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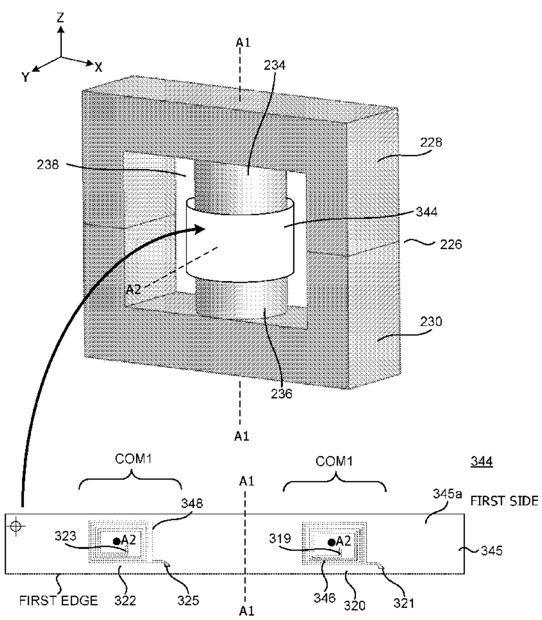

FIG. 5

(57) **Abstract:** A magnetic assembly comprising a first power winding substantially laid around a first axis, a second power winding magnetically coupled to the first power winding and substantially laid around the first axis, and a flexible circuit proximate to the first power winding and the second power winding. The flexible circuit comprising a first communication winding substantially laid around a second axis, and a second communication winding magnetically coupled to the first communication winding. The second communication winding is substantially laid around a second axis, wherein the second axis is substantially perpendicular to the first axis.

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COMMUNICATION LINK ON A FLEXIBLE SUBSTRATE

BACKGROUND OF THE INVENTION

Field of the Invention

[0001] The present disclosure relates generally to communication between circuits with galvanic isolation.

Discussion of the Related Art

[0002] Electronic devices use power to operate. Switched mode power converters, also referred to as switching power converters, are commonly used to power many of today's electronics due to their high efficiency, small size and low weight. Conventional wall sockets provide a high voltage alternating current. In a switched mode power converter, a high voltage alternating current (ac) input is converted to provide a well-regulated direct current (dc) output through an energy transfer element. The switched mode power converter usually provides output regulation by sensing one or more signals representative of one or more output quantities and controlling the output in a closed loop. In operation, a switch is utilized to provide the desired output by varying the duty cycle (typically the ratio of the on time of the switch to the total switching period), varying the switching frequency, or varying the number of pulses per unit time of the switch in a switched mode power converter.

[0003] Safety requirements for isolated switched mode power converters typically require the use of high frequency magnetic components to provide galvanic isolation between the inputs and the outputs of the switched mode power converters in addition to the voltage level change at the output. Power converters generally include one or more controllers which sense the output of the power converter and control the operation of the switch to regulate the output. These controllers may rely on a communication system to send information to operate the power converter. However, this communication system should also provide galvanic isolation.

SUMMARY OF THE DISCLOSURE

[0004] A power converter generally includes a first controller, sometimes referred to as a primary controller, coupled to the input-side of the power converter and a second controller, sometimes referred to as a secondary controller, coupled to the output-side of the power converter. The first controller controls the turn ON and turn OFF of a power switch to transfer energy between the input and the output of the power converter. The second controller may sense the output of the power converter and determine if and how the power switch should be switched. The second controller can communicate with the first controller. For example, the second controller may communicate requests to turn ON the power switch or communicate feedback information regarding the output of the power converter.

[0005] The power converter generally includes an energy transfer element to transfer energy between the input-side of the isolation barrier and the output-side of the isolation barrier in the power converter. An example energy transfer element is a transformer. The communication link between the first controller and the second controller conveys information between the input-side of the isolation barrier and the output-side of the isolation barrier in the power converter. Example communication links could include an inductive coupling, an optical coupling, or a capacitive coupling. Examples of an inductive coupling include a transformer and a coupled inductor. Both the energy transfer element and the communication link should provide galvanic isolation. Typically, the energy transfer element and the communication link are separate assemblies, which can add to the size and cost of a power converter.

[0006] Embodiments of the present disclosure include an assembly in which the energy transfer element and communication link are integrated together. The assembly includes coils of wire which form the energy transfer element, and a flexible circuit embedded with the coils of wire. The flexible circuit includes the communication link. Benefits of integrating the energy transfer element and the communication link in the same assembly may include reduced component count, ease in assembly, reduced point of failure, and improved reliability. The assembly may also include a magnetic core.

[0007] The energy transfer element includes a first power winding and a second power winding. The energy transfer element is one example of an inductive coupling. The first power winding may be an input winding of the energy transfer element while the second power winding is an output winding of the energy transfer element. The first power winding and second power winding are laid around a first axis. In one example, the first power winding is wound around at least a portion of the core. The core is inside at least one turn of the first power winding. The second power winding is wound around at least a portion of the core and is magnetically coupled to the first power winding. The core is inside at least one turn of the second power winding.

[0008] The flexible circuit includes a communication link which includes a first communication winding and a second communication winding. The flexible circuit is located proximate to the first power winding and the second power winding. The flexible circuit may be wound around the core. The first communication winding may be a transmitter winding while the second communication winding may be a receiver winding. The first communication winding and the second communication winding are laid around a second axis. The first axis and second axis may be perpendicular to each other. In one example, the first communication winding may be wound such that the core is outside at least one turn of the first communication winding. The second communication winding is magnetically coupled to the first communication winding. Further, the second communication winding is wound such that the core is outside at least one turn of the second communication winding.

BRIEF DESCRIPTION OF DRAWINGS

[0009] Non-limiting and non-exhaustive embodiments of the present invention are described with reference to the following figures, wherein like reference numerals refer to like parts throughout the various views unless otherwise specified. Corresponding reference characters indicate corresponding components throughout the several views of the figures.

[0010] FIG. 1 illustrates an example power converter with a magnetic assembly including an energy transfer element and a communication link, in accordance with an embodiment of the present disclosure.

[0011] FIG. 2 is a perspective view of a core with a winding.

[0012] FIG. 3A is a cross-sectional view of an example magnetic assembly of FIG. 1, in accordance with an embodiment of the present disclosure.

[0013] FIG. 3B illustrates an example flexible circuit of FIG. 3A, in accordance with an embodiment of the present disclosure.

[0014] FIG. 4A is a cross-sectional view of another example magnetic assembly of FIG. 1, in accordance with an embodiment of the present disclosure.

[0015] FIG. 4B illustrates an example flexible circuit of FIG. 4A, in accordance with an embodiment of the present disclosure.

[0016] FIG. 5 is a perspective view of a flexible circuit wrapped around a core, in accordance with an embodiment of the present disclosure.

DETAILED DESCRIPTION

[0017] Embodiments of the present disclosure include an assembly in which an energy transfer element and a communication link are integrated together. The coils of wire which form the energy transfer element are laid around a first axis. In one example, the coils of wire which form the energy transfer element are wound around a core. A flexible circuit which includes a communication link is also located proximate to the energy transfer element. The communication link is laid around a second axis. In one example, the first axis and the second axis are substantially perpendicular. When the assembly includes a core, the core is outside the turns formed by the windings of the communication link and inside the turns formed by the energy transfer element. Further, the assembly may include a bobbin which provides a holder for the coils of wire which form the energy transfer element and the flexible circuit. In one embodiment, the flexible circuit may occupy only a portion of the coils of wire that form the energy transfer element and may wrap only partially around the core. Integrating the energy transfer element and the communication link may reduce the size of a power converter, increase reliability, and potentially reduce costs.

[0018] FIG.1 illustrates a power converter 100 with a magnetic assembly 124 including an energy transfer element T1 and a communication link COM1, in accordance with an embodiment of the present disclosure. The illustrated power converter 100 further includes a clamp circuit 102, a power switch S1, an input return 108, an output rectifier S2, an output capacitor C_O, an output return 112, and an output sense circuit 116. The power converter 100 includes a control system with a first controller 110 and a second controller 118. The first controller 110 may also be referred to as a primary controller while the second controller 118 may also be referred to as a secondary controller. The communication link COM1 is shown between the first controller 110 and the second controller 118.

[0019] The magnetic assembly 124 includes the energy transfer element T1 and the communication link COM1. The energy transfer element T1 includes a first power winding 104 and a second power winding 106. The first power winding 104 may also be referred to as an input winding of the energy transfer element T1 while the second power winding 106 may also be referred to as an output winding of the energy transfer element T1. Each end of the first power winding 104 is denoted as node 103 and node 105, respectively. Each end of the second power winding 106 is denoted by node 107 and node 109, respectively. The two solid parallel lines between the first power winding 104 and the second power winding 106 indicate that the coupling between the first power winding 104 and the second power winding 106 includes a core of relatively high magnetic permeability. Example materials include iron and ferrite. However, it should be appreciated that the coupling between the first power winding 104 and the second power winding 106 could also be an air-coupling, which may also be referred to as an air-core.

[0020] The communication link COM1 includes a first communication winding 120 and a second communication winding 122. Each end of the first communication winding 120 is denoted by node 119 and node 121, respectively. Each end of the second communication winding 122 is denoted by node 123 and node 125, respectively. The communication link COM1 may also be referred to as a first communication link. In the example shown, there are no lines between the first communication winding 120 and the second communication winding 122 indicating that the coupling between these windings is an air-coupling. While the main coupling between the first communication winding 120 and the second communication winding 122 is through air, it should be appreciated that the coupling between windings 120 and 122 may not be exclusively air-cored.

[0021] Further shown in FIG. 1 are an input voltage V_{IN}, a first switch current I_D, a first drive signal DR, a first power winding voltage V_P, a second power winding voltage V_S, a second power winding current I_S, an output voltage V_O, an output current I_O, an output quantity U_O, a feedback signal FB, a second drive signal SR, a transmit voltage V_T, a transmit current I_T, a receive voltage V_R and a receive current I_R.

[0022] In the illustrated example, the power converter 100 is shown as having a flyback topology. For a flyback power converter, the power switch S1 is turned ON and OFF to control the amount of energy transferred to the output of the power converter 100. When the power switch S1 is turned ON, it conducts current through the first power winding 104 to store energy in the energy transfer element T1. When the power switch S1 is turned OFF, the second power winding 106 delivers energy stored in T1 to the output capacitor C_O.

[0023] Further, the input of power converter 100 is galvanically isolated from the output of the power converter 100, such that input return 108 is galvanically isolated from output return 112. Since the input and output of power converter 100 are galvanically isolated, there is no direct current (dc) path across the isolation barrier of energy transfer element T1, or between the first power winding 104 and the second power winding 106, or between the first communication winding 120 and the second communication winding 122, or between input return 108 and output return 112. It is appreciated that other known topologies and configurations of power converters may also benefit from the teachings of the present disclosure.

[0024] The power converter 100 provides output power to a load 114 from an unregulated input voltage V_{IN}. In one example, the input voltage V_{IN} is a rectified and filtered ac line voltage. In another example, the input voltage V_{IN} is a dc input voltage. The input voltage V_{IN} is coupled to the energy transfer element T1. In some examples, the energy transfer element T1 may be a coupled inductor or transformer. The energy transfer element T1 is shown as including the first power winding 104 and the second power winding 106. However, the energy transfer element T1 may have more than two windings. The first power winding 104 of the energy transfer element T1 is further coupled to the power switch S1 and the power switch S1 is further coupled to input return 108. Coupled across the first power winding 104 is the clamp circuit 102. The clamp circuit 102 limits the maximum voltage on the power switch S1. The first controller 110 outputs the first drive signal DR to control the turn ON and turn OFF of the power switch S1.

[0025] In one example, the power switch S1 may be a transistor such as a metal-oxide-semiconductor field-effect transistor (MOSFET), bipolar junction transistor (BJT), an insulated-gate bipolar transistor (IGBT), or a high electron mobility transistor (HEMT). In another example the power switch may be a cascode switch including a normally-on first switch and a normally-off second switch coupled together in a cascode configuration. The first switch may generally be a silicon (Si), GaN, or SiC based transistor while the second switch may be a MOSFET, BJT, or IGBT.

[0026] The second power winding 106 is coupled to the output rectifier S2. The output rectifier S2 is exemplified as a transistor used as a synchronous rectifier. However, the output rectifier may also be exemplified as a diode. Output capacitor C_O is shown as being coupled to the output rectifier S2 and the output return 112. The power converter 100 further includes circuitry to regulate the output quantity U_O, which in one example may be the output voltage V_O, output current I_O, or a combination of the two. The output sense circuit 116 is configured to sense the output quantity U_O. The output sense circuit 116 provides the feedback signal FB, representative of the output of the power converter 100, to the second controller 118.

[0027] The second controller 118 is configured to output the second drive signal SR to control the turn ON and OFF of the output synchronous rectifier S2. In one example, the second controller is configured to output a request signal in response to the feedback signal FB. In another example, the second controller 118 is configured to pass a signal representative of the feedback signal FB to the first controller 110. For the example of a request signal, the request signal is representative of a request to turn ON the power switch S1. The request signal may include request events which are generated in response to the feedback signal FB. The second controller 118 is configured to compare the feedback signal FB with a regulation reference. In response to the comparison, the second controller 118 may output a request event in the request signal.

[0028] The second controller 118 communicates with the first controller 110 through communication link COM1. The first controller 110 is coupled to receive information from the second controller 118. For example, the first controller 110 may receive information such as a request signal to turn ON the power switch S1 or a feedback signal FB representative of the output quantity U_O. The first controller 110 provides the first drive signal DR to the power switch S1 to control various switching parameters of the power switch S1. The switching of power switch S1 controls the transfer of energy from the input to the output of the power converter 100 through the energy transfer element T1. Examples of such parameters include switching frequency f_{SW} (or switching period T_{SW}), duty cycle, on-time and off-times, or varying the number of pulses per unit time of the power switch S1. In addition, the power switch S1 may be controlled such that it has a fixed switching frequency or a variable switching frequency. The first controller 110 may apply jitter to the switching frequency f_{SW} of the power switch S1 to reduce electromagnetic interference (EMI) regardless of whether the switching frequency f_{SW} is fixed or variable.

[0029] First controller 110 and second controller 118 may be included in an integrated circuit that is manufactured as either a hybrid or monolithic integrated circuit. In one example, first controller 110 is included in a first integrated circuit die and a second controller 118 is included in a second integrated circuit die that are both disposed in the same integrated circuit package. The power switch S1 may be included in a monolithic or hybrid structure in an integrated circuit package that also includes the first controller 110 and the second controller 118. In one example, power switch S1 is disposed on a first integrated circuit die that also includes the first controller 110 and the second controller 118 is included in a second integrated circuit die. In another example, power switch S1 is disposed on a first integrated circuit die, the first controller 110 is included in a second integrated circuit die, and the second controller 118 is included in a third integrated circuit die. Further, it should be appreciated that both the first controller 110, the second controller 118 and power switch S1 need not be included in a single package and may be implemented in separate packages or a combination of combined/separate packages. It should also be appreciated that the first controller 110 or the second controller 118 need not be housed in an integrated circuit package and could be directly attached to a circuit board. The power switch S1 may be a cascode switch including a first switch and a second switch. The first switch may be disposed in the same integrated circuit die as the second switch. Alternatively, the first switch and the second switch may be disposed on separate integrated circuit dies. The first switch and the second switch may be included in a single package or may be implemented in separate packages.

[0030] The second controller 118 and the first controller 110 communicate via the communication link COM1. The second controller 118 is one example of a transmitter while the first controller 110 is one example of a receiver. However, it should be appreciated that communication can also occur from the first controller 110 to the second controller or be bidirectional. For the example shown, the second controller 118 is coupled to the output side of the power converter 100 and is referenced to the output return 112 while the first controller 110 is coupled to the input side of the power converter 100 and is referenced to the input return 108. The first controller 110 and the second controller 118 are galvanically isolated from one another and the communication link COM1 provides galvanic isolation using an inductive coupling. Examples of an inductive coupling include a transformer or a coupled inductor. While FIG. 1 illustrates a single communication link COM1, it should be appreciated that two or more communication links may be included in the magnetic assembly 124.

[0031] The communication link COM1 includes a first communication winding 120 and a second communication winding 122. The first communication winding 120 is one example of a transmitter winding while the second communication winding 122 is one example of a receiver winding. However, it should be appreciated that the first communication winding 120 may be a receiver winding while the second communication winding 122 may be a transmitter winding. Further the first communication winding 120 and the second communication winding 122 may be bidirectional windings.

[0032] The first communication winding 120 has two ends. The first end is denoted as node 119 and the second end is denoted as node 121. Node 119 is shown as the triangle end of first communication winding 120. Node 121 is shown as the non-triangle end of the first communication winding 120.

[0033] The second communication winding 122 has two ends. The first end is denoted as node 123 while the second end is denoted as node 125. Node 123 is shown as the triangle end of the second communication winding 122. Node 125 is shown as the non-triangle end of the second communication winding 122. Further, node 125 is shown as the dot end of the second communication winding 122.

[0034] The first communication winding 120 conducts a transmitter current I_T and there is a transmitter voltage V_T across the first communication winding 120 as shown. The transmitter voltage V_T is shown as positive from node 119 to 121. And transmitter current I_T is shown as positive from node 119 to 121. The second communication winding 122 conducts a receiver current I_R and there is a receiver voltage V_R across receiver winding as shown. The receiver voltage VR is shown as positive from node 123 to node 125. The receiver current I_R is shown as positive from node 125 to node 123.

[0035] It is also noted that the dots and triangles shown in FIG. 1 represent the polarity of voltage that one winding induces in another due to the magnetic coupling between the windings. In particular, the triangle denotes the polarity of voltage induced due to the magnetic coupling between the first communication winding 120 and the second communication winding 122. The dot denotes the polarity of voltage induced due to the magnetic coupling between the first power winding 104 and the second power winding 106. In other words, the dots and triangles help to illustrate the relationship of the windings with respect to each other. For example, the first communication winding 120 is magnetically coupled with the second communication winding 122 such that the polarity of the voltage on node 119 with respect to node 121 is the same as the polarity of voltage on node 123 with respect to note 125. However it should be appreciated that the first communication winding 120 may be magnetically coupled with the second communication winding 122 such that the polarity of the voltage on node 119 with respect to node 121 is opposite of the polarity of the voltage on node 123 with respect to node 125. Further, the dotted line 111 denotes that a magnetic coupling exists between the energy transfer element T1 and the communication link COM1. Due to the proximity of the energy transfer element T1 and the communication link COM1, changing magnetic flux in the energy transfer element T1 may inadvertently induce a voltage in the first communication winding 120 and the second communication winding 122.

[0036] The second controller 118 may send information to the first controller 110 through the magnetic coupling between the first communication winding 120 and the second communication winding 122. The second controller 118 may communicate information as a voltage signal and/or a current signal and the first controller 110 may receive the information as a voltage signal and/or current signal. In embodiments, the second controller 118 may communicate information utilizing the transmitter current I_T. In one example, circuits within the second controller 118 may control various properties of the transmitter current I_T to communicate information to the first controller 110. A request signal or the feedback signal FB are examples of information which the second controller 118 may communicate to the first controller 110. When the transmitter current I_T is changing in magnitude, it produces a changing magnetic field in the proximity of a conductor. In embodiments, the second communication winding 122 is a conductor. Due to the laws of electromagnetic induction, a voltage is generated across a conductor that is subjected to a changing magnetic field. In embodiments, the receiver voltage V_R is induced due to the changing magnetic field generated by changes in transmitter current I_T and may result in receiver current I_R. The first controller 110 includes circuits which may receive the transmitter induced voltage and/or current and interpret the voltage and/or current as information. Properties of the transmitter current I_T which may be controlled to communicate information may include the magnitude and the rate of change of the transmitter current I_T. The communicated signals may take the form of digital information or of analog information. In the case of digital information, communication can be in the form of binary signals or more complex encoded digital data as will be known to one skilled in the art. It should be appreciated that other communication techniques may be used. In other examples, communication techniques which take advantage of the relationship between the transmitter current I_T and the resultant induced receiver voltage V_R and receiver current I_R received by the first controller 110 may be utilized.

[0037] Energy transfer element T1 and communication link COM1 are included in the same magnetic assembly 124. The magnetic assembly 124 may also include a core. The first power winding 104 and the second power winding 106 are wound around a first axis. The first power winding 104 and the second power winding 106 are wound around at least a portion of the core such that the core is inside at least one turn of the first power winding 104 and the second power winding 106. For example, the core may be an E-E or an E-I core, and the first power winding 104 and the second power winding 106 are wound around a center leg of the core. The core may also be an I core and the first power winding 104 and the second power winding 106 are substantially wound around the core. It should be appreciated that coils of wire may form the first power winding 104 and the second power winding 106.

[0038] The magnetic assembly 124 also includes a flexible circuit. The flexible circuit includes the first communication winding 120 and the second communication winding 122 of communication link COM1. As will be further discussed and shown, the flexible circuit is located proximate to the energy transfer element T1. In one example, the flexible circuit is wound around the first axis. The flexible circuit may also be wound around a portion of the core. The flexible circuit is located proximate to the first and second power winding 104, 106 such that at least one turn of the first communication winding 120 and the second communication winding 122 of communication link COM1 are laid around a second axis. In one example, the second axis is substantially perpendicular to the first axis. In one example, the flexible circuit is wound around the core such that the portion of the core is outside at least one turn of the first communication winding 120 and outside at least one turn of the second communication winding 122.

[0039] The flexible circuit may be located between the first power winding 104 and the second power winding 106. In another example, the flexible circuit may be located between layers of turns of the first power winding 104. In a further example, the flexible circuit may be located around the first power winding 104 and the second power winding 106. In another example, the flexible circuit may be located between layers of turns of the second power winding 106.

[0040] The magnetic assembly 124 may also include a bobbin. The bobbin provides support for the coils of wire which form the first power winding 104 and the second power winding 106. The bobbin includes an opening. In one example, the opening is configured to receive the portion of the core. The bobbin defines an area in which a portion of the core may be inserted so the coils of wire which form the first power winding 104 and the second power may encircle the portion of the core. The area around the bobbin where the coils of wire may be wound may be referred to as the bobbin window. The bobbin forms the bobbin window that may be occupied by conductors. The first power winding 104, the second power winding 106 may be wound around the opening of the bobbin. The flexible circuit may be located proximate to the opening of the bobbin. The first power winding 104, the second power winding 106 may be wound in the bobbin window. The flexible circuit may be located in the bobbin window.

[0041] A cartesian coordinate system is introduced to illustrate the orientation of the various embodiments in the figures. As shown, for example in FIG. 2, the coordinates include an x-axis, a y-axis, and a z-axis. The x-axis and the y-axis may be referred to as a first lateral direction and a second lateral direction, respectively. The z-axis may be referred to as a first vertical direction. The arrows illustrate the direction of the axes. It should be appreciated that a “dot” indicates an axis coming out of the page while an “x” indicates an axis going into the page. Each axis is substantially ninety degrees from the others.

[0042] For FIG. 2, the first vertical direction (z-axis) is towards the top of the page, the first lateral direction (x-axis) is diagonally towards the bottom right of the page, and the second lateral direction (y-axis) is diagonally towards the bottom left of the page.

[0043] FIG. 2 illustrates a perspective view of a core 226. The core 226 shown is a generic EE-style core with a first portion 228 and a second portion 230. Each of the first portion 228 and the second portion 230 has a center leg 234, 236, respectively with a circular cross-section. Center leg 234 extends from the first portion 228 parallel with the first vertical direction. Center leg 236 extends from the second portion 230 parallel with the first vertical direction. As shown, when the first portion 228 and the second portion 230 are in position, center leg 236 extends towards center leg 234. First axis A1 is shown as the center axis of the core 226 and intersects the center legs 234, 236 in the first vertical direction (z-axis).

[0044] In addition, there is often a discrete region of relatively low magnetic permeability introduced in the path of the magnetic field provided by the core 226, typically referred to as a gap. The length of the gap may be chosen to manage the distribution of energy in the energy transfer element. The material with relatively low magnetic permeability is typically air, and the gap is often referred to as an air gap, although the gap may contain other material with relatively low magnetic permeability, e.g., paper or varnish. In the example shown, a gap is illustrated between center leg 234 and center leg 236.

[0045] When the first portion 228 and the second portion 230 are aligned, the core 226 forms a window 238 in which coils of wire 240 may be wound around the center legs 234, 236. The window 238 is a volume of space in which the coils of wire may be wound.

[0046] The coil of wire 240 is shown for illustrative purposes. The coil of wire 240 illustrates where and how the first power winding 104 and the second power winding 106 may be wound. The coil of wire 240 may be representative of the first power winding 104 or the second power winding 106. The coil of wire 240 is wound around the first axis A1. The coil of wire 240 is also shown as wound around the center leg 236. In one example, core 226 has a length substantially between 25 millimeters (mm) to 40 mm in the first lateral direction (x-axis), a width substantially between 7 mm to 20 mm in the second lateral direction (y-axis) and a height substantially between 19 mm to 45 mm in the first vertical direction (z-axis). It should be appreciated that these dimensions are illustrative and the core 226 may have other sizes. While core 226 is shown as a generic E-E style core, it should be appreciated that other core shapes may be utilized. For example, an E-I core or an I core may also be used.

[0047] FIG. 3A is a cross-sectional view of a magnetic assembly 324. The cross-section of the magnetic assembly 324 is viewed in the plane of the first lateral direction (x-axis) and the first vertical direction (z-axis). As shown, the first lateral direction (x-axis) is pointing towards the right-hand side of the page, the second lateral direction (z-axis) is pointing up the page, and the second lateral direction (y-axis) is pointing out of the page. Magnetic assembly 324 is one example of magnetic assembly 124 of FIG. 1.

[0048] The magnetic assembly 324 shown includes core 226, first power winding 304, second power winding 306, and flexible circuit 344. The flexible circuit 344 includes the first communication winding 320 and the second communication winding 322 of communication link COM1.

[0049] The cross-section of core 226 is shown in diamond fill. The core 226 includes a first portion 228 with a center leg 234. The core 226 also includes a second portion 230 with a center leg 236. When the first 228 and second 230 portions are positioned to form the core 226, the center legs 234 and 236 are substantially aligned and the core 226 forms a window 238. In the example shown, the window 238 refers to the area to the left and right side of center legs 234, 236 and surrounded by the first 228 and second 230 portions of the core 226. The first axis A1 is shown as the center axis of the core 226 and intersects the center legs 234, 236 in the first vertical direction (z-axis).

[0050] The first power winding 304 is illustrated as a coil of wire wound around the first axis A1. As shown, the first power winding 304 is wound around a portion of core 226. In the example shown, the first power winding 304 is wound around the center legs 234, 236. The first power winding 304 is one example of the first power winding 104 of FIG. 1. The small circles are illustrative of the cross-section of the coil of wire which forms the first power winding 304. Each small circle on one side of the first axis A1 is representative of one turn of the first power winding 304. One turn of a winding substantially forms a conductive path which encircles the first axis A1. In another example, one turn of a winding forms a conductive path which encircles a portion of the core 226. The turns may be organized in layers around the portion of the core. As shown, a layer of turns is substantially the turns which are equidistant to the first axis A1 in the first lateral direction (x-axis).

[0051] Each turn of the first power winding 304 is laid around the first axis A1 such that each turn traverses the plane of the first lateral direction (x-axis) and the second lateral direction (y-axis). As shown, each turn of the first power winding 304 is wound around the portion of the core (e.g., center legs 234, 236). The turns of the first power winding 304 encircle the center legs 234, 236 of the core 226. In other words, the center legs 234, 236 are inside the turns of the first power winding 304. In FIG. 3A, the first power winding 304 has four layers of turns, each layer having nine turns for a total of thirty-six turns in the first power winding 304.

[0052] The second power winding 306 is illustrated as a coil of wire laid around the first axis A1. The second power winding 306 is wound around the portion of the core 226, e.g., the center legs 234, 236. The second power winding 306 is one example of the second power winding 106 of FIG. 1. The large circles are illustrative of the cross-section of the coil of wire which forms the second power winding 306. In the example shown, the coil of wire which forms the second power winding 306 is thicker than the coil of wire which forms the first power winding 304. The first power winding 304 and the second power winding 306 are magnetically coupled to each other. Further, the core 226 strengthens the magnetic coupling between the first power winding 304 and the second power winding 306.

[0053] Each large circle on one side of the first axis A1 is representative of one turn of the second power winding 306. Each turn of the second power winding 306 is laid around the first axis A1 such that each turn traverses the plane of the first lateral direction (x-axis) and the second lateral direction (y-axis). As shown, each turn of the second power winding 306 is wound around the portion of the core (e.g., center legs 234, 236). Each turn of the second power winding 306 encircles the center legs 234, 236 of core 226. In other words, the center legs 234, 236 are inside the turns of second power winding 306. In FIG. 3A, the second power winding 306 has five turns in one layer.

[0054] The flexible circuit 344 is wound around a portion of the core 226. As shown, the flexible circuit 344 is wound around the center legs 234, 236. The flexible circuit 344 includes a substrate 345. The flexible circuit 344 includes the conductive paths which form the first communication winding 320 and the second communication winding 322 of communication link COM1. The cross-section of the substrate 345 is shown in diagonal hatched lines. The cross-sections of the first communication winding 320 and the second communication winding 322 are shown in solid black fill.

[0055] The flexible circuit 344 is disposed between layers of the first power winding 304. As shown, the flexible circuit 344 is shown as disposed between the second and third layer of the first power winding 304. The flexible circuit 344 is laid around the first axis A1 such that the first communication winding 320 substantially overlays the second communication winding 322. The first communication winding 320 overlays the second communication winding 322 in a direction substantially perpendicular to the first axis A1. In other words, the first communication winding 320 and the second communication winding 322 overlay in a direction perpendicular to the first vertical direction (z-axis).

The turns of the first communication winding 320 and the second communication winding 322 are laid around a second axis A2. The second axis A2 is substantially perpendicular to the first axis A1. Further, the flexible circuit 344 is located such the center legs 234, 236 are outside of the turns formed by the first communication winding 320 and the second communication winding 322. It should be appreciated that the relative positioning of the flexible circuit 344 with respect to the first power winding 304 or the second power winding 306 may be chosen to minimize the magnetic coupling between the power windings 304, 306 to the communication windings 320, 322. In other words, the relative positioning of the second axis A2 along the first axis A1 may be chosen to minimize the magnetic coupling between the power windings 304, 306 to the communication windings 320, 322.

[0056] As will be discussed with FIG. 3B, the first communication winding 320 and the second communication winding 322 are disposed on the same side of the flexible circuit 344. The flexible circuit 344 may have an inner side and an outer side. The inner side corresponds to the side facing the axis A1. The outer side corresponds to the side not facing the axis A1. The inner side corresponds to the side facing center legs 234, 236 and the outer side is the side not facing center legs 234, 236. The outer side may be referred to as a first side while the inner side may be referred to as a second side. The first communication winding 320 and the second communication winding 322 are disposed on the outer side of the flexible circuit 344.

[0057] The substrate 345 is shown as wound around the center legs 234, 236 of the core 226 twice to overlay the first communication winding 320 and the second communication winding 322. From the first axis A1 in the negative first lateral direction (negative x-axis), the second layer of the first power winding 304 is followed by the substrate 345, then the second communication winding 322, then the substrate 345 and then the first communication winding 320. In the example shown, the flexible circuit 344 includes one communication link COM1. As such, the first communication winding 320 and the second communication winding 322 are disposed on one side of axis A1 (e.g., the left side of axis A1). As shown, the first and second communication windings 320, 322 are disposed on one side of center legs 234, 236 (e.g. the left side of center legs 234, 236).

[0058] The magnetic assembly 324 as shown includes the bobbin 341. The cross-section of the bobbin 341 is shown in diagonal lines. The bobbin 341 includes an opening 342. The opening 342 intersects the bobbin 341 in the first vertical direction (z-axis). The first axis A1 is shown as intersecting the opening 342 parallel with the first vertical direction (z-axis). The opening 342 is configured such that the center legs 234, 236 may be inserted into the opening 342. The bobbin 341 is also disposed within window 238 of the core 226.

[0059] The bobbin 341 provides support for the first power winding 304, the second power winding 306, and the flexible circuit 344. The shape of the bobbin 341 also outlines a bobbin window 338. The first power winding 304, the second power winding 305, and the flexible circuit 344 are disposed in the bobbin window 338.

[0060] The first power winding 304 is disposed in the bobbin window 338 such that at least one turn of the first power winding 304 is wound around the opening 342 of bobbin 341. In the example shown, the first power winding 304 includes thirty-six turns over four layers which encircle the opening 342. The second power winding 306 is disposed in the bobbin window 338 such that at least one turn of the second power winding 306 is wound around the opening 342 of bobbin 341. In the example shown, the second power winding 306 includes five turns over one layer which encircle the opening 342. The flexible circuit 344 is also wound around the opening 342. The flexible circuit 344 is wound around the opening 342 such that the opening 342 is outside of the turns formed by the first communication winding 320 and the second communication winding 322.

[0061] It should be appreciated that the magnetic assembly 324 may not include the core 226 if the first power winding 304 and the second power winding 306 are air-cored. The bobbin may provide support for the first and second power windings 304, 306 and the flexible circuit 344 without the use of a core. Further, the opening 342 may be optional.

[0062] FIG. 3B illustrates the flexible circuit 344 including a substrate 345, a first conductive path 346, and a second conductive path 348. The substrate 345 has a first side 345a and a second side 345b. A first edge of the substrate 345 is shown in dotted lines to provide a visual reference of the positioning of the flexible circuit 344. A marker is shown as a circle overlayed with a cross and is also utilized to provide a visual reference for the positioning of the flexible circuit 344. It should be appreciated that the marker on the first side 345a substantially overlays the marker on the second side 345b. The marker is shown on the top left of the first side 345a of substrate 345. The marker is also shown on the bottom left of the second side 345b of substrate 345. As such, visually the flexible circuit 344 is shown as rotated about the first edge. The substrate 345 may be a flexible material. Example substrates include tape or a flexible printed circuit board. The substrate 345 may also include Mylar or Kapton.

[0063] The first conductive path 346 and the second conductive path 348 form the windings of the communication link COM1. Both the first conductive path 346 and the second conductive path 348 are disposed on the first side 345a of substrate 345. For the example of FIG. 3B, the second side 345b does not include conductive paths for the communication link COM1. It should be appreciated that the first side 345a and the second side 345b may include other circuit elements independent of communication link COM1. For example, the circuit elements may include logic circuits. The first side 345a may be an outer side of the flexible circuit 444 while the second side 345b may be an inner side of the flexible circuit.

[0064] The first conductive path 346 forms the first communication winding 320 and is one example of the first communication winding 120 of FIG. 1. The first conductive path 346 has an end 319 and end 321. End 319 of the first conductive path 346 corresponds to the electrical node 119 shown in FIG. 1. The end 321 of the first conductive path 346 corresponds to the electrical node 121 shown in FIG. 1. End 319 may be the triangle end of the first communication winding 320 while end 321 may be the non-triangle end of the first communication winding 320. In one example, end 319 may be the positive labeled terminal of transmit voltage V_T while end 321 may be the negative labeled terminal of transmit voltage V_T. First communication winding 320 may be one example of a transmitter winding.

[0065] End 321 is an outer end and is disposed outside of the turns formed by the first conductive path 346 of the first communication winding 320. End 319 is an inner end and is within the turns formed by the first conductive path 346 of the first communication winding 320. Conductive path 346, end 319, and end 321 may be comprised of a conductive material. Copper is one example of a conductive material, but it should be appreciated that other conductive materials may be used.

[0066] For the purposes of this disclosure, the direction which a winding is wound is determined by the direction which a winding traverses from the positive labeled terminal of the winding to the negative labeled terminal of the winding. However, it should be appreciated that other conventions may be utilized. For example, the winding direction may also be determined by the direction in which the winding traverses from the negative labeled terminal to the positive labeled terminal of the winding, the direction the winding is wound from an inner end to an outer end, or vice versa.

[0067] The first conductive path 346 traverses the first side 345a in a clockwise direction from end 319 to end 321. From end 319, the first conductive path 346 traverses in an outward spiral towards end 321. As such, the first communication winding 320 is wound in a clockwise direction. It should be appreciated that the first communication winding 320 may also be wound counter-clockwise. The first conductive path 346 is laid around the second axis A2. The turns of the first communication winding 320 are wound orthogonally from the turns of first power winding 304. As shown, the turns of the first communication winding 320 are laid around the second axis A2 while the turns of first power winding 304 is laid around the first axis A1. The second axis A2 is substantially perpendicular from the first axis A1.

[0068] The first conductive path 346 forms a spiral which is substantially rectangular in shape. However, it should be appreciated that the first conductive path 346 may spiral in other shapes. In FIG. 3B, the first communication winding 320 is shown as having three turns.

[0069] The second conductive path 348 forms the second communication winding 322 and is one example of the second communication winding 322 of FIG. 1. The second conductive path 348 has an end 323 and an end 325. End 323 of the second conductive path 348 corresponds to the electrical node 123 shown in FIG. 1. End 325 of the second conductive path 348 corresponds to the electrical node 125 shown in FIG. 1. End 323 may be the triangle end of the second communication winding 322 while end 325 may be the non-triangle end of the second communication winding 322. In one example, end 321 may be the positive labeled terminal of receiver voltage V_R while end 325 may be the negative labeled terminal of receiver voltage V_R. The second communication winding 322 may be one example of a receiver.

[0070] End 325 is an outer end disposed outside of the turns formed by the second conductive path 348 of the second communication winding 322. End 321 is an inner end disposed inside the turns formed by the second conductive path 348 of the second communication winding 322. Conductive path 348, end 323, and end 325 may be comprised of a conductive material. Copper is one example of a conductive material, but it should be appreciated that other conductive materials may be used.

[0071] The second conductive path 348 traverses the first side 345a in a clockwise direction from end 323 to end 325. From end 323, the second conductive path 348 traverses in an outward spiral towards end 325. As such, the second communication winding 322is wound in a clockwise direction. It should be appreciated that the second communication winding 322 may also be wound counter-clockwise. The second conductive path 348 is laid around the second axis A2. The turns of the second communication winding 322 are wound orthogonally from the turns of first power winding 304. As shown, the turns of the second communication winding 322 are laid around the second axis A2 while the turns of first power winding 304 are laid around the first axis A1. The second axis A2 is substantially perpendicular from the first axis A1.

[0072] The second conductive path 348 forms a spiral which is substantially rectangular in shape. However, it should be appreciated that the second conductive path 348 may spiral in other shapes. In FIG. 3B, the second communication winding 322 is shown as having three turns.

[0073] When the flexible circuit 344 is positioned in the magnetic assembly 324, the first conductive path 346 and the second conductive path 348 substantially overlay. Further, end 319 and end 323 substantially overlay and end 321 and end 325 substantially overlay. From the first side 345a, the second conductive path 348 is shown as disposed on the left-hand side of first conductive path 346. As shown, the first communication winding 320 is substantially the same in size and shape as the second communication winding 322. However, it should be appreciated that their size and shapes may be different.

[0074] FIG. 4A is a cross-sectional view of a magnetic assembly 424. The cross-section of the magnetic assembly 424 is viewed in the same perspective as the magnetic assembly 324 of FIG. 3A. Magnetic assembly 424 is one example of magnetic assembly 124 of FIG. 1.

[0075] Magnetic assembly 424 is shown as including core 226, first power winding 304, second power winding 306, and flexible circuit 444. Magnetic assembly 424 also includes bobbin 341. It should be appreciated that magnetic assembly 424 shares many similarities with magnetic assembly 324 of FIG. 3A and the detailed description for similarly named and numbered elements in FIG. 4A may be found with reference to FIG. 3A.

[0076] At least one difference, however, is the flexible circuit 444 includes two communication links, first communication link COM1 and second communication link COM2. Communication link COM1 includes the first communication winding 420a and the second communication winding 422a. Communication link COM2 includes first communication winding 420b and second communication winding 422b. Further, first communication winding 420a and second communication winding 422a of communication link COM1 are on opposite sides of flexible circuit 444. Similarly, first communication winding 420b and second communication winding 422b of communication link COM2 are on opposite sides of flexible circuit 444.

[0077] The flexible circuit 444 is located proximate to the first power winding 304 and the second power winding 306. In one example, the flexible circuit 444 is laid around the first axis A1. In a further example, the flexible circuit 444 is wound around a portion of core 226. As shown, flexible circuit 444 is wound around center legs 234, 236.

Flexible circuit 444 includes the conductive paths which form first communication winding 420a and second communication winding 422a of communication link COM1 and first communication winding 420b and second communication winding 422b of communication link COM2. Flexible circuit 444 includes a substrate 445. The cross-section of substrate 445 is shown in diagonal hatched lines. The cross-sections of first communication windings 420a, 420b and second communication windings 422a, 422b are shown with solid black fill.

[0078] The flexible circuit 444 is disposed between layers of first power winding 304. Flexible circuit 444 is disposed between the second and third layer of first power winding 304. Flexible circuit 444 is located around first axis A1 such that the windings of communication link COM1 are on the opposite side of the first axis A1 as the windings of communication link COM2. Said differently, the flexible circuit is located around the center legs 234, 236 such that the windings of communication link COM1 are on the opposite side of center legs 234, 236 as the windings of communication link COM2. As shown, first communication winding 420a and second communication winding 422a are on the left side of first axis A1 while first communication winding 420b and second communication winding 422b are on the right of first axis A1. The flexible circuit 444 is wound such that center legs 234, 236 are outside of the turns formed by the first communication windings 420a, 420b, and the second communication windings 422a, 422b.

[0079] As will be discussed with FIG. 4B, the first communication windings 420a, 420b are disposed on the same side of the flexible circuit 444. As shown, communication windings 420a, 420b are disposed on the outer side of flexible circuit 444. The second communication windings 422a, 422b are disposed on the same side of flexible circuit 444. Further, second communication windings 422a, 422b are disposed on the opposite side of flexible circuit 444 from first communication windings 420a, 420b. The second communication windings 422a, 422b are disposed on the inner side of flexible circuit 444.

[0080] For communication link COM1, the first communication winding 420a substantially overlays the second communication winding 422a. The first communication winding 420a and the second communication winding 422a are laid around the second axis A2. For communication link COM2, the first communication winding 420b substantially overlays the second communication winding 422b. The first communication winding 420b and the second communication winding 422b are laid around the third axis A3. The second axis A2 and third axis A2 are perpendicular to the first axis A1. Since the first communication windings 420a, 420b overlay and are on opposite sides of the flexible circuit 444 to their corresponding second communication windings 422a, 422b, the substrate 445 is shown as wound around the first axis A1 once. As shown, the substrate 445 is wound around the center legs 234, 236 once. It should be appreciated that the relative positioning of the flexible circuit 444 with respect to the first power winding 304 or the second power winding 306 may be chosen to minimize the magnetic coupling between the power windings 304, 306 to the communication windings 420a, 422a, 420b, 422b. In other words, the relative positioning of the second axis A2 and the third axis A3 along the first axis A1 may be chosen to minimize the magnetic coupling between the power windings 304, 306 to the communication windings 420a, 422a, 420b, 422b.

[0081] The flexible circuit 444 is also wound around opening 342. The flexible circuit 444 is wound around opening 342 such that opening 342 is outside of the turns formed by the first communication windings 420a, 420b and the second communication windings 422a, 422b.

[0082] It should be appreciated that the magnetic assembly 424 may not include the core 226 if the first power winding 304 and the second power winding 306 are air-cored. The bobbin may provide support for the first and second power windings 304, 306 and the flexible circuit 444 without the use of a core. The opening 342 may be optional.

[0083] FIG. 4B illustrates flexible circuit 444 including a substrate 445, a first conductive path 446a and a second conductive path 448a of communication link COM1, and a first conductive path 446b and second conductive path 448b of communication link COM2. Substrate 445 has a first side 445a and a second side 445b. A first edge of substrate 445 is shown in dotted lines to provide a visual reference of the positioning of the flexible circuit 444. A marker is shown as a circle overlayed with a cross and is also utilized to provide a visual reference for the positioning of the flexible circuit 444. It should be appreciated that the marker on the first side 445a substantially overlays the marker on the second side 445b. The marker is shown on the top left of the first side 445a of substrate 445. The marker is also shown on the bottom left of the second side 445b of substrate 445. As such, visually the flexible circuit 444 is shown rotated about the first edge. The substrate 445 may be a flexible material. Example substrates include tape or a flexible printed circuit board. The substrate 445 may also include Mylar or Kapton.

[0084] The first conductive path 446a and the second conductive path 448a form the windings of the communication link COM1. The turns formed by the first conductive path 446a and the second conductive path 448a are laid around the second axis A2. The second axis A2 is substantially perpendicular to the first axis A1. The first conductive path 446a is disposed on the first side 445a while the second conductive path 448a is disposed on the second side 445b of substrate 445. The first side 445a may be an outer side of the flexible circuit 444 while the second side 445b may be an inner side of the flexible circuit. The first conductive path 446a forms first communication winding 420a and conductive path 448a forms second communication winding 422a. The second side 445b is shown as rotated about the first edge. As such, the second conductive path 448a is a mirror image of the first conductive path 446a.

[0085] The first conductive path 446b and the second conductive path 448b form the windings of the communication link COM2. The turns formed by the first conductive path 446b and the second conductive path 448b are laid around a third axis A3. The third axis A3 is substantially perpendicular to the first axis A1. In the example shown, the second axis A2 and the third axis A3 are substantially parallel. It is appreciated that the third axis A3 need not be parallel to the second axis A2, and that it could be rotated in the plane of A2 through an angle such as 90 degrees with respect to A2. The first conductive path 446b is disposed on the first side 445a while the second conductive path 448ba is disposed on the second side 445b of substrate 445. The first conductive path 446b forms first communication winding 420b and second conductive path 448b forms second communication winding 422b. The second side 445b is shown as rotated about the first edge. As such, the second conductive path 448b is shown as a mirror image of the first conductive path 446b. It should be appreciated that the first side 445a and the second 445b may include other circuit elements independent of communication links COM1 and COM2.

[0086] As shown in the illustrated example, the conductive paths of the first communication windings 420a, 420b are laid out in substantially the same manner as discussed with regard to the conductive paths of first communication winding 320. Similarly, the conductive paths of the second communication windings 422a, 422b are laid out in substantially the same manner as discussed with regard to the conductive paths of second communication winding 322.

[0087] The first conductive path 446a substantially overlays the second conductive path 448a. Further, end 419a and end 423a substantially overlay each other, and end 421a and end 425a substantially overlay each other. Conductive path 446b substantially overlays conductive path 448b. End 419b and 423b substantially overlay each other, while end 421b and end 425b substantially overlay each other. As shown, the first communication windings 420a, 420b are substantially the same in size and shape as their corresponding second communication windings 422a, 422b. However, it should be appreciated that size and shapes may be different.

[0088] Further, conductive paths 446a, 448a, 446b, 448b are shown as wound in a clockwise direction from their positively labeled terminals to their negatively labeled terminals. However, it should be appreciated that they need not all be wound in the same direction.

[0089] FIG. 5 illustrates flexible circuit 344 laid around axis A1. Further, the flexible circuit 344 is shown as laid around center legs 234, 236 of core 226. The core 226 of FIG. 5 is shown in the same perspective as the core in FIG. 2. Core 226 is shown a including a first portion 228 with center leg 234, and a second portion 230 with center leg 236. It should be appreciated that core 226 shown in FIG. 5 shares many similarities with core 226 of FIG. 2 and the detailed description for similarly named and numbered elements in FIG. 5 may be found with respect to FIG. 2. The first side 345a of flexible circuit 344 is reproduced in FIG. 5. The details of similarly named and numbered elements of flexible circuit 344 may be found with respect to FIG. 3B. It should be appreciated that the first power winding and the second power winding are not shown for clarity.

[0090] As shown, the flexible circuit 344 is wrapped around the portion of the core 226. In particular, the flexible circuit 344 is wrapped around center legs 234, 236 of core 226. FIG. 5 is provided to illustrate the positioning of flexible circuit 344. The second axis A2 is shown as substantially perpendicular to the first axis A1. While flexible circuit 344 is reproduced in FIG. 5, it should be appreciated that the flexible circuit 444 may also be shown.

[0091] Numerous specific details are set forth above in order to provide a thorough understanding of the present invention. It will be apparent, however, to one having ordinary skill in the art that the specific detail need not be employed to practice the present invention. In other instances, well-known materials or methods have not been described in detail in order to avoid obscuring the present invention. For example, skilled artisans will appreciate that elements in the previously described figures are illustrated for simplicity and clarity and have not necessarily been drawn to scale. For example, the dimensions of some of the elements in the figures may be exaggerated relative to other elements to help to improve understanding of various embodiments of the present invention. Also, common but well-understood elements that are useful or necessary in a commercially feasible embodiment are often not depicted in the figures in order to facilitate a less obstructed view of these various embodiments of the present invention.

[0092] Reference throughout this specification to “one embodiment”, “an embodiment”, “one example” or “an example” means that a particular feature, structure or characteristic described in connection with the embodiment or example is included in at least one embodiment of the present invention. Thus, appearances of the phrases “in one embodiment”, “in an embodiment”, “one example” or “an example” in various places throughout this specification are not necessarily all referring to the same embodiment or example. Furthermore, the particular features, structures or characteristics may be combined in any suitable combinations and/or subcombinations in one or more embodiments or examples. Particular features, structures or characteristics may be included in an integrated circuit, an electronic circuit, a combinational logic circuit, or other suitable components that provide the described functionality.

[0093] The description of illustrated examples of the present invention, including what is described in the Abstract, are not intended to be exhaustive or to be a limitation to the precise forms disclosed. While specific embodiments of, and examples for, the invention are described herein for illustrative purposes, various equivalent modifications are possible without departing from the broader spirit and scope of the present invention. Indeed, it is appreciated that any specific example voltages, currents, frequencies, power range values, times, etc., are provided for explanation purposes and that other values may also be employed in other embodiments and examples in accordance with the teachings of the present invention.

[0094] Although the present invention is defined in the claims, it should be understood that the present invention can alternatively be defined in accordance with the following examples:

[0095] Example 1. A magnetic assembly, comprising a core; a first power winding wound around at least a portion of the core, wherein the portion of the core is inside at least one turn of the first power winding; a second power winding magnetically coupled to the first power winding and wound around the portion of the core, wherein the portion of the core is inside at least one turn of the second power winding; and a flexible circuit wound around the core, the flexible circuit comprising a first communication winding, wherein the portion of the core is outside at least one turn of the first communication winding; and a second communication winding magnetically coupled to the first communication winding, wherein the portion of the core is outside at least one turn of the second communication winding.

[0096] Example 2. The magnetic assembly of example 1, wherein the first power winding and the second power winding are wound around a first axis, wherein the first axis intersects the portion of the core, the first communication winding and the second communication winding are laid around a second axis, wherein the first axis is substantially perpendicular to the second axis.

[0097] Example 3. The magnetic assembly of example 1 or 2, wherein the flexible circuit is wound between the first power winding and the second power winding.

[0098] Example 4. The magnetic assembly of any one of examples 1 to 3, wherein the flexible circuit is wound between layers of turns of the first power winding.

[0099] Example 5. The magnetic assembly of any one of examples 1 to 4, further comprising: a bobbin including an opening configured to receive the portion of the core, wherein the first power winding, the second power winding, and the flexible circuit are wound around the bobbin.

[0100] Example 6. The magnetic assembly of any one of examples 1 to 5, wherein the magnetic assembly is configured to be used as an energy transfer element.

[0101] Example 7. The magnetic assembly of any one of examples 1 to 6, the flexible circuit comprising: a flexible substrate with a first side and a second side, wherein the first communication winding and the second communication winding are disposed on the flexible substrate.

[0102] Example 8. The magnetic assembly of any one of examples 1 to 7, wherein the first communication winding and the second communication winding are disposed on the first side of the flexible substrate such that the first communication winding and the second communication winding are configured to substantially overlay when the flexible circuit is wound around the portion of the core.

[0103] Example 9. The magnetic assembly of claim 7, wherein the first communication winding is disposed on the first side of the flexible substrate and the second communication winding is disposed on the second side of the flexible substrate such that the first communication winding and the second communication winding substantially overlay.

[0104] Example 10. The magnetic assembly of any one of examples 1 to 9, wherein the flexible circuit further comprises: a third communication winding, wherein the portion of the core is outside at least one turn of the third communication winding; and a fourth communication winding magnetically coupled to the third communication winding, wherein the portion of the core is outside at least one turn of the second communication winding, wherein the first communication winding and second communication winding forms a first communication link and the third communication winding and the fourth communication winding forms a second communication link.

[0105] Example 11. The magnetic assembly of any one of examples 1 to 10, wherein the core comprises a material of relatively high magnetic permeability.

[0106] Example 12. A magnetic assembly configured to be used with a core, comprising: a bobbin including an opening configured to receive at least a portion of the core, wherein the bobbin forms a bobbin window; a first power winding disposed in the bobbin window, wherein the opening is inside at least one turn of the first power winding; a second power winding magnetically coupled to the first power winding and disposed in the bobbin window, wherein the opening is inside at least one turn of the second power winding; and a flexible circuit disposed in the bobbin window, the flexible circuit comprising: a first communication winding, wherein the opening is outside at least one turn of the first communication winding; and a second communication winding magnetically coupled to the first communication winding, wherein the opening is outside at least one turn of the second communication winding.

[0107] Example 13. The magnetic assembly of example 12, wherein the first power winding and the second power winding are wound around a first axis, wherein the first axis intersects the opening, the first communication winding and the second communication winding are laid around a second axis, wherein the first axis is substantially perpendicular to the second axis.

[0108] Example 14. The magnetic assembly of example 12 or 13, wherein the flexible circuit is wound between the first power winding and the second power winding.

[0109] Example 15. The magnetic assembly of any one of examples 12 to 14, wherein the flexible circuit is wound between layers of turns of the first power winding.

[0110] Example 16. The magnetic assembly of any one of examples 12 to 15, wherein the magnetic assembly is configured to be used as an energy transfer element.

[0111] Example 17. The magnetic assembly of any one of examples 12 to 16, the flexible circuit comprising a flexible substrate with a first side and a second side, wherein the first communication winding and the second communication winding are disposed on the flexible substrate.

[0112] Example 18. The magnetic assembly of any one of examples 12 to 17, wherein the first communication winding and the second communication winding are disposed on the first side of the flexible substrate such that the first communication winding and the second communication winding are configured to substantially overlay when the flexible circuit is wound around the opening.

[0113] Example 19. The magnetic assembly of any one of examples 12 to 18, wherein the first communication winding is disposed on the first side of the flexible substrate and the second communication winding is disposed on the second side of the flexible substrate such that the first communication winding and the second communication winding substantially overlay.

[0114] Example 20. The magnetic assembly of any one of examples 12 to 19, wherein the flexible circuit further comprises: a third communication winding, wherein the opening is outside at least one turn of the third communication winding; and a fourth communication winding magnetically coupled to the third communication winding, wherein the opening is outside at least one turn of the second communication winding, wherein the first communication winding and second communication winding forms a first communication link and the third communication winding and the fourth communication winding forms a second communication link.

[0115] Example 21. The magnetic assembly of any one of examples 12 to 20, wherein the core comprises a material of relatively high magnetic permeability.

[0116] Example 22. A flexible circuit comprising a flexible substrate including a first side and a second side; a first conductive path disposed on the flexible substrate, wherein the first conductive path spirals outward from an inner end of the first conductive path to an outer end of the first conductive path; and a second conductive path disposed on the flexible substrate, wherein the second conductive path is configured to be magnetically coupled to the first conductive path, the second conductive path spirals outward from an inner end of the second conductive path to an outer end of the second conductive path.

[0117] Example 23. The flexible circuit of example 22, wherein the first conductive path and the second conductive path are substantially similar in size and shape.

[0118] Example 24. The flexible circuit of example 22 or 23, wherein the first conductive path and the second conductive path are substantially rectangular in shape.

[0119] Example 25. The flexible circuit of any one of examples 22 to 24, wherein the first conductive path and the second conductive path are disposed on the first side.

[0120] Example 26. The flexible circuit of any one of examples 22 to 25, wherein the first conductive path is disposed on the first side and the second conductive path is disposed on the second side, wherein the first conductive path and the second conductive path substantially overly.

[0121] Example 27. A magnetic assembly, comprising: a first power winding substantially laid around a first axis; a second power winding magnetically coupled to the first power winding and substantially laid around the first axis; and a flexible circuit proximate to the first power winding and the second power winding, the flexible circuit comprising: a first communication winding substantially laid around a second axis; and a second communication winding magnetically coupled to the first communication winding, the second communication winding is substantially laid around a second axis, wherein the second axis is substantially perpendicular to the first axis.

[0122] Example 28. The magnetic assembly of example 27, wherein the flexible circuit is located between the first power winding and the second power winding.

[0123] Example 29. The magnetic assembly of example 27 or 28, wherein the flexible circuit is located between layers of turns of the first power winding.

[0124] Example 30. The magnetic assembly of any one of examples 27 to 29, further comprising: a core, wherein the first axis intersects the core, wherein a portion of the core is inside at least one turn of the first power winding and at least one turn of the second power winding, the portion of the core is outside at least one turn of the first communication winding and at least one turn of the second communication winding.

[0125] Example 31. The magnetic assembly of any one of examples 27 to 30, further comprising: a bobbin including an opening, wherein the first axis intersects the opening and the first power winding, the second power winding, and the flexible circuit are laid around the opening.

[0126] Example 32. The magnetic assembly of any one of examples 27 to 31, wherein the magnetic assembly is configured to be used as an energy transfer element.

[0127] Example 33. The magnetic assembly of any one of examples 27 to 32, the flexible circuit comprising: a substrate with a first side and a second side, wherein the first communication winding and the second communication winding are disposed on the substrate.

[0128] Example 34. The magnetic assembly of any one of examples 27 to 33, wherein the first communication winding and the second communication winding are disposed on the first side of the substrate such that the first communication winding and the second communication winding are configured to substantially overlay when the flexible circuit is wound around the first axis.

[0129] Example 35. The magnetic assembly of any one of examples 27 to 34, wherein the first communication winding is disposed on the first side of the substrate and the second communication winding is disposed on the second side of the substrate such that the first communication winding and the second communication winding substantially overlay.

[0130] Example 36. The magnetic assembly of any one of examples 27 to 35, wherein the flexible circuit further comprises: a third communication winding substantially laid around a third axis; and a fourth communication winding magnetically coupled to the third communication winding and substantially laid around the third axis, wherein the third axis is substantially perpendicular to the first axis, the first communication winding and second communication winding forms a first communication link and the third communication winding and the fourth communication winding forms a second communication link.

CLAIMS

What is claimed is:

1. A magnetic assembly, comprising:

a core;

a first power winding wound around at least a portion of the core, wherein the portion of the core is inside at least one turn of the first power winding;

a second power winding magnetically coupled to the first power winding and wound around the portion of the core, wherein the portion of the core is inside at least one turn of the second power winding; and

a flexible circuit wound around the core, the flexible circuit comprising:

a first communication winding, wherein the portion of the core is outside at least one turn of the first communication winding; and

a second communication winding magnetically coupled to the first communication winding, wherein the portion of the core is outside at least one turn of the second communication winding.

2. The magnetic assembly of claim 1, wherein

the first power winding and the second power winding are wound around a first axis, wherein the first axis intersects the portion of the core,

the first communication winding and the second communication winding are laid around a second axis, wherein the first axis is substantially perpendicular to the second axis.

3. The magnetic assembly of claim 1, wherein the flexible circuit is wound between the first power winding and the second power winding.

4. The magnetic assembly of claim 1, wherein the flexible circuit is wound between layers of turns of the first power winding.

5. The magnetic assembly of claim 1, further comprising:

a bobbin including an opening configured to receive the portion of the core, wherein the first power winding, the second power winding, and the flexible circuit are wound around the bobbin.

6. The magnetic assembly of claim 1, wherein the magnetic assembly is configured to be used as an energy transfer element.

7. The magnetic assembly of claim 1, the flexible circuit comprising:

a flexible substrate with a first side and a second side, wherein the first communication winding and the second communication winding are disposed on the flexible substrate.

8. The magnetic assembly of claim 7, wherein the first communication winding and the second communication winding are disposed on the first side of the flexible substrate such that the first communication winding and the second communication winding are configured to substantially overlay when the flexible circuit is wound around the portion of the core.

9. The magnetic assembly of claim 7, wherein the first communication winding is disposed on the first side of the flexible substrate and the second communication winding is disposed on the second side of the flexible substrate such that the first communication winding and the second communication winding substantially overlay.

10. The magnetic assembly of claim 1, wherein the flexible circuit further comprises:

a third communication winding, wherein the portion of the core is outside at least one turn of the third communication winding; and

a fourth communication winding magnetically coupled to the third communication winding, wherein the portion of the core is outside at least one turn of the second communication winding, wherein the first communication winding and second communication winding forms a first communication link and the third communication winding and the fourth communication winding forms a second communication link.

11. The magnetic assembly of claim 1, wherein the core comprises a material of relatively high magnetic permeability.

12. A magnetic assembly configured to be used with a core, comprising:

a bobbin including an opening configured to receive at least a portion of the core, wherein the bobbin forms a bobbin window;

a first power winding disposed in the bobbin window, wherein the opening is inside at least one turn of the first power winding;

a second power winding magnetically coupled to the first power winding and disposed in the bobbin window, wherein the opening is inside at least one turn of the second power winding; and

a flexible circuit disposed in the bobbin window, the flexible circuit comprising:

a first communication winding, wherein the opening is outside at least one turn of the first communication winding; and

a second communication winding magnetically coupled to the first communication winding, wherein the opening is outside at least one turn of the second communication winding.

13. The magnetic assembly of claim 12, wherein

the first power winding and the second power winding are wound around a first axis, wherein the first axis intersects the opening,

the first communication winding and the second communication winding are laid around a second axis, wherein the first axis is substantially perpendicular to the second axis.

14. The magnetic assembly of claim 12, wherein the flexible circuit is wound between the first power winding and the second power winding.

15. The magnetic assembly of claim 12, wherein the flexible circuit is wound between layers of turns of the first power winding.

16. The magnetic assembly of claim 12, wherein the magnetic assembly is configured to be used as an energy transfer element.

17. The magnetic assembly of claim 12, the flexible circuit comprising:

a flexible substrate with a first side and a second side, wherein the first communication winding and the second communication winding are disposed on the flexible substrate.

18. The magnetic assembly of claim 17, wherein the first communication winding and the second communication winding are disposed on the first side of the flexible substrate such that the first communication winding and the second communication winding are configured to substantially overlay when the flexible circuit is wound around the opening.

19. The magnetic assembly of claim 17, wherein the first communication winding is disposed on the first side of the flexible substrate and the second communication winding is disposed on the second side of the flexible substrate such that the first communication winding and the second communication winding substantially overlay.

20. The magnetic assembly of claim 12, wherein the flexible circuit further comprises:

a third communication winding, wherein the opening is outside at least one turn of the third communication winding; and

a fourth communication winding magnetically coupled to the third communication winding, wherein the opening is outside at least one turn of the second communication winding, wherein the first communication winding and second communication winding forms a first communication link and the third communication winding and the fourth communication winding forms a second communication link.

21. The magnetic assembly of claim 12, wherein the core comprises a material of relatively high magnetic permeability.

22. A flexible circuit comprising:

a flexible substrate including a first side and a second side;

a first conductive path disposed on the flexible substrate, wherein the first conductive path spirals outward from an inner end of the first conductive path to an outer end of the first conductive path; and

a second conductive path disposed on the flexible substrate, wherein the second conductive path is configured to be magnetically coupled to the first conductive path, the second conductive path spirals outward from an inner end of the second conductive path to an outer end of the second conductive path.

23. The flexible circuit of claim 22, wherein the first conductive path and the second conductive path are substantially similar in size and shape.

24. The flexible circuit of claim 22, wherein the first conductive path and the second conductive path are substantially rectangular in shape.

25. The flexible circuit of claim 22, wherein the first conductive path and the second conductive path are disposed on the first side.

26. The flexible circuit of claim 22, wherein the first conductive path is disposed on the first side and the second conductive path is disposed on the second side, wherein the first conductive path and the second conductive path substantially overly.

27. A magnetic assembly, comprising:

a first power winding substantially laid around a first axis;

a second power winding magnetically coupled to the first power winding and substantially laid around the first axis; and

a flexible circuit proximate to the first power winding and the second power winding, the flexible circuit comprising:

a first communication winding substantially laid around a second axis; and

a second communication winding magnetically coupled to the first communication winding, the second communication winding is substantially laid around a second axis, wherein the second axis is substantially perpendicular to the first axis.

28. The magnetic assembly of claim 27, wherein the flexible circuit is located between the first power winding and the second power winding.

29. The magnetic assembly of claim 27, wherein the flexible circuit is located between layers of turns of the first power winding.

30. The magnetic assembly of claim 27, further comprising:

a core, wherein the first axis intersects the core, wherein

a portion of the core is inside at least one turn of the first power winding and at least one turn of the second power winding,

the portion of the core is outside at least one turn of the first communication winding and at least one turn of the second communication winding.

31. The magnetic assembly of claim 27, further comprising:

a bobbin including an opening, wherein the first axis intersects the opening and the first power winding, the second power winding, and the flexible circuit are laid around the opening.

32. The magnetic assembly of claim 27, wherein the magnetic assembly is configured to be used as an energy transfer element.

33. The magnetic assembly of claim 27, the flexible circuit comprising:

a substrate with a first side and a second side, wherein the first communication winding and the second communication winding are disposed on the substrate.

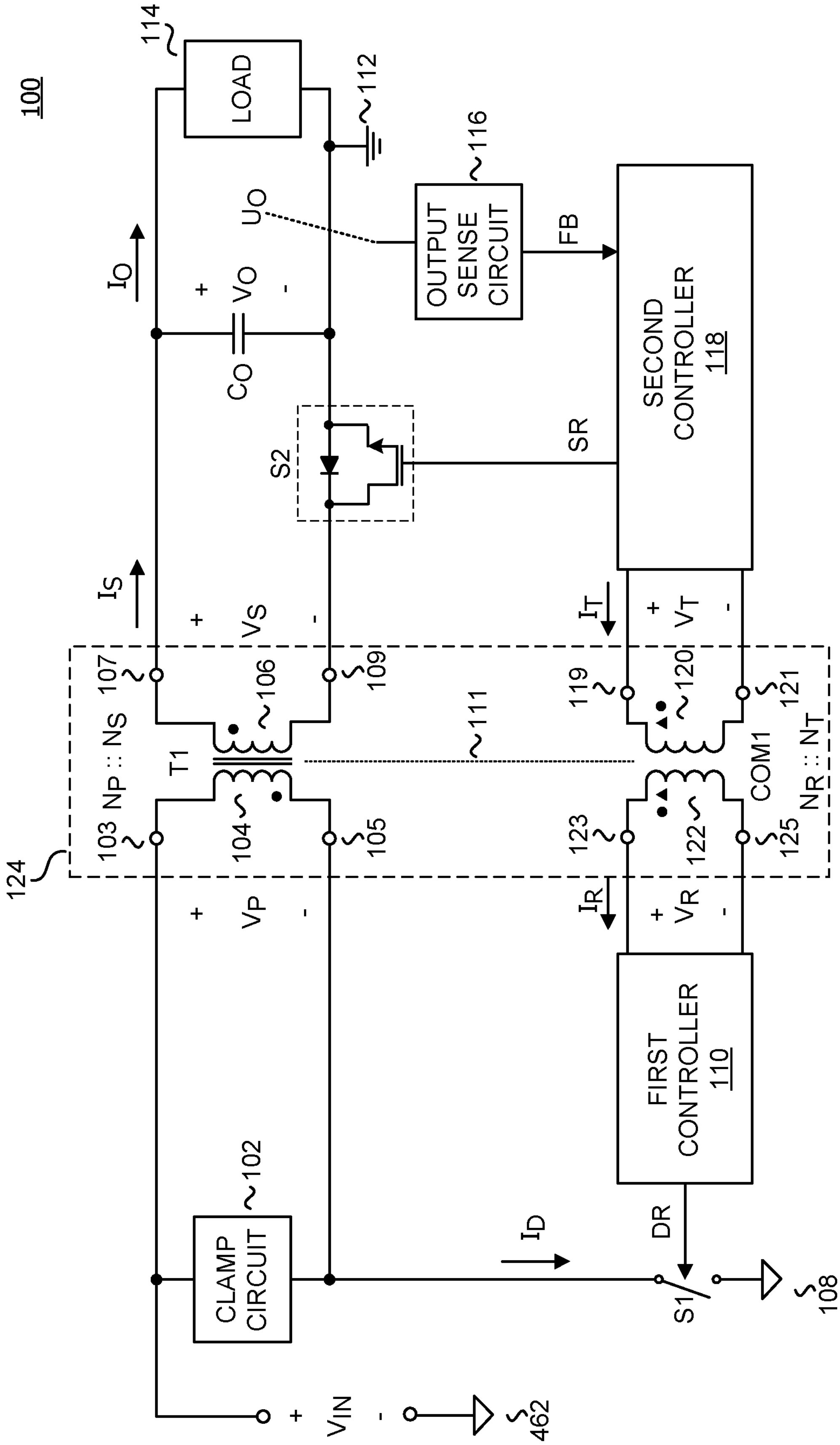
34. The magnetic assembly of claim 33, wherein the first communication winding and the second communication winding are disposed on the first side of the substrate such that the first communication winding and the second communication winding are configured to substantially overlay when the flexible circuit is wound around the first axis.

35. The magnetic assembly of claim 33, wherein the first communication winding is disposed on the first side of the substrate and the second communication winding is disposed on the second side of the substrate such that the first communication winding and the second communication winding substantially overlay.

36. The magnetic assembly of claim 27, wherein the flexible circuit further comprises:

a third communication winding substantially laid around a third axis; and

a fourth communication winding magnetically coupled to the third communication winding and substantially laid around the third axis, wherein the third axis is substantially perpendicular to the first axis, the first communication winding and second communication winding forms a first communication link and the third communication winding and the fourth communication winding forms a second communication link.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S2
T1
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106
107
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121
122
123
125
COM1

FIG. 1

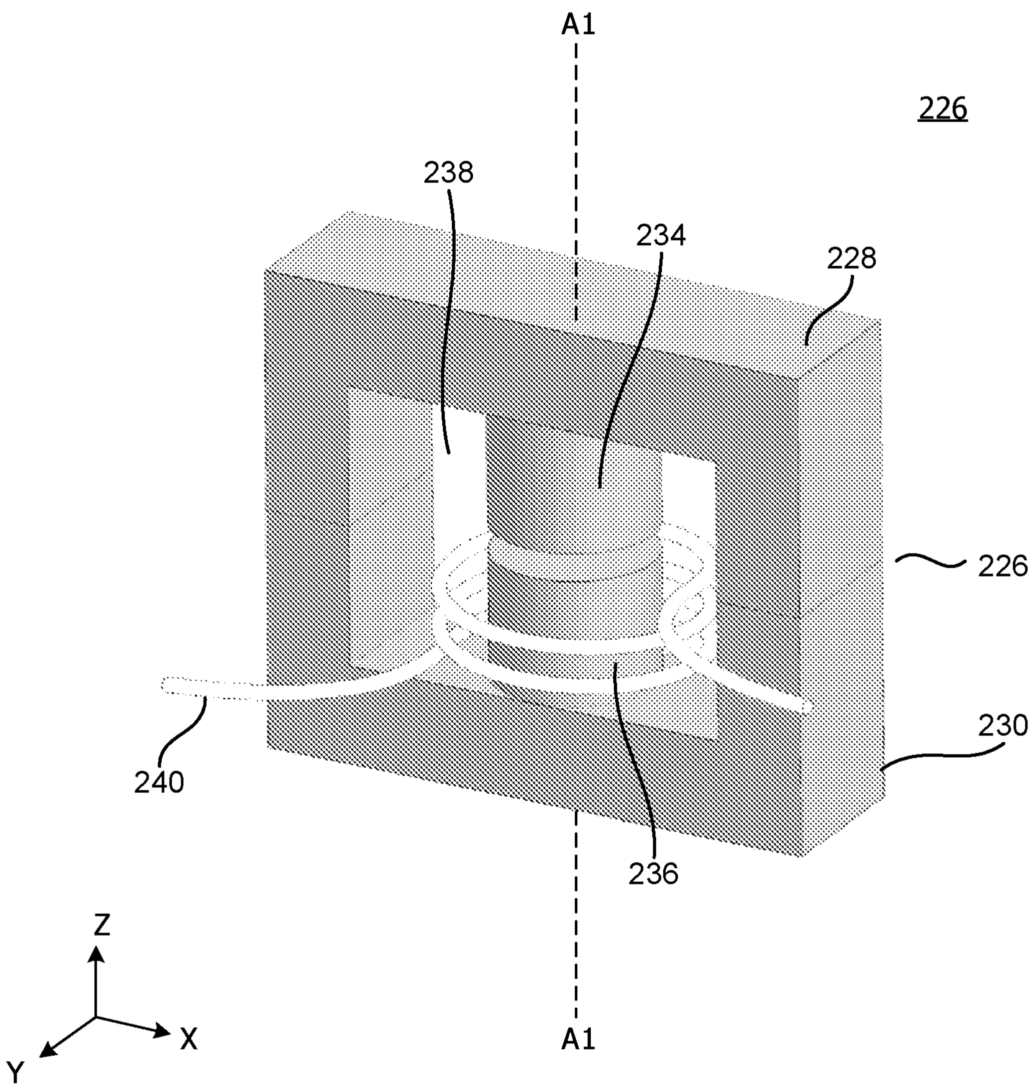
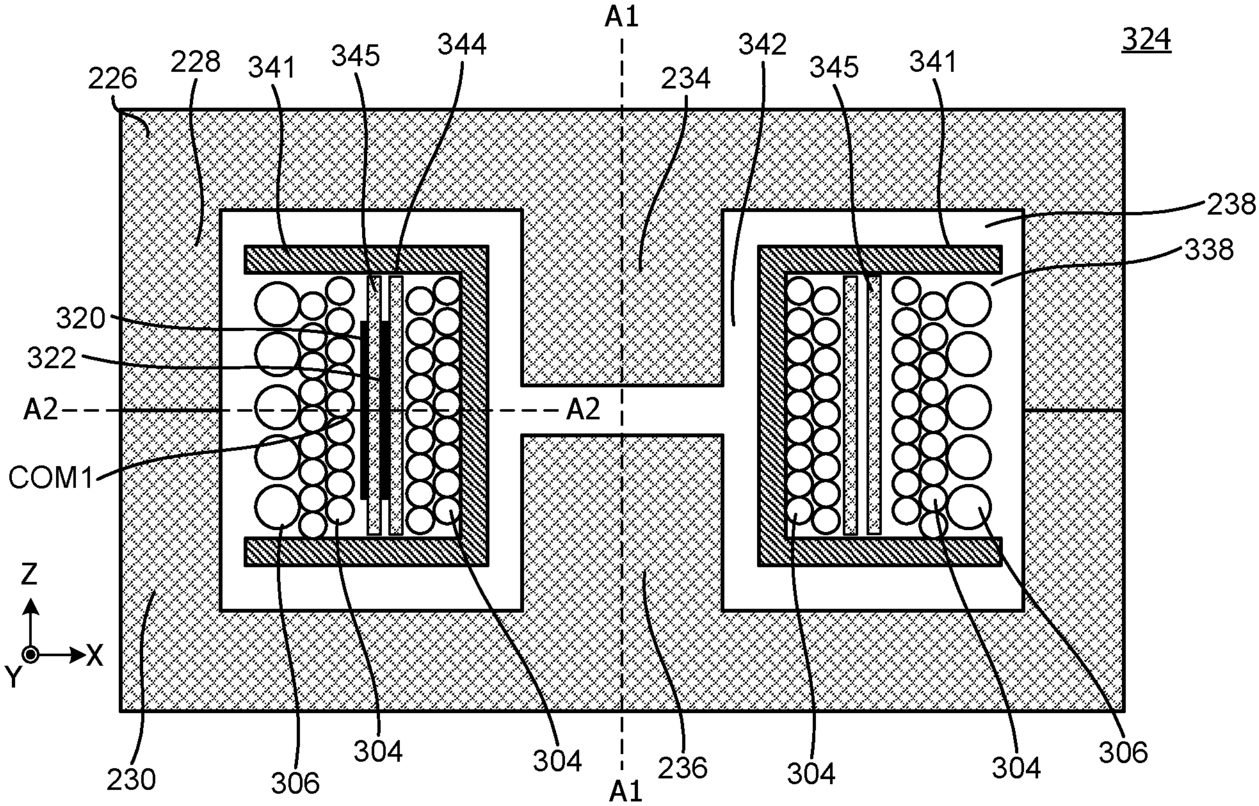


FIG. 2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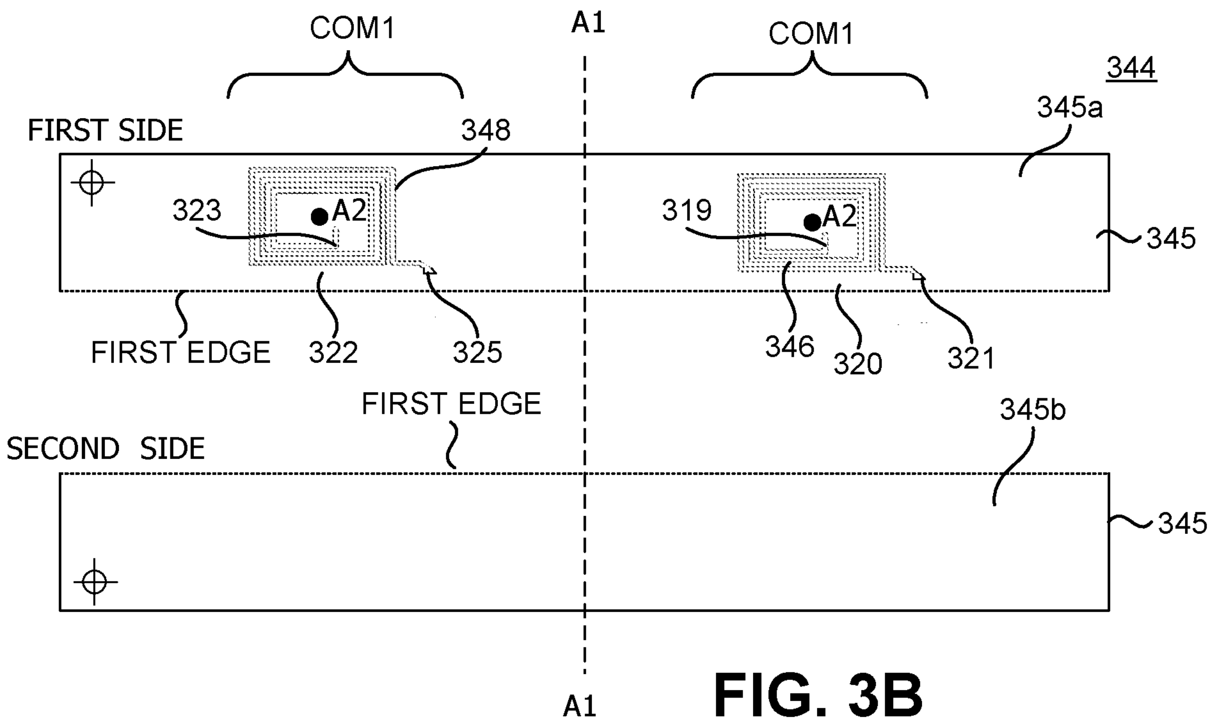
304
304
306

FIG. 3A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COM1
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345a
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A2
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A2
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322
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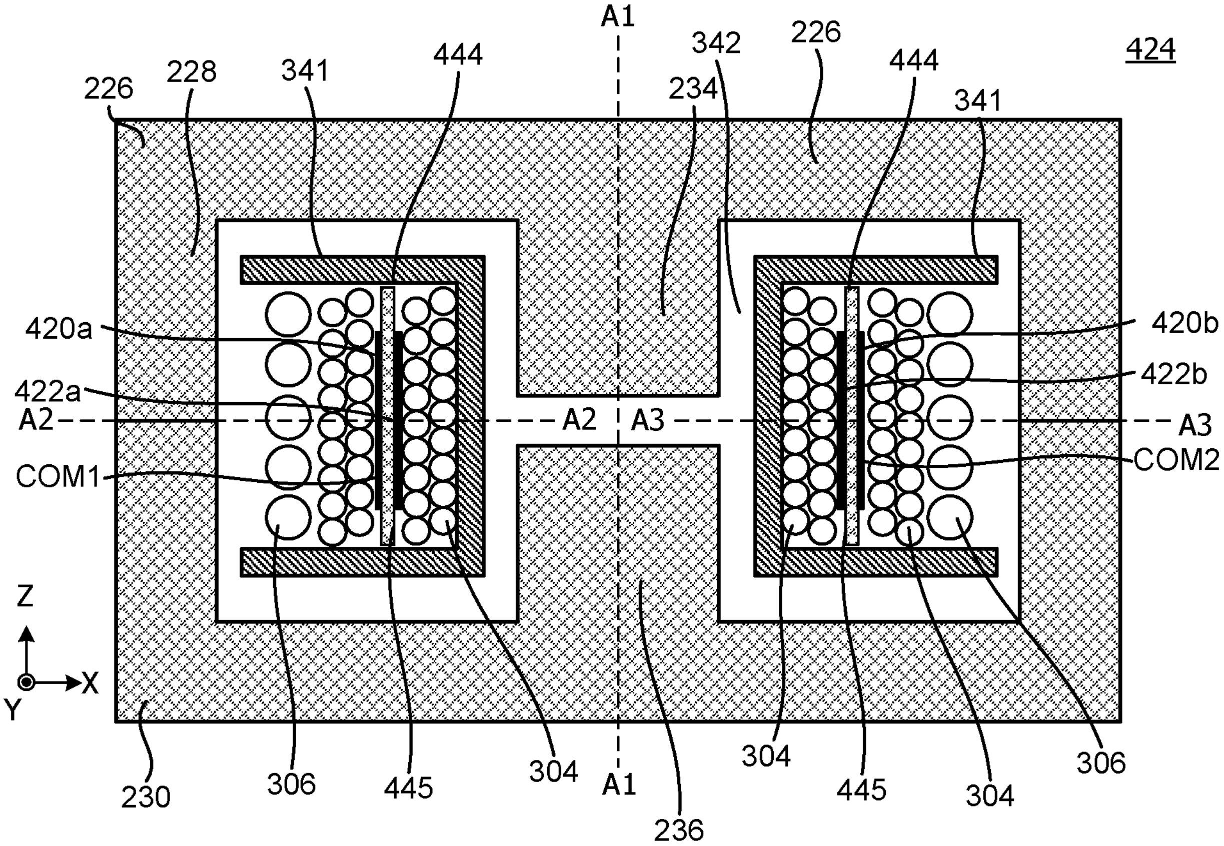
346
320
321
FIRST EDGE
345b
SECOND SIDE
345
A1

FIG. 3B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420b
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422b
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A2
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COM1
COM2
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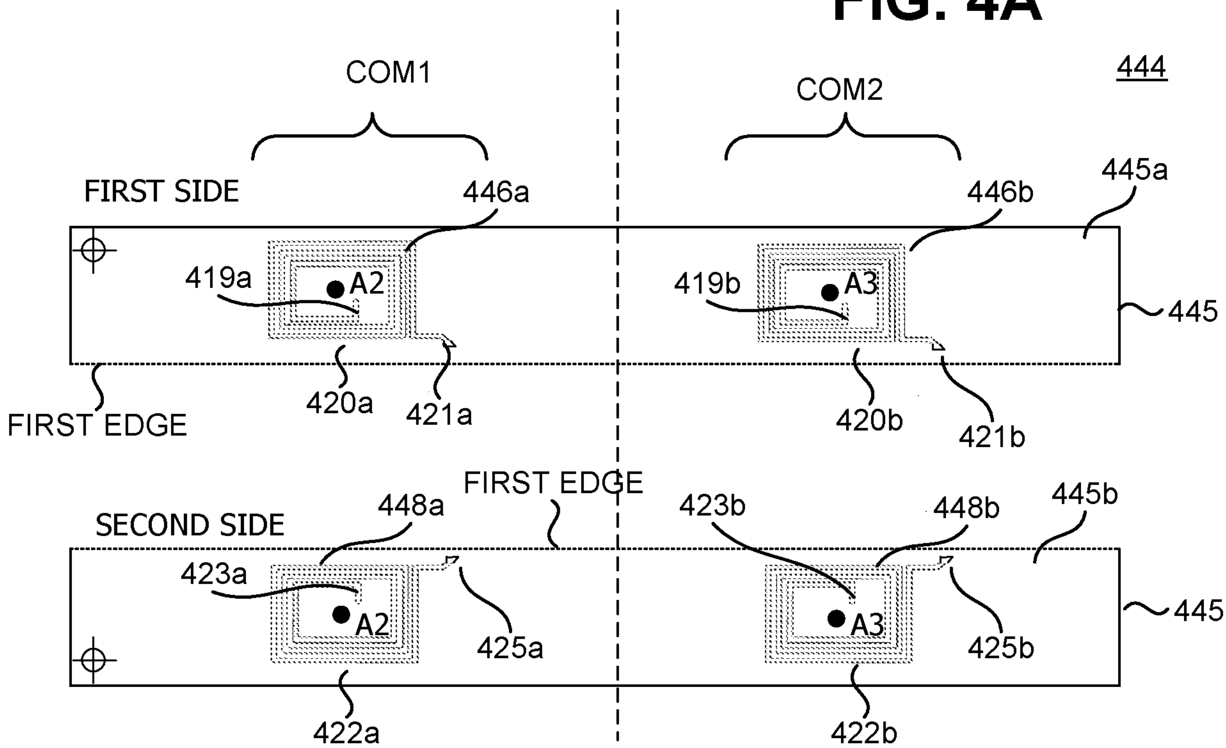
FIG. 4A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421b
FIRST EDGE
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445b
SECOND SIDE
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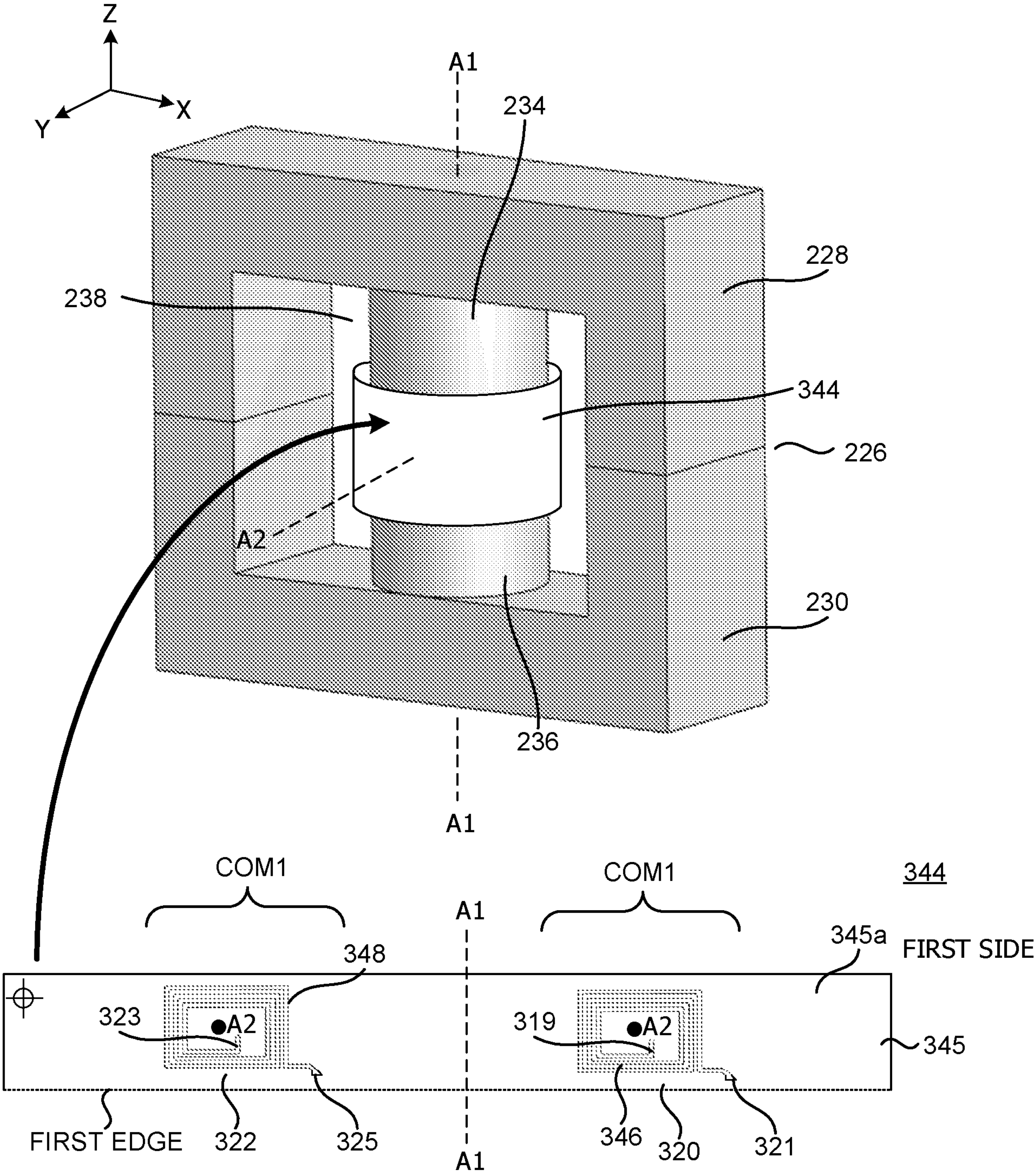
A3
425b
445
422a
422b

FIG. 4B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A2
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COM1
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A1
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A2
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FIRST EDGE
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320
321
A1

FIG. 5

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2023/084793

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01F27/28 H01F27/30 H01F27/32 H01F27/38 H02M1/00
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H01F H02M H02J H04B

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

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

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2018/102213 A1 (HANABUSA KAZUYOSHI [JP] ET AL) 12 April 2018 (2018-04-12)	1-6, 10-16, 20,21, 27-32,36
A	figures 1-7,11 corresponding description	7-9, 17-19, 33-35
A	US 2022/255447 A1 (ZOU YANBO [CN] ET AL) 11 August 2022 (2022-08-11) figures 1-18 corresponding description	1-21, 27-36
A	WO 2021/034745 A1 (POWER INTEGRATIONS INC [US]) 25 February 2021 (2021-02-25) figures 1-8 corresponding description	1-21, 27-36

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

[X] 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 another 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
2 July 2024	12/07/2024

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

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INTERNATIONAL SEARCH REPORT

International application No
PCT/US2023/084793

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DE 10 2010 029470 B4 (AVAGO TECHNOLOGIES GENERAL IP [SG]) 24 November 2016 (2016-11-24)	22-26
Y	figures 1-4,8	24
A	corresponding description	1-21, 27-36
X	DE 10 2021 119240 A1 (HELLA GMBH & CO KGAA [DE]) 26 January 2023 (2023-01-26)	22-26
Y	figures 1-3 corresponding description	24
X	EP 2 348 516 A1 (RWAYTECH [FR]) 27 July 2011 (2011-07-27)	22-26
Y	figures 1-7 corresponding description	24
X	US 11 120 940 B2 (ANALOG DEVICES INC [US]) 14 September 2021 (2021-09-14)	22,23, 25,26
Y	figures 5-7 corresponding description	24

4

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2023/084793

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2018102213 A1	12-04-2018	CN 107919734 A	17-04-2018
		JP 6493351 B2	03-04-2019
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		EP 3769448 A1	27-01-2021
		KR 20200134242 A	01-12-2020
		US 2019295770 A1	26-09-2019
		US 2021012958 A1	14-01-2021
		WO 2019182815 A1	26-09-2019

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2023/084793

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☒ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims;; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☒ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-21, 27-36

   A magnetic assembly as claimed in present claims 1, 12, 27, respectively, with the particular arrangement of the first power winding and of the second power winding with regard to the core portion / bobbin opening / first axis, and with the particular arrangement of the first communication winding and of the second communication winding with regard to the core portion / bobbin opening / second axis.

   ---

2. claims: 22-26

   A flexible circuit as claimed in present claim 22, with
   a flexible substrate including a first side and a second side;
   a first conductive path disposed on the flexible substrate, wherein the first conductive path spirals outward from an inner end of the first conductive path to an outer end of the first conductive path; and
   a second conductive path disposed on the flexible substrate, wherein the second conductive path is configured to be magnetically coupled to the first conductive path, the second conductive path spirals outward from an inner end of the second conductive path to an outer end of the second conductive path.
   Further, in claims 23-26 the size, shape and position of the first and second conductive paths is particularly specified.
