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(71) Applicant (*for all designated States except US*): 3M INNOVATIVE PROPERTIES COMPANY [US/US]; 3M Center, Post Office Box 33427, Saint Paul, Minnesota 55133-3427 (US).

(72) Inventors: HAGEN, Kathy L.; 3M Center, Post Office Box 33427, Saint Paul, Minnesota 55133-3427 (US). LIBBEY, Albert H.; 1372 State Road, Eliot, Maine 03903 (US).

(74) Agents: BERN, Steven, A. et al.; 3M Center, Office of Intellectual Property CounselPost Office Box 33427, Saint Paul, Minnesota 55133-3427 (US).

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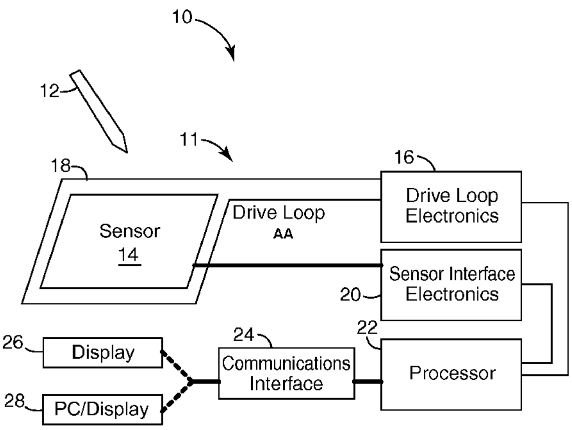

(57) Abstract: An untethered stylus is configured to cooperate with a location sensor. The location sensor is configured to generate a magnetic field comprising a number of frequencies and communicatively couple to the stylus. The stylus is configured to include a housing having a tip and a shield. An antenna arrangement, provided at the housing, includes a number of coil resonant circuits each tuned to a different frequency of the magnetic field. Each of the coil resonant circuits is configured to be energized in response to the magnetic field. The coil resonant circuits of the antenna arrangement may each include an inductive coil disposed about a ferrite rod in a spaced relationship. A connection couples the coil resonant circuits between the tip and shield of the housing to define separate channels for communicatively coupling the stylus tip and the location sensor.

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UNTETHERED STYLUS EMPLOYING SEPARATE COMMUNICATION CHANNELS

The present invention relates generally to location sensing systems and methods and, more particularly, to location sensing systems and methods that employ an untethered stylus as a user input implement.

BACKGROUND

Personal computing systems of varying type and configuration typically provide one or more user interface devices to facilitate user interaction with such computing systems. Well known user interface devices include a keyboard, mouse, trackball, joystick, and the like. Various types of personal computing devices, such as tablet PCs, provide a pen apparatus that can be manipulated by the user, much in the same way as a pencil or ink pen.

Conventional computing devices that provide for user input via a pen or other pointer implement typically employ an electromagnetic inductive system. The electromagnetic inductive system usually comprises an electromagnetic pen or pointer apparatus and a digitizer in the form of a tablet. Changes in pen location relative to the digitizer's sensing surface are detected and location computations are made to determine the coordinates of the pen.

SUMMARY OF THE INVENTION

The present invention is directed to communicative interaction between an untethered implement and a location sensing device. According to embodiments of the present invention, an untethered stylus is configured to cooperate with a location sensor, such as a touch location sensor. The location sensor is configured to generate a magnetic field comprising a number of frequencies and communicatively couple to the stylus. The stylus may be configured to include a housing having a tip and a shield. Circuitry is provided in the housing, and an antenna arrangement is provided at the housing.

The antenna arrangement preferably includes a number of coil resonant circuits each tuned to a different frequency of the magnetic field. Each of the coil resonant circuits is configured to be energized in response to the magnetic field. The coil resonant circuits of the antenna arrangement may each include an inductive coil disposed about a ferrite rod in a spaced relationship.

A connection is provided between the coil resonant circuits. The connection couples the coil resonant circuits between the tip and shield of the housing to define separate channels for communicatively coupling the stylus tip and the location sensor. The connection between the coil resonant circuits may be a series connection or a parallel connection.

According to various configurations, at least one of the coil resonant circuits is configured to capacitively couple to the location sensor. According to other configurations, at least one of the coil resonant circuits is configured to magnetically couple to the location sensor.

In various configurations, a stylus position signal is communicatively coupled between a first coil resonant circuit and the location sensor, and a stylus status signal is communicatively coupled between a second coil resonant circuit and the location sensor. In other configurations, a stylus position signal and a stylus status signal is communicatively coupled between one of the coil resonant circuits and the location sensor. A number of stylus status signals may be communicatively coupled between the coil resonant circuits and the location sensor, and the stylus status signals may be detected in terms of a phase change at the location sensor.

The circuitry of the stylus may include modulation circuitry coupled to at least one of the coil resonant circuits. A stylus status signal may be modulated by the modulation circuitry and communicatively coupled between at least one coil resonant circuit and the location sensor.

In accordance with various embodiments, methods of communicatively coupling a stylus and a location sensor may involve receiving, at the stylus, a magnetic field comprising a number of frequencies, and energizing, in response to the received magnetic field, a number of coil resonant circuits of the stylus each tuned to a different frequency of the magnetic field. Methods may further involves establishing separate channels for communicatively coupling the stylus and the location sensor, wherein each of the separate channels is associated with one of the coil resonant circuits. Communication between the stylus and the location sensor may be effected via the separate channels.

Stylus position information and stylus status information may be communicated between the stylus and the location sensor via one or more of the separate channels. For example, stylus position signal may be communicated between the stylus and the location sensor via a first separate channel, and a stylus status signal may be communicated between the stylus and the location sensor via a second separate channel. By way of further example, a stylus position signal may be communicated between the stylus and the location sensor via a first separate channel, and a stylus status signal may be communicated between the stylus and the location sensor via the first separate channel.

A number of stylus status signals may be communicated between the stylus and the location sensor, and the stylus status signals may be detected as a phase change detectable at the location sensor. Methods may further involve modulating a stylus status signal and communicating the modulated stylus signal between the stylus and the location sensor.

The above summary of the present invention is not intended to describe each embodiment or every implementation of the present invention. Advantages and attainments, together with a more complete understanding of the invention, will become apparent and appreciated by referring to the following detailed description and claims taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a diagram of a location sensing system that includes an untethered stylus and a location sensing device in accordance with embodiments of the present invention;

Figure 2 is a diagram of various components of a location sensing device that cooperates with a stylus in accordance with embodiments of the present invention;

Figure 3 is a diagram of an apparatus for generating an excitation magnetic field which is received by a stylus in accordance with embodiments of the present invention;

Figure 4 is a diagram of another apparatus for generating an excitation magnetic field which is received by a stylus in accordance with embodiments of the present invention;

Figure 5 is an illustration of various components of a stylus implemented in accordance with embodiments of the present invention;

Figure 6 shows a schematic model of a parallel coil-capacitor circuit that may be implemented in a stylus in accordance with embodiments of the present invention;

Figure 7 shows a schematic model of a multiplicity of coil-capacitor resonant circuits connected in series that may be implemented in a stylus to effect communication of stylus information for detection by a location sensor in accordance with embodiments of the present invention;

Figure 8 shows a schematic model of a multiplicity of coil-capacitor resonant circuits connected in parallel that may be implemented in a stylus to effect communication of stylus information for detection by a location sensor in accordance with embodiments of the present invention; and

Figure 9 shows a schematic model of a multiplicity of coil-capacitor resonant circuits connected in series, at least one of the coil-capacitor resonant circuits configured to provide power for electronics of the stylus, and one or more other coil-capacitor resonant circuits configured to effect communication of stylus information for detection by a location sensor in accordance with embodiments of the present invention;

Figure 10 is a schematic of a power converter circuit that does not employ a Zener diode in accordance with embodiments of the present invention;

Figure 11 is a plot showing a comparison of stylus coil voltage and stable V_{CC} voltage as a function of drive current through a nearby inductively coupled drive loop, the plot demonstrating provision of a substantially stable DC voltage, V_{CC}, in response to a relatively high AC induced coil voltage of increasing amplitude; and

Figure 12 illustrates circuitry of a dual coil stylus that includes a dedicated power channel that incorporates the power converter circuitry of Figure 10 and a single data communication channel in accordance with embodiments of the present invention.

While the invention is amenable to various modifications and alternative forms, specifics thereof have been shown by way of example in the drawings and will be described in detail. It is to be understood, however, that the intention is not to limit the invention to the particular embodiments described. On the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within the scope of the invention as defined by the appended claims.

DETAILED DESCRIPTION OF EMBODIMENTS

In the following description of the illustrated embodiments, reference is made to the accompanying drawings which form a part hereof, and in which is shown by way of illustration, various embodiments in which the invention may be practiced. It is to be understood that the embodiments may be utilized and structural changes may be made without departing from the scope of the present invention.

The present invention is directed to methods and systems for communicating information between an untethered stylus and a location sensing system using multiple communication channels. Embodiments of the present invention provide for powering an untethered stylus using a dedicated power channel and communicating information using one or more separate data communication channels, the power and data communication channels established between the untethered stylus and a location sensing system.

Embodiments of the present invention provide for powering circuitry of an untethered stylus and communicating analog and/or digital stylus information between the untethered stylus and a location sensor, such as a digitizer or a touch location sensor in combination with a digitizer, via a continuous or discontinuous magnetic field. An excitation coil arrangement is provided at the location sensor and employed to produce a continuous or discontinuous magnetic field in the plane of the location sensor, the magnetic field comprising multiple harmonics or frequency components.

According to some embodiments, separate data communication channels are established between an untethered stylus and a location sensor, wherein each data communication channel corresponds to one of the harmonics or frequency components of the excitation magnetic field. The independent channels may be used for communication of position or data to and from the untethered stylus and the location sensor. The addition of supplemental channels increases the available communication bandwidth, allowing use of simple and inexpensive modulation schemes. Additional channels allow data communication without disrupting the communication of stylus position.

According to other embodiments, a power channel and one or more data communication channels are established between an untethered stylus and a location sensor. The power channel and each data communication channel corresponds to one of the harmonics of frequency components of the excitation magnetic field.

An untethered stylus according to embodiments of the present invention includes an antenna arrangement comprising multiple resonant circuits that are tuned to resonate at different frequencies of a harmonic magnetic excitation field. In some embodiments, power for the resonant circuits of all data communication channels is derived from the harmonic magnetic field. In other embodiments, power needed for active circuitry of the stylus is derived from a dedicated resonant circuit that is coupled to a power regulator or converter. The power regulator includes an AC-to-DC converter that is used to supply DC power to active circuitry of the stylus. One or more other resonant circuits of the stylus are configured for coupling with the location sensor via separate data communication channels from which stylus proximity and status data may be acquired.

According to embodiments of the present invention, a drive coil or coils provided at a location sensor produce a harmonic magnetic field with two or more frequency components corresponding to two or more coil resonance frequencies of the stylus. The stylus preferably houses two or more inductive coils wrapped around a ferrite cylinder each tuned with a capacitor to resonate at a different frequency of the excitation magnetic field. The stylus coils may be configured for coupling magnetically to detection coils in the location sensor, such as a digitizer. The stylus coils may be coupled in series or parallel (with a coupling circuit) and connected between the stylus shield and the stylus tip. The location sensor, such as a digitizer, is configured to receive the signals coupled to the stylus tip.

A stylus of the present invention may employ two or more coils that may be used for a variety of purposes. The following are illustrative examples of several implementations or uses that can be combined to achieve desired stylus functionality. For example, the magnetic field excitation frequencies may be fixed and one coil of the stylus may be tuned with an inductive or capacitive stylus pressure sensor to produce a phase change detectable at the location sensor. Another coil of the stylus may be tuned to indicate user-actuatable switch closures and produce a phase change detectable at the location sensor. A given coil of the stylus may be used for stylus position detection and tuned with switch closures to produce a phase change detectable at the location sensor.

By way of further example, one magnetic field excitation frequency may be fixed and one magnetic field may be swept over a range of frequencies including the frequency of one stylus resonant coil. The fixed frequency coil may be used for stylus position detection and tuned with switch closures to produce a phase change detectable at the location sensor. The resonance frequency of the swept stylus coil may be tuned with an inductive or capacitive pen pressure sensor. The receiving circuit of the location sensor may be configured to detect the resonance in the swept stylus coil by detecting the frequency at which the voltage is at a maximum.

Further, one magnetic field excitation frequency may be fixed and one magnetic field alternately turned on and off. The constant excitation drive coil may be used for stylus position detection and tuned with switch closures to produce a phase change detectable at the location sensor. The transient excitation stylus coil may be tuned with an inductive or capacitive stylus pressure sensor. The receiving circuit of the location sensor may be configured to detect the resonance in the transient stylus coil by detecting the frequency when the excitation magnetic field is off.

In other embodiments, one or more user-actuatable switches may be configured to change the resonance frequency of stylus circuitry. Frequency control and/or feedback circuitry of the stylus may be used to convey stylus status information in response to the state of one or more stylus switches. For example, an oscillator circuit provided at the stylus may be configured to oscillate at a frequency corresponding to data to be communicated from the stylus. The oscillator circuit may be configured to amplitude modulate a voltage signal at the oscillator frequency. An amplitude demodulator at the location sensor may be configured to demodulate the amplitude modulated signal received from the stylus and to produce a sinusoid at the stylus oscillator frequency. A frequency demodulator at the location sensor may be configured to detect the stylus data. Various forms of amplitude modulation, for example, may be used, preferably with separation of AM modulation frequency from adaptive frequency control bandwidth. A stylus implemented in accordance with embodiments of the present invention may incorporate a low power oscillator of a type disclosed in commonly owned U.S. Patent Application entitled “Oscillator Circuit for Use in an Untethered Stylus,” filed concurrently herewith under Attorney Docket No. 62136US002, which is hereby incorporated herein by reference.

Embodiments of an untethered stylus of the present invention may be implemented in the context of a location sensing system, embodiments of which are illustrated in Figures 1 and 2. According to the embodiments shown in Figures 1 and 2, a location sensing system 10 includes a stylus 12 that interacts with a sensing device 11. The sensing device 11 includes a location sensor 14, such as a digitizer. The stylus 12 is preferably configured as a tetherless or cordless implement that does not have a battery. Rather, the stylus 12 derives power from a magnetic field generated by the sensing device 11. Although preferred embodiments of an untethered stylus do not include a battery, some embodiments may employ a battery, such as a rechargeable battery that is recharged from energy derived from the magnetic field of the drive signal. A battery may be used to provide power to various circuits of the stylus, such as a modulator or pressure sensor (e.g., tip or eraser pressure sensor).

The sensing device 11 is shown to include one or more drive loops or coils 18 coupled to drive loop electronics 16 that cooperate to generate a magnetic field comprising multiple frequency components. The magnetic field may be a continuous or discontinuous harmonic magnetic field. The stylus 12, having derived power from the magnetic field emanating from the drive coil(s) 18, broadcasts a signal(s) from which stylus location and status may be determined by the sensing device 11.

The stylus 12 is preferably configured to include one or more user-actuatable buttons or switches, such as those commonly employed to implement various mouse functions (e.g., right and left mouse buttons). The tip of the stylus 12 may incorporate a pressure sensor from which applied pressure can be resolved and transmitted to the sensing device 11. Eraser functionality may also be incorporated in the form of a switch or pressure sensor at the stylus end opposite the tip.

Sensor interface electronics 20 is coupled to the sensor 14 and facilitates measurement of signals developed at the sensor 14 in response to signals broadcast by the stylus 12. The sensor interface electronics 20 is preferably connected to the sensor 14 via a shielded connector. The sensor interface electronics 20 includes circuitry for measuring the signal levels present on the individual traces of the sensor 14, and is typically configured to reject as much noise as possible.

According to one configuration, the sensor 14 includes a digitizer that incorporates a detection grid and electronics as is known in the art. For example, such a detection grid may include pairs of position resolving conductors each of which forms one or more differential coil elements in the sensor 14, with each conductor pair receiving a magnetic signal transmitted by the stylus 14. An illustrative example of a digitizer having such a detection grid configuration, elements of which may be employed in a touch location sensor system of the present invention, is disclosed in U.S. Patent Nos. 4,786,765; 5,218,174; 5,633,471; 5,793,360; 6,667,740; and 7,019,672; which are hereby incorporated herein by reference.

According to another configuration, the sensing device 11 may incorporate a sensor 14 that effectively incorporates a digitizer and a touch-sensitive sensor. The digitizer, according to this configuration, allows the location and status of the stylus 12 to be determined. The touch-sensitive sensor allows the location of a finger touch to be determined. This configuration allows a user to use either the stylus 12 or a finger to indicate a desired location on a computer display, as well as determine the location and status of the stylus 12.

The touch-sensitive sensor 14 typically includes a matrix that capacitively couples to the stylus 12 and/or a finger. In this configuration, the sensor 14 of the sensing device 11 is preferably made up of a series of transparent conductors placed upon a glass or plastic cover that can be placed in front of an LCD display. One side of the glass or plastic sheet has conductors in the X direction, and the opposite side has conductors in the Y direction. Examples of suitable touch-sensitive sensors 14 are disclosed in commonly owned U.S. Patent Nos. 6,133,906 and 6,970,160, in commonly owned U.S. Published Application No. 2005/0083307, in U.S. Patent Nos. 6,762,752 and 6,690,156, and in U.S. Published Application No. 2004/0095333, each of which is hereby incorporated herein by reference.

An embodiment that incorporates a digitizer and touch-sensitive sensor advantageously allows a user to point a stylus at a computer display and have the location and status of the pointing device determined and, when a finger is used to point at the display device, allows for the determination of the location of a finger touch at the display device. The dual use aspects of this embodiment of a sensing device 11 make it particularly useful in tablet PC applications.

For example, a digitizer arrangement allows a user to use a stylus to input information, indicate operations the user wants to take, and write or draw on the display. The touch-sensitive sensor allows the user to “type” information onto a virtual keyboard on the display screen, for example. This would allow the vendor of the computing system, in which a dual touch location sensor system of the present invention is implemented, to eliminate the keyboard and the associated bulk it requires. It is understood that a digitizer and a touch-sensitive sensor need not be implemented together in all configurations, but inclusion of both sensing devices provides for enhanced user interaction with a computing system that incorporates a sensing system 10 of the present invention.

According to one embodiment, the drive coil or coils 18 may be constructed of wire, such as 36 gauge wire, looped several times (e.g., 4 times) around the periphery of the frame of sensing device 11. In one implementation, the drive coil(s) 18 may have an inductance of about 21 μH and an impedance of about 14 Ohms at 100 kHz. The drive coil(s) 18 is connected to a signal generator of the drive loop electronics 16. The signal generator may be configured to produce multiple periods (e.g., 200) of a sine wave signal at each of a number of different frequencies (e.g., 92 kHz and 163.5 kHz). The signal generator may, for example, produce an output signal of 0.4 V_{pp}, resulting in approximately 28mA of current that flows in the drive coil(s) 18.

Figures 3 and 4 are simplified illustrations of a drive coil(s) 18 and signal generators 17A, 17N that cooperate to generate a harmonic magnetic excitation field comprising multiple frequency components. In general, drive coil(s) 18 in the plane of the location sensor 14 provide a harmonic excitation magnetic field at frequencies corresponding to the resonance frequencies of the respective stylus coils.

Figure 3 illustrates a dual excitation coil approach to harmonic magnetic field generation according to embodiments of the present invention. In this illustrative example, two separate coil loops 18A, 18N are preferably arranged in the plane of the location sensor 14. A sinusoidal current ($I = A_1 * sin(\omega_1 * t)$ is produced by a first signal generator 17A with peak magnitude A_1 at radian frequency ω_1 and is applied to the rectangular coil 18A. A sinusoidal current ($I = A_2 * sin(\omega_2 * t)$ is produced by a second signal generator 17N with peak magnitude A_2 at radian frequency ω_2 and is applied to the rectangular coil 18N.

The combination of these drive coils 18A, 18N produces a harmonic magnetic field with radian frequency components at ω_1 and ω_2. Alternatively, and as shown in Figure 4, a single coil 18 may be driven at each end by voltage sources 17A, 17N with respective harmonic frequencies ω_1 and ω_2. Additional excitation frequencies may be added by increasing the number of coil(s) (e.g., 18A, 18B, 18C, ... 18N) and/or signal generators (e.g., 17A, 17B, 17C, ... 17N).

In general terms, the stylus 12 is configured to collect energy from the magnetic field generated by drive coil 18/drive loop electronics 16 using tank circuitry. The tank circuitry is preferably tuned to resonate at the frequencies that the drive coil(s) 18 are driven. In one illustrative example, the tank circuitry may include two tank circuits set to resonate at 92 kHz and 163.5kHz, respectively. Each of the resonant tank circuits of the stylus 12 builds amplitude during the burst produced by the drive coil(s) 18 and then gradually loses signal amplitude after the drive coil(s) 18 is turned off. The time associated with the exponential charging and discharging of the resonant tank circuits of the stylus 12 is determined by the capacitive and inductive elements in the tank circuits.

As is shown in Figure 2, an envelope detector circuit 30 of the sensor interface electronics 20 is configured to detect signals developed on individual traces of the sensor 14. The signals output by the envelope detector circuit 30 are digitized by use of analog-to-digital (A/D) converters 32. Each trace of the sensor 14 may have a dedicated A/D converter 32. Alternatively, two or more traces may share a common A/D converter 32 via a switch having a sufficient switching frequency. The envelope detector circuit 30 is configured to provide sufficient gain to make the resultant signal match the requirements of A/D converters 32. The envelope detector circuit 30 may be configured to generate a signal(s) having the same shape as an imaginary line describing the upper bound of the sensor signal. In such a configuration, the envelope detector circuit 30 effectively transforms each of the stylus signals (e.g., 92 kHz and 163.5kHz, respectively) into a DC or low frequency signal that is more readily digitized. The envelope detector circuit 30 preferably incorporates one or more synchronous demodulators.

A processor 22 is coupled to the drive loop electronics 16, sensor interface electronics 20, and a communications interface 24, as is shown in Figure 1. The processor 22 coordinates the operations of drive loop electronics 16 and sensor interface electronics 20, and is configured to determine stylus/finger location and stylus status. Stylus/finger location and stylus status determinations may be made by the processor 22 using known approaches, such as those discussed in the patent references incorporated herein by reference. In one embodiment, processor 22 determines stylus/finger location and stylus status in accordance with the methodologies disclosed in commonly owned U.S. Patent Application No. 11/557,829, entitled “Touch Location Sensing System and Method

Employing Sensor Data Fitting to a Predefined Curve," filed on November 8, 2006, which is hereby incorporated herein by reference.

The location and status information computed by the processor 22 is communicated to a computer and/or display 26 via a communications interface 24. The communications interface 24 may be configured as an RS-232 or USB interface, for example. The processor 22 may be configured to drive a display 26 directly. Alternatively, a computer 28 may be coupled to the communications interface 24 and receive the location and status information from the processor 22, and drive its display. The processor 22 or computer 28 may be configured to control cursor velocity, momentum and other factors to enhance the user experience with the sensing system 11.

Referring now to Figure 5, there is shown an embodiment of an untethered stylus 12 of the present invention that may be implemented in the context of a location sensing system as described above or other sensing system known in the art. In accordance with the embodiment shown in Figure 5, a stylus 12 houses electronics 52, which may include an oscillator circuit 55 (optional), and a multiplicity of coils 54A, 54N wrapped around a ferrite cylinder 53. The ferrite cylinder 53 serves to increase signal amplitude. An applied harmonic magnetic field produced at the surface of the location sensor (e.g., digitizer) or a display, for example, couples flux through the ferrite cylinder 53 and thus to the coils 54A, 54N when the stylus 12 is placed in the applied field.

In one implementation, the coils 54A, 54N may be configured as 315 turn coils each having a length of about 4.5 mm. The coils 54A, 54N may be spaced about 11 mm apart on the ferrite cylinder 53. The ferrite cylinder 53 may have a length of about 25 mm with a relative permeability of about 2300. Each of the coils 54A, 54N is coupled to additional circuitry, such as that shown in Figures 6-9, to define resonant circuits.

It is understood that more than two coils 54 may be provided in stylus 5 to provide a corresponding number of data communication channels or a combination of data communication channels and a power channel. The magnetic coupling between the coils 54A, 54N, however, must be kept relatively low. It is not considered practical to have separate resonance conditions associated with the two or more coils 54A, 54N when the magnetic coupling is relatively high. Low coupling may be accomplished by separating the coils 54A, 54N on the ferrite cylinder 53 so that most of the magnetic flux lines associated with one coil's current do not pass through the second coil. Experiments have demonstrated good results with a dual coil arrangement with a coupling of approximately 28%.

In general, each of the ferrite coil arrangements 56A, 56N resonates with a separate parallel-connected capacitor arrangement of electronics 52, and each is tuned to a different excitation field frequency. In some embodiments, two or more parallel coil-capacitor combinations associated with a corresponding number of coils 54A, 54N are connected (in series or parallel) between the stylus tip 57 and the stylus shield 59 to define a corresponding number of data communication channels.

In other embodiments, one parallel coil-capacitor combination associated with one coil 54A, 54N is connected to a power regulation circuit to define a power channel. One or more other parallel coil-capacitor combinations associated with other coils 54A, 54N is/are connected (in series or parallel) between the stylus tip 57 and the stylus shield 59 to define one or more data communication channels.

The shield 59 may form part of, or otherwise be connected to, the stylus housing so that it can be touched, and therefore grounded, by a user's hand when held. The shield 59 may be situated to extend over the circuitry region of the stylus 12, and preferably has a discontinuous shape, such as a "C" shape, so as to avoid eddy currents that could otherwise arise in a closed loop shield arrangement.

The stylus tip 57 couples capacitively to the location sensor from which location information is derived. To provide stylus status information according to embodiments of the present invention, stylus status and changes thereof may be detected by observing a change in phase of the stylus transmitted frequency or though a transient frequency change caused when the drive coil current is turned off.

According to other embodiments, at least one of the ferrite coil arrangement 56A, 56N powers the electronics 52, which may include a low power oscillator or oscillators provided on oscillator circuit 55. The oscillator(s) provided on oscillator circuit 55 are typically configured to amplitude modulate the stylus tip voltage at the oscillator(s) frequency or frequencies. The frequency of the oscillations is changed to reflect the stylus status, such as switch closures or tip pressure changes.

In other embodiments, the invention may be implemented with magnetic-sensing digitizer systems as are known in the art. An untethered magnetic stylus is similar to the capacitive stylus shown in Figure 5, except the resonant circuit comprising ferrite coil arrangement 56 and separate parallel-connected capacitor of the electronics 52 need not be connected to tip 57 nor to a shield 59. Untethered magnetic styluses are well known in the art, and are described in previously incorporated U.S. Patent Nos. 4,786,765; 5633471; 5793360; 6,667,740, and 7,019,672. Embodiments of the present invention that are implemented using an untethered magnetic stylus may employ a location sensor that includes multiple drive loops as disclosed in the referenced patents. In such embodiments, a separate sensing grid and separate drive loops need not used. Rather, each of the drive loop coils is alternately coupled to transmitting circuitry and then to receiving circuitry to alternately transmit and receive from one of multiple drive loop coils that are placed in the active area, typically under the display.

Figure 6 shows a schematic model of a parallel coil-capacitor circuit that may be implemented in a stylus in accordance with embodiments of the present invention. Figure 6 shows a capacitor C1 connected in parallel with a coil 54 that defines a coil-capacitor resonant circuit configured to resonate at an excitation frequency or a transmitted frequency. The voltage developed across the coil 54, which is shown modeled as voltage generator 61, is coupled to the stylus tip 57 and then capacitively coupled to the location sensor, such as sensor 14 shown in Figure 1. The voltage developed across the resonating coil 54 is modulated with one or a combination of the techniques discussed herein. An added ferrite cylinder 53 about which coil 54 is preferably wrapped, as shown in Figure 5, has the effect of increasing the magnetic flux B and signal coupled by the drive coil of the location sensor to the receiving coil 54 of the stylus 12.

The capacitance value of capacitor C1 shown in Figure 6 is selected such that the capacitance, C, of capacitor C1 resonates with the coil inductance, L, at an excitation angular frequency ω so that there is no voltage drop across the LC combination. Two different voltages in this circuit can be considered. The first voltage of consideration is the voltage V (shown in terms of voltage source 61) that develops across the coil 54 through magnetic induction. It is well understood that this voltage 61 is basically equal to the number of stylus coil turns N times the coil cross section A times the rate of change of the magnetic flux density passing through the ferrite cylinder, which is given by $V=N*A*dB/dt$.

The second voltage of consideration is the voltage that develops across the capacitor C1. This voltage V_C is also the stylus tip voltage. From basic circuit analysis at resonance, it follows that: $V_C = V/(\omega RC) = V(\omega L/R)$ with the quantity $1/(\omega RC) = (L\omega)/R$ defined as the resonant circuit quality factor *Q,* where ω is expressed in terms of radians per second. As will be discussed below, this second voltage may be modulated for purposes of communicating stylus status data to a location sensor according to embodiments of the present invention.

With continued reference to Figure 6, one approach to transmitting stylus status information in addition to stylus position information is through addition of a second capacitor C2 connected to the first capacitor C1 through a switch 76. Opening and closing the switch 76 causes the resonance frequency of the coil-capacitor combination 54/C1 to change. This change may be detected by observing a change in phase of the stylus transmitted frequency or though a transient frequency change caused when the drive coil current is turned off. Alternatively, it is possible to turn off and on the connection to the stylus thus providing a sequence of bits representing a digital information. Other approaches may be implemented to provide this communication. For example, similar schemes may be used to communicate data or timing information from the location sensor to the stylus.

Because many of such data communication methods involve the frequencies associated with the position detection scheme implemented by the location sensor, these techniques may interfere with the detection of the position information and require, and it may be desirable to add circuitry to reduce the interference. Embodiments that incorporate an oscillator of a type described herein that employ frequency modulation of an amplitude-modulated signal removes these difficulties, as it is practical to demodulate the amplitude modulation and detect the frequency of the modulation without having to turn off the excitation coil and in the presence of varying phase.

Various dual coil stylus configurations are shown in Figures 7-9. Dual coils are illustrated in Figures 7-9 for purposes of clarity, and it is understood that more than two coils may be implemented in a stylus to provide for a multiplicity of data communication channels and, if desired, a dedicated power channel. Figures 7 and 8 illustrate two configurations of a dual coil stylus that provide for two frequency-separated data communication channels. Figure 9 illustrates a dual coil stylus configuration that includes a dedicated power channel and a single data communication channel. As was discussed previously, this single data communication channel may be used to effect communication of one or both of stylus tip proximity and stylus status (i.e., one type or multiple types of information communicated via a single data communication channel).

Figures 7-9 show different coil stylus configurations that include circuitry of the type previously described with reference to Figure 6. Each of these configurations includes coils 54A, 54N that are respectively coupled to a circuit of the type shown in Figure 6. The operation of these circuits is essentially the same as that described above with reference to Figure 6, and is generally applicable to the operation of the circuitry shown in Figures 7-9. These circuits differ somewhat from that shown in Figure 6, as there is magnetic coupling 65 from one coil 54A to the other 54N.

Figure 7 shows the circuitry for the two coils 54A, 54N connected in series between the stylus tip 57 and stylus shield 59. In Figure 7, there are two circuits with the form shown in Figure 6, but they are connected in series and there is magnetic coupling 65 between the coils 54A, 54N. Alternatively, the circuits for coils 54A, 54N may be connected in parallel with a coupling circuit to the stylus tip 57. This configuration is shown in Figure 8. The coupling circuit includes the combination of resistors R11 and R21.

As was discussed previously, it is desirable to reduce magnetic coupling between coils 54A, 54N, which may be accomplished by separating the coils 54A, 54N on the ferrite cylinder so that most of the magnetic flux lines associated with one coil's current do not pass through other coils. It is noted that the voltage sources 61A, 61N generate a voltage basically equal to the number of stylus coil turns N times the coil cross section A times the rate of change of the magnetic flux density passing through the ferrite cylinder, which is given by $V_1=N_1*A*dB/dt$ for voltage source 61A and $V_N=N_N*A*dB/dt$ for voltage source 61N, where the number of coil turns N_1 and N_N may be equal or different.

Figure 9 illustrates circuitry of a dual coil stylus that includes a dedicated power channel and a single data communication channel, it being understood that more than one data communication channel may be included. An untethered stylus according to embodiments of the present invention may incorporate a power source that provides power for electronics of the stylus but does not interfere with the communication of stylus position and/or data information. In certain stylus configurations, extraction of power from frequency sensitive circuitry of the stylus can reduce and/or distort the stylus position signal level and interfere with the transmission of the stylus data signal. In accordance with the embodiment of Figure 9, an independent power source for the stylus provides stylus circuit power without disrupting the communication of stylus position or data.

As is shown in Figure 9, one of the parallel coil-capacitor combinations that includes coil 54N and voltage source 61N is connected between the stylus tip and the stylus shield 59. The stylus tip 57 then couples capacitively to a location sensor to provide position and/or stylus status information in a manner previously described.

A second parallel coil-capacitor combination that includes coil 54A and voltage source 61A is connected to a power regulator or conversion circuit 66 configured to derive power from the excitation magnetic field. The power circuit 66 shown in Figure 9 includes a rectifier-capacitor combination that effectively operates as an AC-to-DC converter to provide DC power for stylus electronics, which is denoted by stylus power load R12 in Figure 9.

In many applications, it may be desirable to obtain a stable DC voltage derived from an arbitrary AC voltage of high amplitude, as exists in untethered styluses that are inductively coupled to a nearby drive coil. A variety of suitable AC-to-DC converters can be implemented for incorporation in untethered styluses and other devices. Such AC-to-DC converters typically include Zener diodes to provide DC voltage stabilization. The power conversion circuit 66 shown in Figure 9, for example, represents one such implementation that incorporates a Zener diode to provide DC voltage stabilization.

Although DC voltages can be stabilized using Zener diodes, such implementations can result in excess current being used for charging of a capacitor and diverted as a discharging current. A power converter according to embodiments of the present invention may be implemented to provide a stabilized DC voltage derived from an arbitrary AC voltage without use of a Zener diode. Eliminating Zener diodes from power converter circuitry according to embodiments of the present invention advantageously saves valuable current by stopping the charging process instead of starting the discharge process.

Figure 10 is a schematic of a power converter circuit that does not employ a Zener diode in accordance with embodiments of the present invention. A power converter of the type shown in Figure 10 may be implemented in a wide range of applications, including use in untethered styluses, such as those described herein. The following discussion provides illustrative examples of a power converter circuit of the type shown in Figure 10 implemented in an untethered stylus that is energized by a magnetic field generated by a drive coil apparatus of a location sensing device. It is understood that a power converter according to the present invention can be used in many applications other than in those described herein.

The power converter 30 shown in Figure 10 provides a DC voltage (V_{cc}) derived from an arbitrary AC resonating coil voltage. As discussed previously, the DC voltage V_{cc} may be stabilized using a parallel Zener diode over the source capacitor. This approach, however, shorts excess charge to ground so that the source capacitor voltage does not exceed a certain value. This approach may be wasteful, in that the shorted Zener current does not benefit the circuitry that V_{cc} is supposed to drive.

In the context of AC-to-DC power conversion within an untethered stylus, it is desirable to minimize wasted current because of the limited available current budget. Instead of starting to discharge the source capacitor through a Zener diode after a certain voltage is reached, it may be desirable to stop charging the source capacitor when this voltage level has been reached, which is achieved by the power converter implementation shown in Figure 10.

The power converter circuit 30 shown in Figure 10 includes a coil-capacitor resonant circuit 32 implemented using a coil or inductor 36 coupled in parallel with a capacitor 34. The anode of diode 40 is coupled to the coil 36 of the coil-capacitor resonant circuit 32 at a tap location 38. The cathode of the diode 40 is coupled to the drain of a transistor 42. The source of the transistor 42 is coupled to one node of a parallel connected capacitor 44 and resistor 46 combination. The gate of the transistor 42 and the other node of the parallel connected capacitor 44 and resistor 46 are respectively coupled to ground. The DC voltage V_{CC} is provided at the first node of the parallel connected capacitor 44 (i.e., the DC charged capacitor) and resistor 46 combination.

According to one implementation, the transistor 42 shown in Figure 10 is preferably an N-channel depletion JFET that has the property of having a negative gate source voltage, V_{gs}, as the threshold or pinch-off voltage. Thus, the JFET transistor 42 is normally open, so that the capacitor 34 always gets charged when a small AC voltage develops across the coil 36. As soon as the voltage of capacitor 34 approaches the threshold voltage, V_{gs}, of the transistor 42, the drain (I_D)/source (I_S) current is reduced to zero, so that the capacitor voltage is clamped to near the threshold voltage, V_{gs}. A modest load of about 1 MΩ for resistor 46 is sufficient to keep the capacitor voltage from increasing further because of a small leakage source current that may exist.

When the DC voltage V_{cc} is used to drive additional circuitry, such as MOS circuitry, the value of the threshold voltage, V_{gs}, is typically not critical and can be anywhere between roughly −5 and −10 V. A suitable JFET for use as transistor 42 shown in Figure 10 is the 2N5432 JFET available from Vishay Siliconix. According to other implementations, a MOSFET with similar ratings could serve equally as well.

As is shown in Figure 10, the anode of diode 40 is coupled to the coil 36 at a tap location 38. The tap location 38 is preferably selected as a location that prevents the drain-gate voltage, V_{dg}, from exceeding the maximum specification, such as a specified maximum of 20 V. The diode 40 is included in the implementation shown in Figure 10 to prevent clamping of the coil voltage to a diode voltage drop of a forward biased gate-drain junction in case the coil voltage reverses polarity.

The plot of Figure 11 is a comparison of stylus coil voltage (indicated as stylus voltage [V0-p] and stable V_{CC} voltage (indicated as V_{CC} [V]) as a function of drive current through a nearby inductively coupled drive loop. Figure 11 demonstrates provision of a substantially stable DC voltage, V_{CC}, at the output of the power converter circuit 30 in response to a relatively high AC induced coil voltage of increasing amplitude. The measured results reflected in Figure 11 were obtained using the circuit in Figure 10. The measurement was performed at a frequency of about 96 kHz with the coil 36 inductively coupled to a nearby drive coil. The curves of Figure 11 show that the DC voltage, V_{cc}, voltage is indeed stable when the stylus coil voltage continues to increase above about 20 $V_{0\text{-}p}$.

Figure 12 illustrates circuitry of a dual coil stylus that includes a dedicated power channel that incorporates the power converter circuitry of Figure 10 and a single data communication channel, it being understood that more than one data communication channel may be included. An untethered stylus according to embodiments of the present invention may incorporate a power source that provides power for electronics of the stylus but does not interfere with the communication of stylus position and/or data information. In accordance with the embodiment of Figure 12, an independent power source for the stylus provides circuitry of the stylus with a stable DC supply voltage, V_{CC}, without disrupting the communication of stylus position or data.

As is shown in Figure 12, one of the parallel coil-capacitor combinations that includes coil 54N and voltage source 61N is connected between the stylus tip and the stylus shield 59. The stylus tip 57 then couples capacitively to a location sensor to provide position and/or stylus status information in a manner previously described.

A second parallel coil-capacitor combination that includes coil 36 and capacitor 34 is connected to a power regulator or conversion circuit 30 configured to derive power from the excitation magnetic field and provide a stable DC supply voltage, V_{CC}, for circuitry of the stylus. The power circuit 30 shown in Figure 12 is essentially that shown in Figure 10 and described in the accompanying text.

The foregoing description of the various embodiments of the invention has been presented for the purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise form disclosed. Many modifications and variations are possible in light of the above teaching. It is intended that the scope of the invention be limited not by this detailed description, but rather by the claims appended hereto.

CLAIMS

What is claimed is:

1. An untethered stylus configured to cooperate with a location sensor, the location sensor configured to generate a magnetic field comprising a plurality of frequencies and communicatively couple to the stylus, the stylus comprising:

a housing comprising a tip and a shield;

circuitry provided in the housing; and

an antenna arrangement provided at the housing and comprising:

a plurality of coil resonant circuits each tuned to a different frequency of the magnetic field, each of the coil resonant circuits configured to be energized in response to the magnetic field; and

a connection between the plurality of coil resonant circuits, the connection coupling the coil resonant circuits between the tip and shield of the housing to define separate channels for communicatively coupling the stylus tip and the location sensor.

2. The stylus of claim 1, wherein at least one of the coil resonant circuits is configured to capacitively couple to the location sensor.

3. The stylus of claim 1, wherein at least one of the coil resonant circuits is configured to magnetically couple to the location sensor.

4. The stylus of claim 1, wherein a stylus position signal is communicatively coupled between a first coil resonant circuit of the plurality of coil resonant circuits and the location sensor, and a stylus status signal is communicatively coupled between a second coil resonant circuit of the plurality of coil resonant circuits and the location sensor.

5. The stylus of claim 1, wherein a stylus position signal and a stylus status signal is communicatively coupled between one of the coil resonant circuits of the plurality of coil resonant circuits and the location sensor.

6. The stylus of claim 1, wherein a plurality of stylus status signals is communicatively coupled between a plurality of the coil resonant circuits and the location sensor, the stylus status signals detected as a phase change detectable at the location sensor.

7. The stylus of claim 1, wherein the circuitry comprises modulation circuitry coupled to at least one of the coil resonant circuits, and a stylus status signal is modulated by the modulation circuitry and communicatively coupled between the at least one coil resonant circuit and the location sensor.

8. The stylus of claim 1, wherein the antenna arrangement comprises inductive coils of the plurality of coil resonant circuits respectively disposed about a ferrite rod in a spaced relationship.

9. The stylus of claim 1, wherein the connection between the plurality of coil resonant circuits comprises a series connection.

10. The stylus of claim 1, wherein the connection between the plurality of coil resonant circuits comprises a parallel connection.

11. A method of communicatively coupling a stylus and a location sensor, comprising:

receiving, at the stylus, a magnetic field comprising a plurality of frequencies;

energizing, in response to the received magnetic field, a plurality of coil resonant circuits of the stylus each tuned to a different frequency of the magnetic field;

establishing separate channels for communicatively coupling the stylus and the location sensor, each of the separate channels associated with one of the plurality of coil resonant circuits; and

effecting communication between the stylus and the location sensor via the separate channels.

12. The method of claim 11, wherein stylus position information and stylus status information is communicated between the stylus and the location sensor via one or more of the separate channels.

13. The method of claim 11, wherein a stylus position signal is communicated between the stylus and the location sensor via a first separate channel of the separate channels, and a stylus status signal is communicated between the stylus and the location sensor via a second separate channel of the separate channels.

14. The method of claim 11, wherein a stylus position signal is communicated between the stylus and the location sensor via a first separate channel of the separate channels, and a stylus status signal is communicated between the stylus and the location sensor via the first separate channel.

15. The method of claim 11, wherein a plurality of stylus status signals is communicated between the stylus and the location sensor, the stylus status signals detected as a phase change detectable at the location sensor.

16. The method of claim 11, further comprising modulating a stylus status signal and communicating the modulated stylus signal between the stylus and the location sensor.

17. A stylus configured for communicatively coupling to a location sensor, comprising:

means for receiving a magnetic field comprising a plurality of frequencies;

means for energizing each of a plurality of resonant circuits of the stylus in response to one of the plurality of magnetic field frequencies;

means for establishing separate channels for communicatively coupling the stylus and the location sensor, each of the separate channels associated with one of the plurality of coil resonant circuits; and

means for effecting communication between the stylus and the location sensor via the separate channels.

18. The stylus of claim 17, further comprising means for modulating a stylus status signal, the effecting communication means comprising means for communicating the modulated stylus signal between the stylus and the location sensor.

19. The stylus of claim 17, wherein a stylus position signal is communicated between the stylus and the location sensor via a first separate channel of the separate channels, and a stylus status signal is communicated between the stylus and the location sensor via a second separate channel of the separate channels.

20. The stylus of claim 17, wherein a stylus position signal is communicated between the stylus and the location sensor via a first separate channel of the separate channels, and a stylus status signal is communicated between the stylus and the location sensor via the first separate channel.

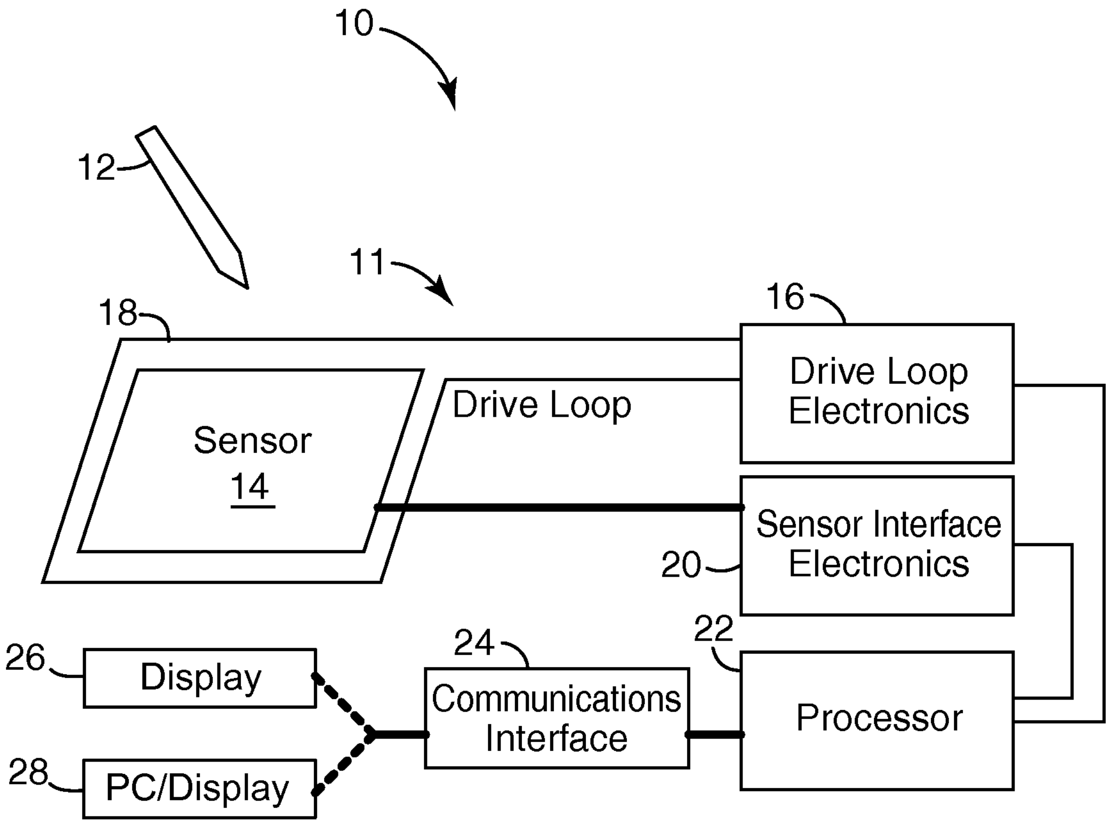


Figure 1

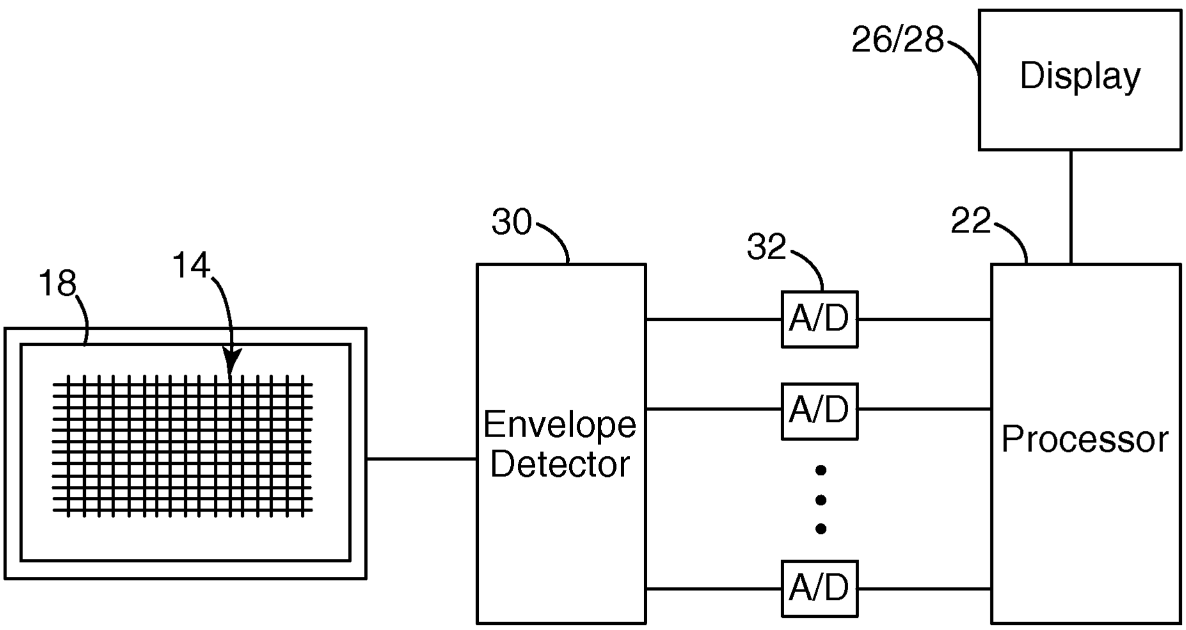


Figure 2

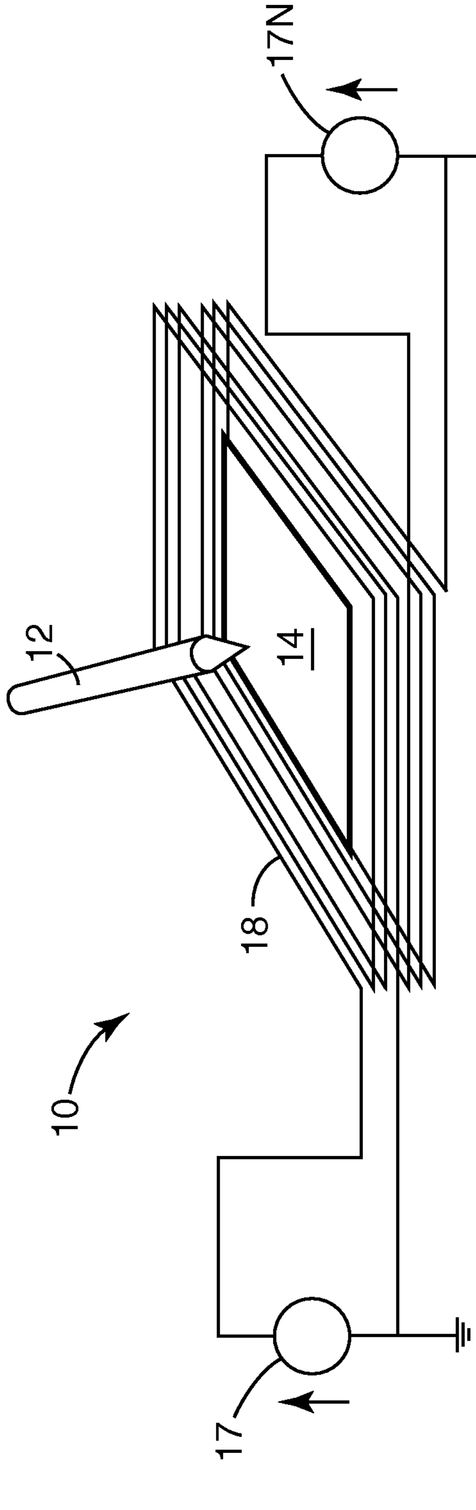


Figure 3

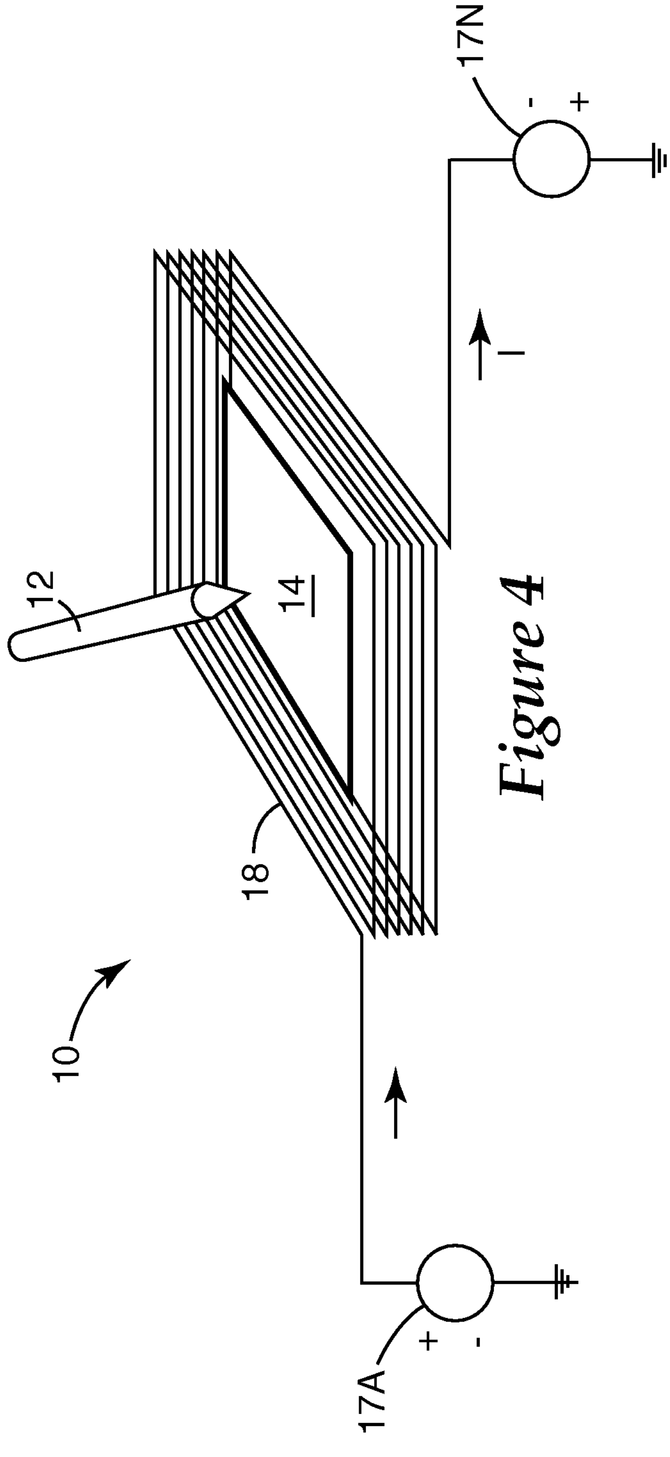


Figure 4

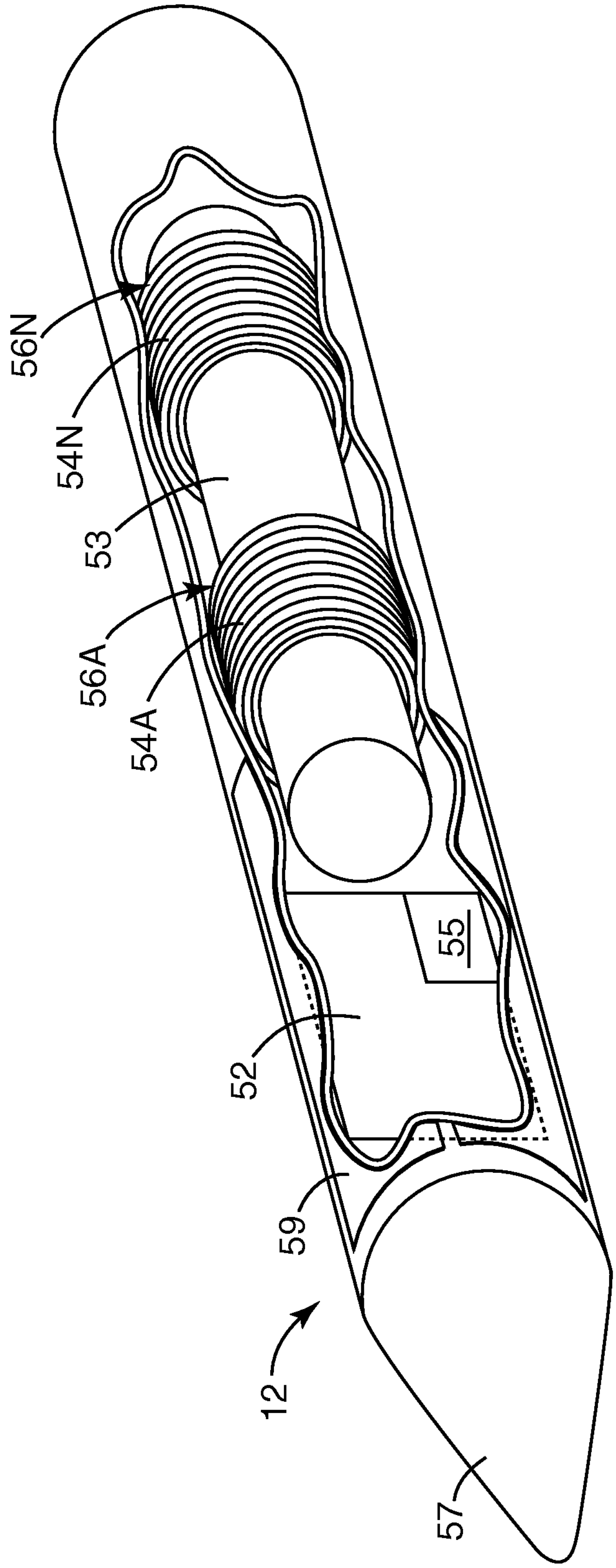


Figure 5

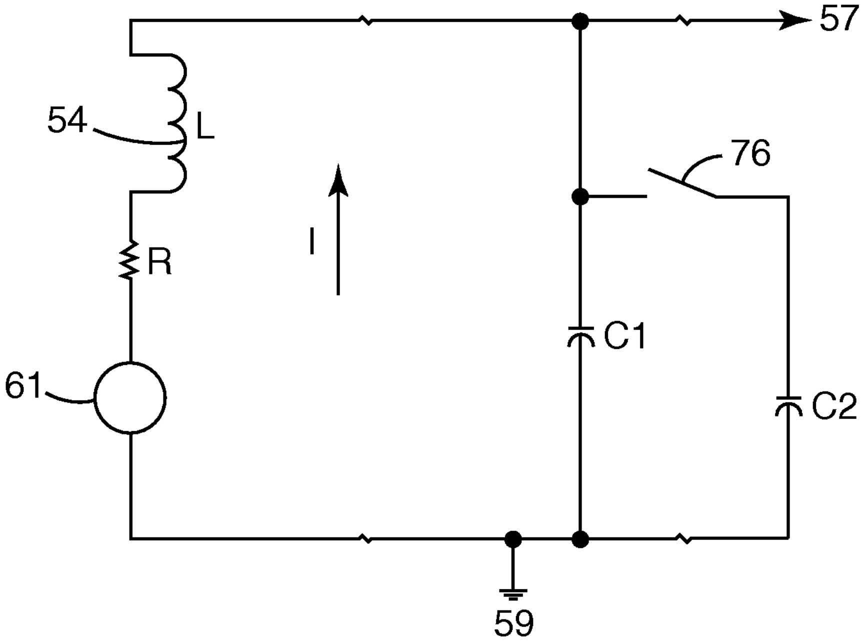


Figure 6

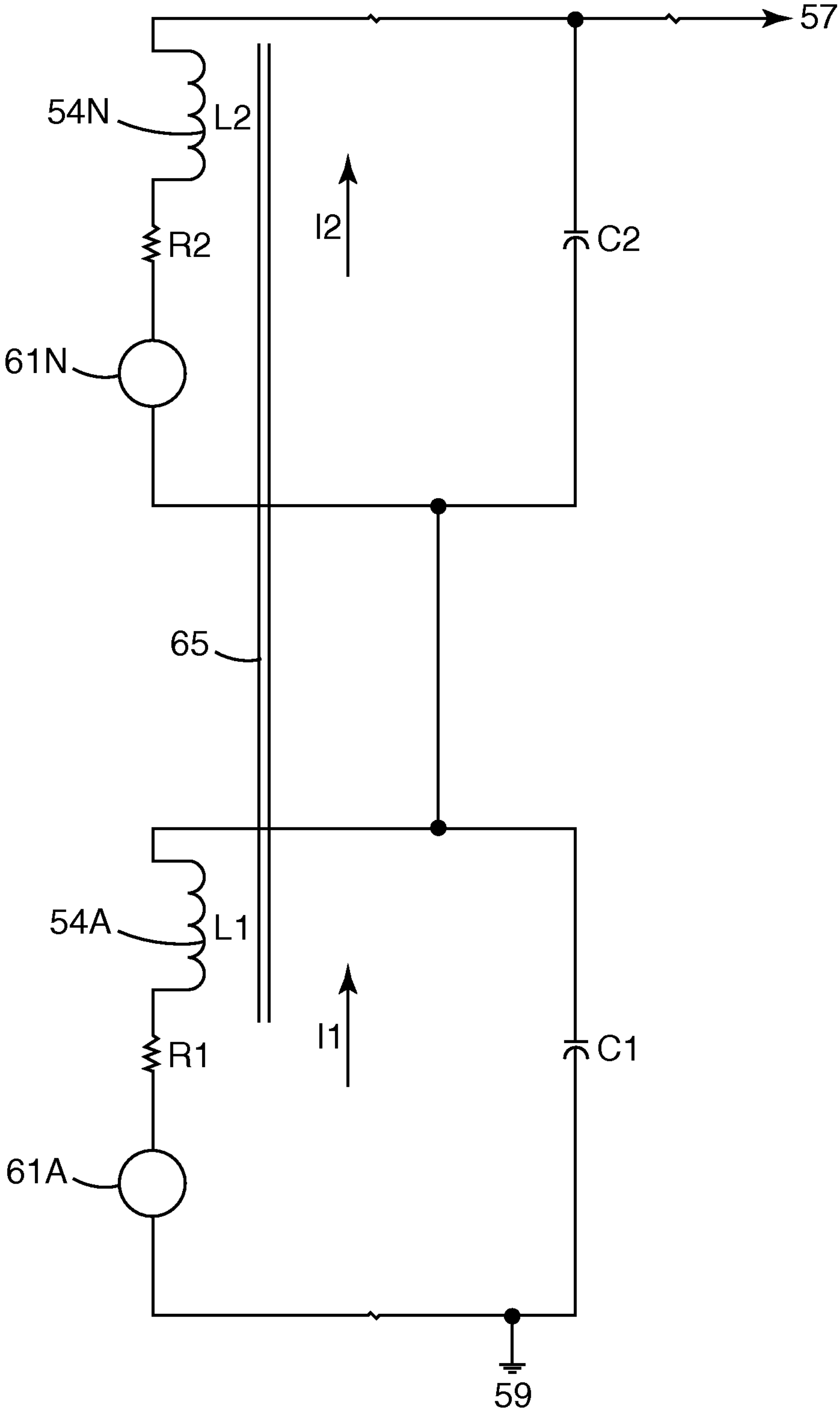


Figure 7

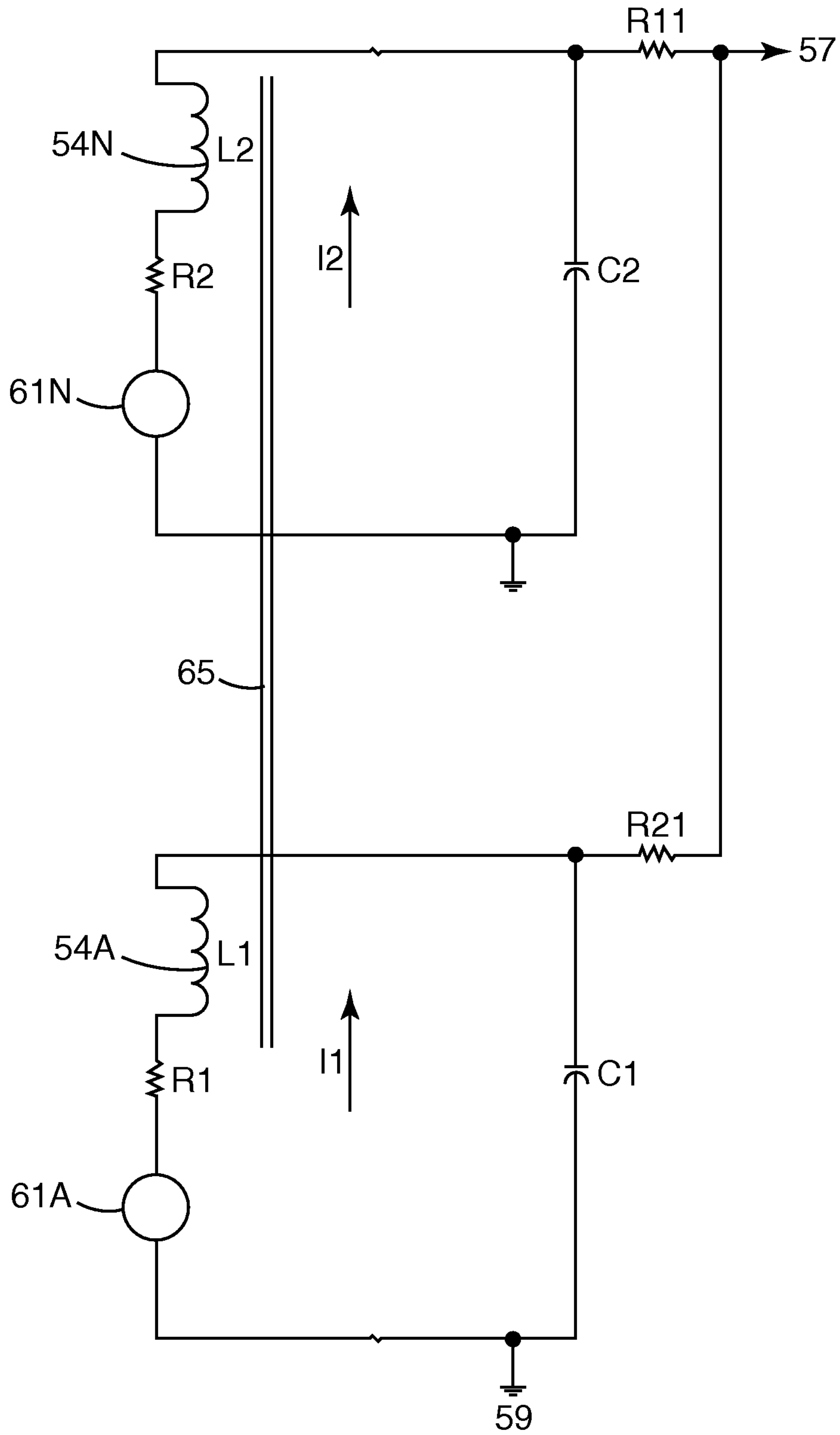
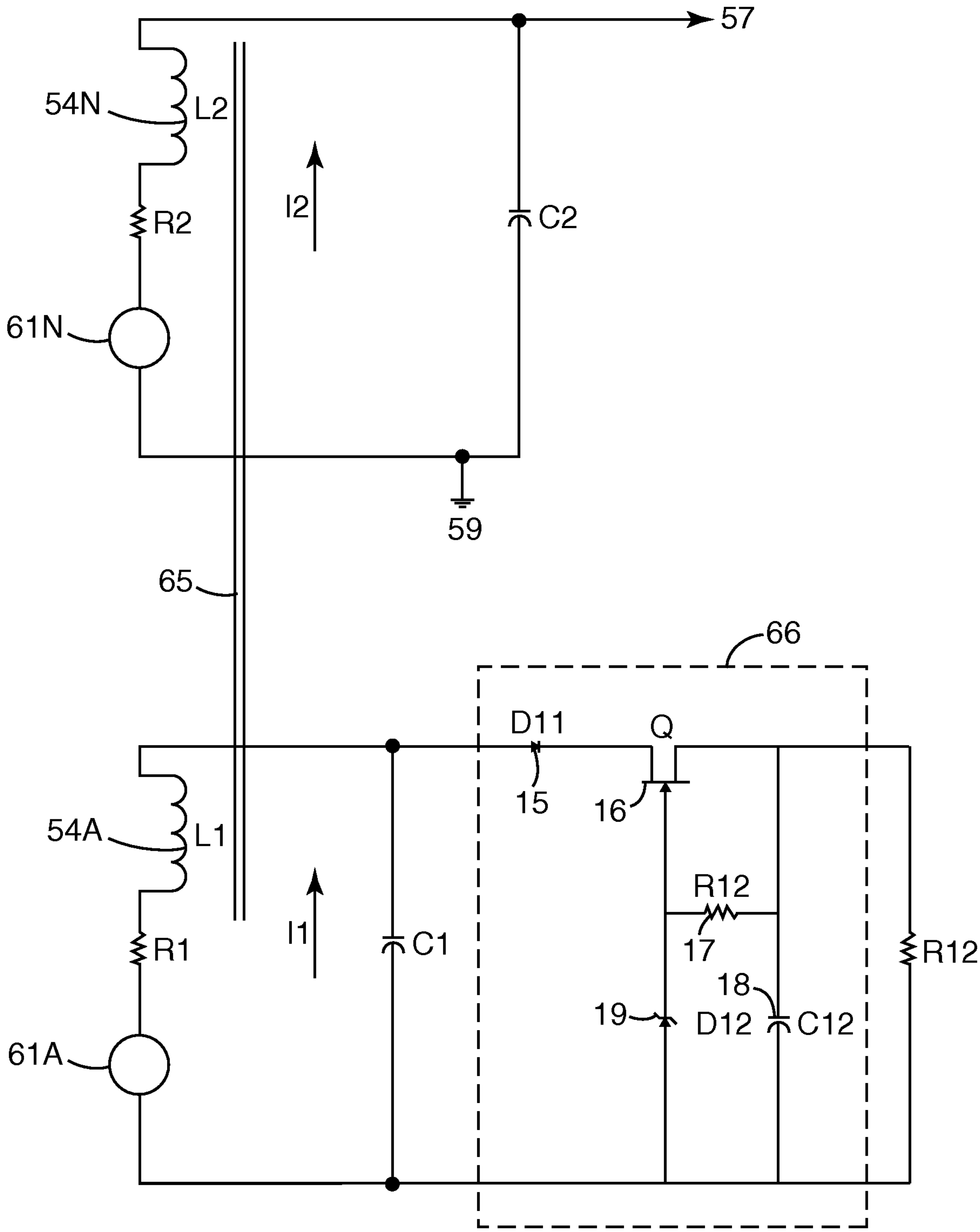


Figure 8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65
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D11
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D12
C12
61A

Figure 9

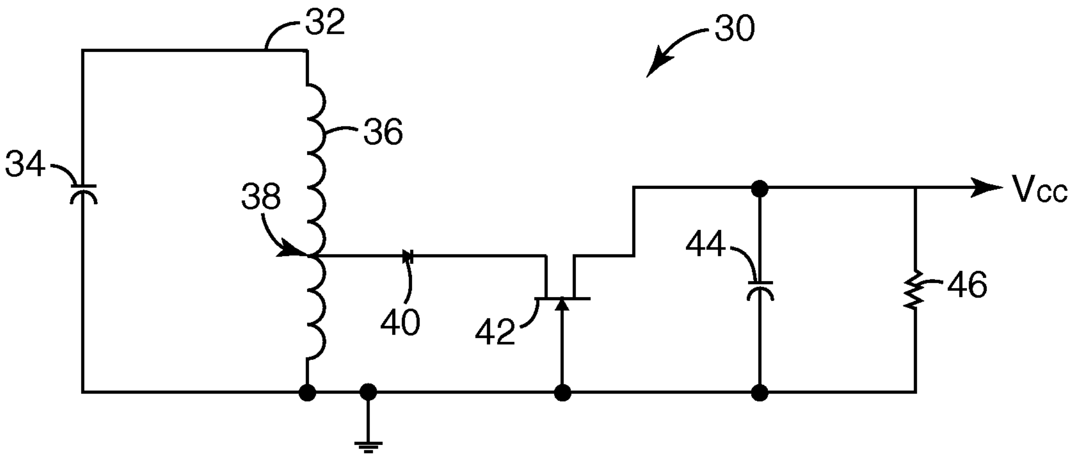

Figure 10

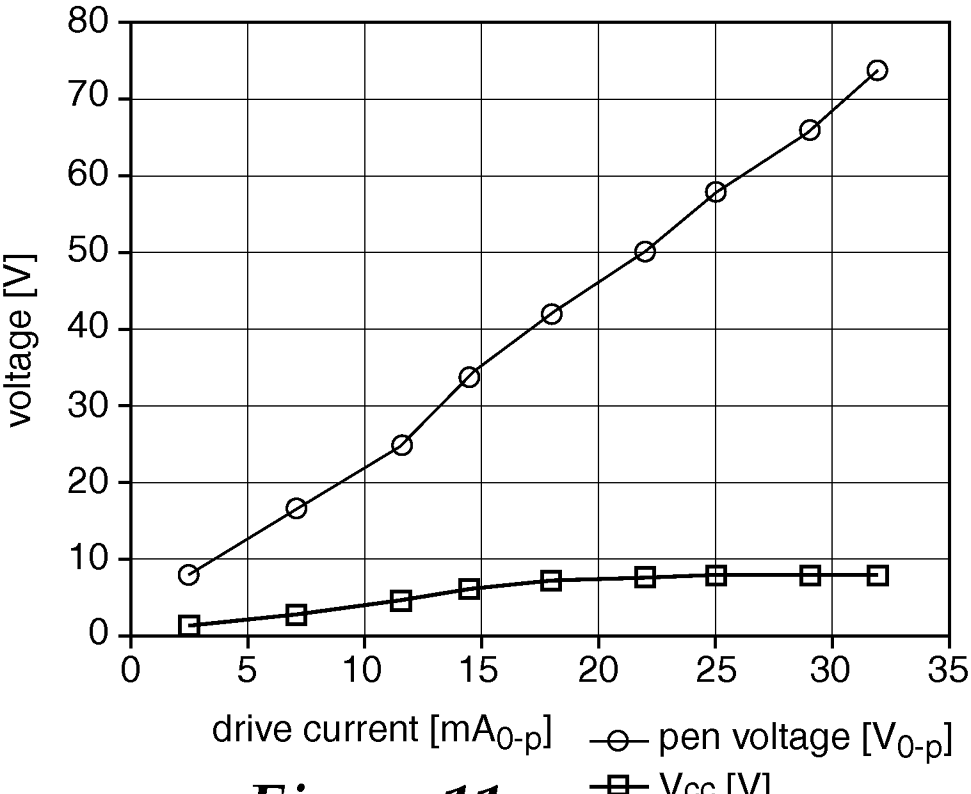

Figure 11

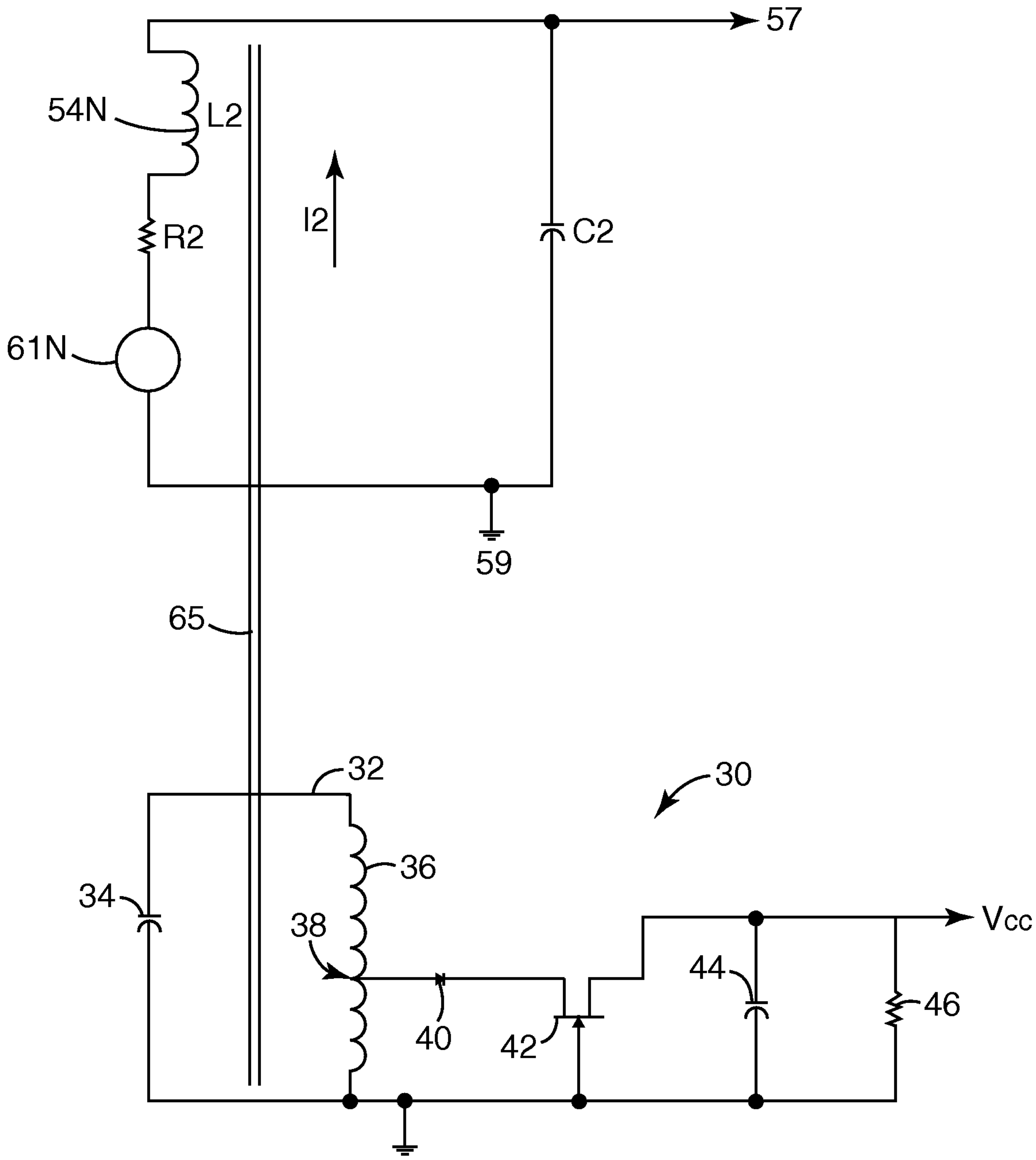

Figure 12

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2007/087400

A. CLASSIFICATION OF SUBJECT MATTER

G06F 3/033(2006.01)i, G06F 3/03(2006.01)i

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)

IPC 8 G06F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Korean Utility Models and Applications for Utility Models since 1975
Japanese Utility Models and Applications for Utility Models since 1975

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKIPASS (KIPO internal) " Keyword : (wireless, untethered), (magnetic), (power), (resonance, resonant), (coil, inductor), (frequency), (capacitor) "

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US06667740 B2 (DAVID T. ELY, et.al.) 23 Dec. 2003 Abstract, Claims 1,6,7,17,23,37, Figs. 1,3,9, Column 1 Line 3 - Column 4 Line 3	1-20
A	US07019672 B2 (DAVID T. E. ELY) 28 Mar. 2006 Abstract, Claims 1,2,29-32,40,48, Figs. 1,3,15, Column 1 Line 9 - Column 1 Line 63	1-20
A	US06476799 B1 (JEFFREY LEE, et.al.) 05 Nov. 2002 Abstract, Claims 1,8,13, Figs. 1,3,4, Column 1 Line 7 - Column 2 Line 27	1-20
A	US04786765 A (TSUGUYA YAMANAMI, et.al.) 22 Nov. 1988 Abstract, Claims 1,7,8, Figs. 1-4, Column 1 Line 6 - Column 4 Line 3	1-20

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents,such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
20 MAY 2008 (20.05.2008)	**20 MAY 2008 (20.05.2008)**

Name and mailing address of the ISA/KR	Authorized officer
Korean Intellectual Property Office Government Complex-Daejeon, 139 Seonsa-ro, Seo-gu, Daejeon 302-701, Republic of Korea Facsimile No. 82-42-472-7140	CHUN, Dae Sik 전대식 Telephone No. 82-42-481-5871

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/US2007/087400

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