging of an electroacoustic system in a modern automobile according to an additional embodiment of the present invention.

DETAILED DESCRIPTION

As mentioned above, the present application is directed to the transmission of electrical power between electronic devices without the use of wires. More specifically, the present application pertains to the transmission of electrical power between a charging pad and electronic devices using ultrasound to overcome the aforementioned limitations enumerated in the background. One or more embodiments or implementations are hereinafter described in conjunction with the drawings, where like reference numerals are used to refer to like elements throughout, and where the various features are not necessarily drawn to scale.

Unlike electromagnetic radiation, ultrasound requires a medium for transmission, such as solids, air, gases, liquids, and liquid-laden gels. At frequencies above 100 kHz, it is

significantly absorbed by air which limits the efficacy of its propagation. On the other hand, ultrasound propagation can be highly directional over short distances. Ultrasound, being a pressure wave, will not interfere with electromagnetic transmissions of nearby electronic devices in any frequency band. Ultrasound mitigates the exposure of electromagnetic radiation to the body. Although there is a dearth of research, some conjecture high intensity cell phone radiation may have negative effects on tissue of the brain. Ultrasound power transmission into tissue is reviewed by U.S. Pat. No. 8,082,041 (Radziemski), which is hereby incorporated by reference in its entirety.

Ultrasound can be used to recharge batteries or capacitors (UltraSound Electrical Recharging—USer™) or to provide power directly to a device (UltraSound Electrical Power transfer—Usep™), both of which the present application is applicable to. Convenient charging of batteries for small electronics remains problematic, particularly in the area of cell phones where quotidian use requires frequent recharging. The appearance of various charging methods on the market, including electromagnetic induction chargers from Panasonic, Qualcomm, et al. is evidence of an unmet technological need which the present invention addresses, in addition to pocket chargers such as the Halo2Cloud.

FIG. 1 illustrates an exemplary electro-acoustic power pad 100. Although only a single portable electronic device 110 is depicted, multiple devices, such as cellular telephones, are able to be charged simultaneously. The current examples are intended to be generalize beyond just cell phones, including to other mobile computing or entertainment or communication devices, etc., generally “personal data devices”. Described in greater detail later in the disclosure, electroacoustic power pad comprises a charging surface 120 which mates the transmitter transducer 130 with the receiver transducer 140 which is disposed within the portable electronic device 110. The ultrasound receiver is contained within a receiver unit which may be external to portable electronic device 110 or integrated therein during fabrication of the electronic device 110.

The distance between the transmitter and receiver transducers 130, 140 may be zero (in contact) or up to 10 cm. Charging surface 120 may comprise one or more transfer media. The medium may be a liquid, solid, gas, or gel suitable for acoustic transmission. The front, flat face of the charging surface 120 may be approximately parallel to the front, flat face of the proximal to the receiver transducer 140. In another embodiment, curved faces are used to enhance focusing effects that ameliorate power transfer. In other embodiments, the distance between the transmitter and receiver transducers 130, 140 may be up to 100 cm or more, depending on the application, the ultrasound frequency, power delivered to the transmitter transducers 130 and, most importantly, acoustic medium.

FIG. 2 depicts an exemplary block abstraction of an electroacoustic charging system 200 comprising electroacoustic transmitter 210 and electroacoustic receiver 225. Electroacoustic transmitter 210 comprises power source 280, active power adaptor 275, transmitter controller 270, signal generator 230, amplifier 235, transmitter interface 240, transmitter transducer 245 and electromagnetic antenna 260. As will be discussed in greater detail with respect to FIG. 3, power source 280 can be direct or alternating current with active power adaptor 275 having the capacity to handle both.

Transmitter controller 270 maintains command over numerous components of electroacoustic transmitter 210 either by pre-programming or active feedback loop using

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user set or predetermined parameters. Transmitter controller 270 sets the output current and voltage egressing from active power adaptor 275. Transmitter controller 270 then proceeds to set the output (frequency, magnitude, phase, etc.) of signal generator 230. Signal generator 230 can be a variable frequency oscillator or a synthesized signal generator or other suitable waveform generating device, such as an LC circuit.

After setting the predetermined ultrasonic frequency, transmitter controller 270 amplifies the electrical signal via amplifier 235 and transmitter interface 240. Electroacoustic power levels can be set manually by an input command or be placed under the control of a feedback loop which keeps it at the predetermined value. A useful feedback parameter, whose value is relayed from the electroacoustic receiver 225 to the transmitter controller 270, is the power received at the ultrasonic receiver transducer 250. This information is transmitted over electromagnetic communication between antennae 260, 265. Typically it would be desirable to keep the output power stable for optimum operation of the device for the purpose of direct power. However, for battery 220 charging purposes, particularly in conjunction of modern lithium ion batteries, it is desirable to vary the power as a function of discharge.

Another important function of the transmitter controller 270 is to monitor and change the frequency of the ultrasound in order to continuously maximize the power delivery. Typically the range of changes due to temperature are approximately 10% of the resonant frequency. Compensation is achieved via signal generator 230 or other methods which are well known to those skilled in the art. Again the frequency can be set manually with an input command, or can be placed under the governance of the transmitter controller 270 utilizing input the feedback loop.

EA receiver 225 comprises battery 220, rectifier 215, receiver controller 285, receiver interface 290, receiver transducer 250 and electromagnetic antenna 265. In the present embodiment, battery 220 is a lithium ion battery. However, any chemical storage battery, such as lead acid, is suitable. In other embodiments, power storing capacitors are not beyond the scope of the present invention.

In operation, receiver transducer 250 and receiver interface 290 converts ultrasonic acoustic energy 255 to electrical power. Electrical power retains the shape of the transmitted waveform of ultrasonic acoustic energy 255 and needs to be transformed via rectification so as to be useful for battery 220 charging. Rectifier 215 is an electrical device that converts alternating current (AC), which periodically reverses direction, to direct current (DC), which flows in only one direction. In one or more embodiments, rectifier 215 may comprise one or more of the following: vacuum tube diodes, mercury-arc valves, copper and selenium oxide rectifiers, semiconductor diodes, silicon-controlled rectifiers and other silicon-based semiconductor switches.

In the present embodiment, rectifier 215 also comprises voltage regulation circuitry for maintaining battery 220 voltage by receiver controller 285. Within the receiver unit 225 are components for wireless communication to electroacoustic transmitter 210. These parameters comprise the disposition of battery charge, sensor location and temperature, and the load and state of the device being charged.

FIG. 3 illustrates an exemplary adaptive power supply 275 to an electroacoustic charging system. Adaptive power supply 275 determines whether ingressing power is derived from a DC source 310, AC source 340 or combination thereof, such as a sine wave with a DC offset. When utilizing power from DC source 310, adaptive power supply 275 converts to a voltage determined by transmitter controller

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270 using a DC-DC transformer, such as, a step down, buck boost or other suitable power transistor circuitry. In one embodiment, AC source 340 is 120V, 60 Hz. AC signal is processed through rectifier 320 in accordance with prior rectification discussion. It then can either be manipulated by regulator 330 or routed through DC-DC transform circuitry, both of which achieve the same result at output 345.

FIG. 4 illustrates an exemplary electroacoustic transducer mechanical alignment stage 420 disposed between electroacoustic transmitter and receiver units 430, 435. Piezoelectric element 440 is placed on the front face of electroacoustic receiver unit 435 which converts the acoustic energy to electrical and transferred to receiver output 445. Alignment is achieved by inserting acoustic coupling medium 425 into mechanical alignment flanges 415. The transmitter transducer 420 transmits acoustic energy of waveforms comprising continuous or pulsed width with variable duty cycle, pure sine waves, square waves, triangular waves or an arbitrary repetitive shape.

Acoustic coupling medium 425 can be a gel pad, ultrasound coupling pad, liquid, or a gas. The primary criterion in choosing an acoustic coupling medium is matching acoustic impedance(s) so that power transmission is maximized with a low loss material. Exclusion of air is also desired because air attenuates (lossy) ultrasound over frequencies of 100 kHz. Charging pad surface 410 maintains relatively parallel geometries for alignment.

FIG. 5 illustrates the feedback loop of an exemplary receiver module 500 an electroacoustic charging system. Receiver module 500 comprises electroacoustic receiver controller 560, graphic user interface 520, regulator/rectifier 550, output power monitor 510, sensor inputs 590, receiver transducer 530 and electromagnetic antenna 505. Data is collected and stored as parameters which is then transmitted over electromagnetic antenna 505 as an electromagnetic signal 580. The feedback loop is used to maximize acoustic power transmission 540 and monitor the health of the circuit. Power is monitored 510 and displayed at the GUI 520.

FIG. 6 demonstrates the selective activation of an exemplary transducer array of an electroacoustic charging system 600. In the present embodiment, feedback looping is used to activate transducers which are proximal to portable devices for charging. As can be seen, portable device 610 is being charged through receiver transducer 640 from transmission transducers 650-651. Portable device 620 is receives acoustic power through receiver transducers 641, 642 via transmission transducers 653-654. Portable device 630 is receives acoustic power through receiver transducers 643, 644 via transmission transducers 657-659. To conserve power, transducers 652, 655 and 656 are not activated.

FIG. 7 is the top down view of an exemplary transducer array 700 of an electroacoustic charging system with an exaggerated receiver transducer 710 in accordance with the present embodiment. There are two geometrical issues affecting alignment of a transmitter to the receiver in both the electromagnetic and ultrasound methods. The first is lateral translation over the receiver. The second is angular misalignment between the transmitter and receiver. The use of an array transmitter enables compensation for both of these misalignments. The voltage, current and/or power out of the receiver is a signal fed back to the external controller which commands the array transmitter to search for the optimum alignment. In another embodiment, an imaging ultrasound system is added to the transmitter unit to provide the feedback on the depth and orientation of the receiver, thereby assisting alignment. This may compensate for misalignment but may not search for a receiver in some designs.

FIG. 8 projects an isometric view of an exemplary two dimensional ultrasonic transducer array **820** of an electroacoustic power pad **800** for the purposes of charging in a non-mechanical alignment environment. In one or more embodiments two dimensional arrays are used for the purposes of non-mechanical alignment. A phased array is an array of transducers in which the relative phases of the respective signals feeding the transducers are varied in such a way that the effective radiation pattern of the array is reinforced in a desired direction and suppressed in undesired directions.

To keep the temperature of a device within tolerances, a cooling device such as a circulating-liquid heat exchanger may be provided. One or more Peltier coolers, miniature high-capacity fans, or other methods can be attached to or nearby the transmitter/receiver assembly. Temperature sensing devices within the transmitter and receiver may relay temperatures to the external controller, which will then apply the correct power to the cooling device in order to keep the temperature of the transmitter and receiver unit, and application under charge at safe values.

Piezoelectric elements of the transmitter and receiver may be monolithic elements of piezo ceramics, composite materials, polymers or other emerging materials. They may be one- or two-dimensional arrays of small piezoelectric elements of the same variety of materials. Capacitively Machined Ultrasound Transducers (CMUTs) or other mechanisms for inducing ultrasound vibrations are an alternative to conventional piezoelectric elements. In one embodiment, a 2-dimensional array can be used to provide non-mechanical alignment of transmitter and receiver in response to optimization signals generated within the receiver unit and relayed back to the transmitter.

In one environment, high temperatures, CMUTs are especially attractive, because temperatures of over 150 C can cause piezoelectric elements to fail. CMUTs can withstand temperatures up to 800 C and several atmospheres of pressure. So they are attractive options for engine compartment environments. They can also be easily made into arrays that can be used for wavefront steering.

FIG. 9 depicts an exemplary temporal abstraction of the side view of 2-dimensional electroacoustic phased array **920** and corresponding wavefront steering for non-mechanical alignment. In the present embodiment, signals **930** propagating from phased array **920** are differentiated by a constant phase **910**. The result is a beam steered acoustic wavefront **940**, which can be directed towards a portable device for the purposes of charging.

For angular alignment two effects are considered. The first of these is the turning of the beam's wave front from parallel to the face of the transmitter array, through an angle that makes the wave front parallel to the face of the receiver. This compensates for angular misalignment of the faces of the two transducers. For two dimensional surfaces this needs to be done along two axes. It is well known to those skilled in the art that this is accomplished by embedding a constant time differential, which results in a phase difference, between each element of the array.

FIG. 10 illustrates an abstraction circuit used to produce electrical signals delivered to 2-dimensional electroacoustic phased arrays. Clock **1010** supplies a timing standard to phase shifters **1025-1035**. Relative phase is received from beam position and feedback controller **1080** and sent to amplifiers **1060** which are tied to power supply **1020**. The amplified signals drive acoustic transducers **1050** in accordance with the latest embodiment. Transmitted power information **1040** is scanned and communicated back to beam

position and feedback controller **1080** through electromagnetic antenna **1070**. Phase can then be adjusted to maximize transmitted power to portable device.

FIG. 11 illustrates the side view of an exemplary electroacoustic charging cover **1100** to be used with any generic portable device **1110**. Electroacoustic charging cover adapts to any generic portable device **1110** using its charging port (e.g., USB) **1140** through the electroacoustic charging cover **1100** interface **1130**. Charging or direct power is accomplished through piezo element and conversion circuitry **1120**.

In an aspect, the present concepts may be applied to an existing market which needs retrofit batteries; in another aspect, the present concepts may be applied to a market where ultrasonic rechargeable batteries are integrated into the fabrication process of phones. The ability to add a retrofit battery pack to any cell phone can be useful. The battery pack contains piezoelectric elements that convert mechanical stress to electrical energy. The small pack sends the electrical energy to the battery inside the cell phone. This can eliminate the need to replace existing cell phone batteries with piezo batteries. Again, those skilled in the art will appreciate that the present exemplary device of a cellular phone can equally be generalized to cover other personal data devices such as personal digital assistants, gaming devices, communication platforms and mobile computers and tablets. In other words, electroacoustic elements that convert mechanical energy to electrical energy are designed within the battery packs, to which existing personal devices can be connected. Other personal data devices may have incorporated within them, the electromechanical receiver element or elements as well as the associated circuitry, which is activated by an external matched transmitter source.

FIG. 12 depicts top and side views of an exemplary electroacoustic charging system comprising electroacoustic power pad **1210** and cell phones **1230**, **1220**. Cell phones **1220**, **1230** have piezo receiver elements **1240**, **1250** integrated therein. Charging pads can be of sizes to accommodate one, two, or several devices at a time. The upper side view shows the latter case which the transmitter pad is made up of many independent piezo elements. These sense when a receiver is over them. Only those elements are then active. This keeps power requirements low and reduces heating of the pad and device. A soft cover can be used to avoid air in the interface with receiver. The charging pad houses transmitter elements, electronics and connection to a wall plug for input power. A pad that could accommodate several small appliances would be from 4 to 6 inches wide and from 6 to 8 inches long, and 1/2 to 1 inch thick. One inch square comprises approximately 20 to 45 such piezos. In another embodiment the entire pad comprises a single ultrasound producing element. This can be a piezoelectric material, CMUTs or flexible polymer PVDF.

FIG. 13 depicts top and side views of an exemplary electroacoustic charging system comprising electroacoustic power pad **1300** and portable devices **1310** according to an alternate embodiment. Portable devices **1310** are inserted into charging ports **1340** and held in place with soft springs whereby they are acoustically coupled to ultrasonic transducers **1420** through coupling media **1330**. The present configuration is desirable due to the exclusion of air at the boundary layer.

When a device is placed on the pad, the transmitter elements send out ultrasound signals, and powers up the receiver, which returns a signal to the pad indicating it is there. The proper transmitter elements are then activated to

perform charging. Alternately a proximity switch senses where the phone or battery is on the pad and piezos are activated only around the device. This way power is not lost when all piezos are activated. Only the ones around the device are activated. Then a signal goes from receiver to transmitter when the battery is fully charged.

FIG. 14 illustrates in-situ autonomous sensor charging of an electroacoustic system 1400 in a modern automobile according to an additional embodiment of the present invention. In the automobile industry, ultrasound power delivery will decrease costs and increase safety. Ultrasound recharging may be a power saving method in cases where sensors 1410, 1420, 1430 and transmitters are close to one another. However, the ability of recharging without running wires, like in car or truck doors, will save manufacturers money and reduce maintenance issues. Another embodiment attaches a stage via a slight suction generated by a boot and clamp method, as used for affixing items to the inside of an automobile windshield. A manual adjustment method, in one embodiment, uses three screws of fine pitch set in a triangle, which aligns the platform transmitter angularly over the receiver.

According to one embodiment, low-frequency ultrasound is used to illuminate one or more receivers in vibrational energy. The only limitation on the ultrasound frequency is its ability to penetrate a few feet of air without significant absorption. The receivers would convert vibrational energy into electrical energy. This is stored near the sensors or used in real time and functions like an RF-ID system. A few acoustic transmitters strategically positioned in places in the engine compartment, trunk and body can deliver power to a majority of the sensors of interest. The acoustic transmitters are powered from the main automotive battery or the power train itself. The availability of significant amount of power for transmitters will compensate for receiver inefficiencies. Issues of personnel safety can be avoided by appropriate placement of the transmitters, avoiding for example propagating through the auto's passenger compartment.

FIG. 14 illustrates a cutaway of an auto 1400 with a variety of sensors 1410-1440 and receivers (triangles) that pertain to the suspension and steering. The sensors and receivers may be in close proximity to one another. Or, the receivers may be tethered to the sensors and in a location more favorable to reception of the incoming ultrasound. Illustrated are the possible placements of a few ultrasound transmitters (diamonds) that may provide power to several sensors simultaneously. In one embodiment, the ratio of the frequency and size of the transmitters will be chosen so that the ultrasound is emitted over a large cone angle that contains the receivers of several sensors. Because ultrasound transducers can be made thin, less than 5 mm in thickness, they can fit up against flat panels in the compartments where they are mounted.

In the oil and gas industry, recharging batteries for undersea sensors or other applications is expensive requiring waterproof connections for the recharging lines, and dangerous because electrical recharging equipment can cause sparks which could lead to fires or explosions. Underwater compliant contact connections can be used with ultrasound to transmit to a receiver without an electrical connection and wirelessly, increasing safety and reducing cost.

Ultrasound spans a large range of frequencies, from roughly 20 KHz out to hundreds of MHz. Frequencies below about 100 kHz are characterized by less absorption in air, larger ultrasound transmitters, longer wavelengths and wider cone angles into which the ultrasound is transmitted. The latter can be reduced by using arrays of transmitters emitting

coherently, which also can be used to turn or focus ultrasound radiation. However these arrays will tend to be bulky. Frequencies above 100 kHz are characterized by being strongly absorbed by air, have more compact transmitters, more collimated radiation in the near and mid-fields, and shorter wavelengths.

While the former regime is appealing for the prospect of transmitting wireless power through air to many receivers, it also brings up questions of safety because people will be irradiated by the generally uncollimated beams. Also because the radiation will typically be emitted into a cone some 10 or 20 or more degrees in angular width, much of the transmitted power will miss receivers, requiring high power transmitters, so that some energy is incident on small receivers, again bringing up the issue of safety. Small electronics that have incident high power vibrational amplitudes could be damaged. Hence any scheme for ultrasound delivery through air in locations where humans are generally present may be rejected on the basis of safety and its effect on people and materials.

Some embodiments use frequencies in the 500 kHz to 1 to 2 MHz range. Other embodiments apply ultrasound in a range between 20 kHz and 100 kHz, depending on the application at hand. Also advantageous will be charging geometries that bring the transmitter close to the receiver, within 1 cm or less, with the two possibly separated by a thin flexible pad that excludes air. This type of arrangement ensures that no ultrasound radiation escapes the charging path and that much lower transmitted powers can be used because there is little power lost in side lobes. Narrowing this band of frequencies or choosing specific small frequency bands will depend on details of construction that minimize reflections, match ultrasound impedances for the materials used and optimize useful power transfer.

The present system and method may be applied to powering or charging automobile sensors at frequencies in the sub-100 kHz range, avoiding transmission into the driver/passenger compartment, thereby eliminating safety or electronic interference issues. Other applications hereof may be in underwater vehicles and systems. The ultrasound energy may propagate in these applications through liquid filled bladders, and then wirelessly to the device or battery under charge or power.

Other aspects hereof are directed to a novel electroacoustic charging system of portable devices. However, it is not beyond the scope of the present invention to apply ultrasound recharging or direct power to many small consumer appliances where suitable. These include ultrasonic toothbrushes, battery powered hearing aids, and a variety of electronic devices such as cell phones, pads, and notebook computers. In the communication data device field, the present concepts can be applied to receivers, transmitters, transceivers, including those that are network-enabled such as Web-enabled to carry out communications of any presently known or equivalently understood format.

Another embodiment includes a portable, compact, lightweight power pack that can be placed in a conventional bag, purse, pocket or similar personal container for transporting to wherever the power delivery is needed.

The embodiments described and illustrated herein are not meant by way of limitation, and are rather exemplary of the kinds of features and techniques that those skilled in the art might benefit from in implementing a wide variety of useful products and processes. For example, in addition to the applications described in the embodiments relating to power transmission and conversion for use in battery charging, those skilled in the art would appreciate that the present

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disclosure can be applied to any electroacoustic direct power topologies. However, it is to be appreciated that the present exemplary embodiments are also amenable to other like applications.

The present invention should not be considered limited to the particular embodiments described above, but rather should be understood to cover all aspects of the invention as fairly set out in the attached claims. Various modifications, equivalent processes, as well as numerous structures, materials and unforeseen technologies to which the present invention may be applicable, will be readily apparent to those skilled in the art to which the present invention is directed upon review of the present disclosure. The claims are intended to cover such modifications and equivalents.

What is claimed is:

1. A portable device charging system comprising:
 - a transmitter comprising:
 - an electroacoustic charging pad having one or more electroacoustic transmitting elements;
 - a power source;
 - a signal generator;
 - an amplifier;
 - a proximity switch; and
 - a first antenna;
 - a receiver comprising:
 - one or more electroacoustic receiving elements;
 - a battery; and,
 - a second antenna;
 whereby, said first and second antennae are in electromagnetic communication and said electroacoustic transmitting and receiving elements are in ultrasonic communication,
 said proximity switch senses a location of said receiver on said charging pad, and
 said controller only activates said electroacoustic transmitting elements proximal to said location.
2. The charging system of claim 1, wherein said power source is a direct current.
3. The charging system of claim 1, wherein said power source is an alternating current.
4. The charging system of claim 1, whereby signals are generated by said signal generator and amplified by said amplifier.
5. The charging system of claim 4, whereby said amplified signals are transmitted over said one or more electroacoustic transmitting elements.
6. The charging system of claim 5, whereby said transmitted ultrasonic signals are received by said electroacoustic receiving elements.
7. The charging system of claim 1, wherein said controller controls a feedback control loop.
8. The charging system of claim 7, wherein parameters utilized in said feedback control loop are transmitted over first and second antennae via electromagnetic communication.
9. The charging system of claim 1, wherein said one or more electroacoustic transmitting elements comprise an electroacoustic material such as a piezoelectric material.

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10. The charging system of claim 1, wherein said one or more electroacoustic transmitting elements are comprised by a phased array.

11. The charging system of claim 1, wherein said receiver is integrated into a personal data device.

12. The charging system of claim 1, whereby said one or more electroacoustic transmitting elements transmit at a frequency between 500 kHz and 2 MHz.

13. The charging system of claim 1, wherein said one or more electroacoustic transmitting elements and electroacoustic receiving elements are disposed less than 1 cm from one another.

14. The charging system of claim 13, wherein said charging pad includes a charging surface comprised of an acoustic medium, said acoustic medium disposed between said one or more electroacoustic transmitting elements and electroacoustic receiving elements, the acoustic medium excluding air between said one or more electroacoustic transmitting elements and electroacoustic receiving elements.

15. The charging system of claim 14, wherein the acoustic medium is a low loss material between the frequencies of 500 kHz and 2 MHz.

16. The charging system of claim 1, wherein the density of said one or more electroacoustic transmitting elements is between 20-45 elements per square inch.

17. The charging system of claim 1, further comprising a mechanical alignment stage disposed on said charging pad.

18. The charging system of claim 1, further comprising any of: a power output monitor, rectifier, a voltage regulator, a phase delay circuit, and a clock.

19. A system for delivering energy to power or charge an electrical source, comprising:

- an electrical power supply;
- a transmitting ultrasound transducer that takes electrical energy from said electrical power supply and transmits an ultrasound energy wavefront in a determined direction;
- a receiving ultrasound transducer, coupled to said transmitting ultrasound transducer through an acoustic coupling medium, that receives said ultrasound energy wavefront and generates a generated electrical output through transduction in said receiving ultrasound transducer;
- an electronic signal conditioning circuit including a rectifier receiving said generated electrical output and outputting a conditioned electrical output;
- a controller for controlling an amount of conditioned electrical output to generate a controlled electrical output; and
- a battery unit receiving said controlled electrical output so as to charge said battery with electrical energy derived from said controlled electrical output.

20. The charging system of claim 17, further comprising an acoustic coupling medium disposed in mechanical alignment flanges of said mechanical alignment stage, the acoustic coupling medium comprising a gel pad, an ultrasound coupling pad, or a liquid.

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