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- (54) Title:** MAGNETIC ASSEMBLY WITH AN INTEGRATED COMMUNICATION LINK

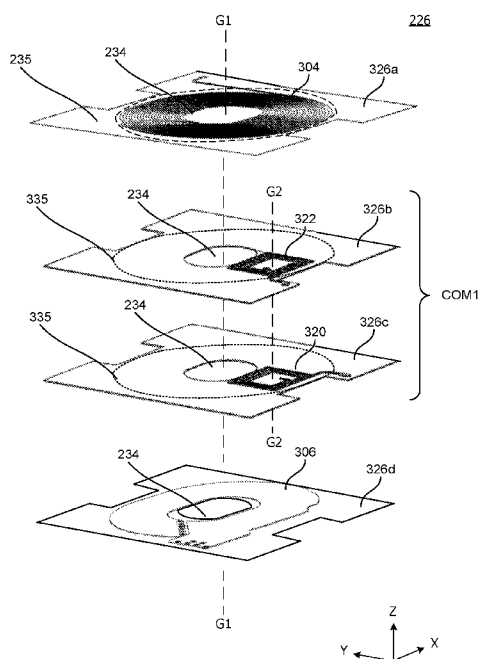


FIG. 3

- (57) Abstract:** A planar energy transfer element comprising a magnetic core and a multilayer circuit. The multilayer circuit comprising an opening configured to receive the magnetic core, a first power winding, the first power winding spans a winding area and the opening is inside the first power winding, a second power winding magnetically coupled to the first power winding and the opening is inside the second power winding, and a first communication link arranged substantially within a projection of the winding area of the first power winding. The first communication link comprises a first communication winding arranged substantially within the projection of the winding area, wherein the opening is outside of the first communication winding, and a second communication winding arranged substantially within the projection of the winding area, wherein the first communication winding and the second communication winding are magnetically coupled and the opening is outside of the second communication winding.

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MAGNETIC ASSEMBLY WITH AN INTEGRATED COMMUNICATION LINK**BACKGROUND OF THE INVENTION**

Field of the Invention

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

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 and may 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 generally 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.

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 to 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 and the output-side of the power converter. An example energy transfer element includes a transformer. The communication link between the first controller and the second controller conveys information between the input-side and the output-side of 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 may 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 into a multilayer circuit. The multilayer circuit includes conductive layers for the energy transfer element and conductive layers for the communication link. In one example, one or more communication links may be integrated proximate to layers for the energy transfer element. The one or more communication links may be in layers above the layers for the energy transfer element. The one or more communication links may be in layers below the layers for the energy transfer element. In another example, layers with one or more communication links may be integrated between layers of the energy transfer element. Integrating the energy transfer element and the communication link within the same multilayer circuit may lead to a reduction in the size and number of components of the power converter. Benefits of reduced component count may include ease in assembly, reduced point of failure, and improved reliability.

[0007] The energy transfer element includes a first power winding and a second power winding. 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 is disposed on a first power layer of the multilayer circuit. The first power winding spans a winding area. Further, the first power winding is wound around a first axis. The second power winding is disposed on a second power layer of the multilayer circuit and is wound around the first axis.

[0008] The communication link includes a first communication winding and a second communication winding. The first communication winding may be a transmitter winding while the second communication is a receiver winding. The first communication winding is disposed on a first communication layer and is arranged within a projection of the winding area. The first

communication winding is wound around a second axis. The second communication winding is disposed on a second communication layer and is arranged within the projection of the winding area. The second communication winding is wound around the second axis. The second axis is different from the first axis. Further, the first communication winding and the second communication winding may substantially overlay one another.

[0009] In one example, the multilayer circuit board may include an opening. The first power winding and the second power winding may be wound around the opening. The first communication winding and the second communication winding may be wound such that these windings do not surround the opening.

BRIEF DESCRIPTION OF DRAWINGS

[0010] 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.

[0011] 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.

[0012] FIG. 2A illustrates a perspective view of the magnetic assembly of FIG. 1 including the energy transfer element and the communication link, in accordance with an embodiment of the present disclosure.

[0013] FIG. 2B is an exploded view of the magnetic assembly of FIG. 2A including the energy transfer element and the communication link, in accordance with an embodiment of the present disclosure.

[0014] FIG. 2C is a side view of an example core of FIGS. 2A and 2B.

[0015] FIG. 3 is an exploded view of example layers of the energy transfer element and the communication link of the magnetic assembly of FIG. 2A, in accordance with an embodiment of the present disclosure.

[0016] FIG. 4A is an illustrative top-down view of a communication layer including the second communication winding of FIG. 3 overlaid with a first power winding, in accordance with an embodiment of the present disclosure.

[0017] FIG. 4B is an illustrative top-down view of a communication layer including the first communication winding of FIG. 3 overlaid with the first power winding, in accordance with an embodiment of the present disclosure.

[0018] FIG. 5A illustrates a top-down view of a first power layer including the first power winding of FIG. 3, in accordance with an embodiment of the present disclosure.

[0019] FIG. 5B illustrates a top-down view of a second communication layer including the second communication winding of FIG. 3, in accordance with an embodiment of the present disclosure.

[0020] FIG. 5C illustrates a top-down view of a first communication layer of FIG. 3 including the first communication winding, in accordance with an embodiment of the present disclosure.

[0021] FIG. 5D illustrates a top-down view of a second power layer of FIG. 3 including the second power winding, in accordance with an embodiment of the present disclosure.

[0022] FIG. 6A illustrates an example first and second partial loop of a communication winding, in accordance with an embodiment of the present disclosure.

[0023] FIG. 6B illustrates another example first and second partial loop of a communication winding including a jog, in accordance with an embodiment of the present disclosure.

[0024] FIG. 6C illustrates a further example first and second partial loop of a communication winding including one or more jogs, in accordance with an embodiment of the present disclosure.

[0025] FIG. 6D illustrates an example first and second partial loop of a communication winding including one or more jogs, in accordance with an embodiment of the present disclosure.

[0026] FIG. 6E illustrates an example second communication winding, in accordance with an embodiment of the present disclosure.

[0027] FIG. 6F illustrates an example first communication winding, in accordance with an embodiment of the present disclosure.

[0028] FIG. 6G illustrates the example first communication winding of FIG. 6F with relation to a reference line, in accordance with an embodiment of the present disclosure.

[0029] FIG. 7A is an illustrative top-down view of a layer including the second communication winding of FIG. 6E overlayed with a first power winding, in accordance with an embodiment of the present disclosure.

[0030] FIG. 7B is an illustrative top-down view of a layer including the first communication winding of FIG. 6F overlayed with the first power winding, in accordance with an embodiment of the present disclosure.

[0031] FIG. 8A illustrates a top-down view of a first power layer including a first power winding, in accordance with an embodiment of the present disclosure.

[0032] FIG. 8B illustrates a top-down view of a second communication layer including the second communication winding of FIG. 6E, in accordance with an embodiment of the present disclosure.

[0033] FIG. 8C illustrates a top-down view of a first communication layer including the first communication winding of FIG. 6F, in accordance with an embodiment of the present disclosure.

[0034] FIG. 8D illustrates a top-down view of a second power layer including the second power winding, in accordance with an embodiment of the present disclosure.

[0035] FIG. 9A illustrates a perspective view of the first power winding, the second communication winding of FIG. 6E and the first communication winding of FIG. 6F.

[0036] FIG. 9B illustrates a cross section of the first power winding, the second communication winding, and the first communication winding shown in FIG. 9A.

[0037] FIG. 10 illustrates an example power converter with another magnetic assembly including an energy transfer element, a communication link, and enhancement windings, in accordance with an embodiment of the present disclosure.

[0038] FIG. 11A is an illustrative top-down view of a layer including a second communication winding and a first enhancement winding overlayed with a first power winding, in accordance with an embodiment of the present disclosure.

[0039] FIG. 11B is an illustrative top-down view of a layer including a first communication winding and a second enhancement winding overlayed with the first power winding, in accordance with an embodiment of the present disclosure.

[0040] FIG. 12A illustrates a top-down view of a first power layer including a first power winding, in accordance with an embodiment of the present disclosure.

[0041] FIG. 12B illustrates a top-down view of a second communication layer including the second communication winding and the first enhancement winding of FIG. 11A, in accordance with an embodiment of the present disclosure.

[0042] FIG. 12C illustrates a top-down view of a first communication layer including the first communication winding and the second enhancement winding of FIG. 11B, in accordance with an embodiment of the present disclosure.

[0043] FIG. 12D illustrates a top-down view of a second power layer including a second power winding, in accordance with an embodiment of the present disclosure.

[0044] FIG. 13A illustrates a top-down view of a second communication layer including another second communication winding and first enhancement winding, in accordance with an embodiment of the present disclosure.

[0045] FIG. 13B illustrates a top-down view of a first communication layer including another first communication winding and second enhancement winding, in accordance with an embodiment of the present disclosure.

[0046] FIG. 14 illustrates a switch controller with a magnetic assembly including an energy transfer element and multiple communication links, in accordance with an embodiment of the present disclosure.

[0047] FIG. 15 is an exploded view of example layers of the multiple communication links of the magnetic assembly of FIG. 14, in accordance with an embodiment of the present disclosure.

[0048] FIG. 16 is a top-down view of communication layers on the interface side of FIG. 15, in accordance with an embodiment of the present disclosure.

[0049] FIG. 17 is an enlarged view of the communication layers of FIG. 16, in accordance with an embodiment of the present disclosure.

[0050] FIG. 18 is a top-down view of communication layers on the driver side of FIG. 15, in accordance with an embodiment of the present disclosure.

[0051] FIG. 19 is an enlarged view of communication layers of FIG. 18, in accordance with an embodiment of the present disclosure.

[0052] FIG. 20 is a perspective view of a communication winding of FIGS. 19, in accordance with an embodiment of the present disclosure.

[0053] The figures are shown in a certain example orientation and may be referenced by the orientation shown using terminology such as top, bottom, upper, lower, left, right, above, below, vertical, lateral, etc. It should be appreciated that the orientation and arrangement may change and not functionally affect the embodiments of the present disclosure. For ease and clarity of explanation, the elements discussed herein will be referred to by the specific example orientation shown in the figures.

DETAILED DESCRIPTION

[0054] Embodiments of the present disclosure include an assembly in which an energy transfer element and a communication link are integrated together into a multilayer circuit. Further, multiple communication links may be integrated into the same multilayer circuit as the energy transfer element. Integrating the energy transfer element and the communication link may reduce the size of a power converter, increase reliability, and potentially reduce costs.

[0055] 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.

[0056] 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.

[0057] 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 path between windings 120 and 122 is through air, it should be appreciated that the coupling between windings 120 and 122 may not be exclusively air-cored.

[0058] 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.

[0059] 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, the first power winding 104 conducts current and energy is stored by the energy transfer element T1. When the power switch S1 is turned OFF, the second power winding 106 conducts current and energy is stored in the output capacitor C_O or delivered to a load 114.

[0060] 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.

[0061] The power converter 100 provides output power to the 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 either a coupled inductor, transformer, or an inductor with a single winding. It should be appreciated that an inductor with a single winding does not provide galvanic isolation. 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.

[0062] 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 (HEMT) transistor. The power switch S1 may also be a silicon (Si) based transistor, a gallium nitride (GaN) based transistor, or a silicon carbide (SiC) based transistor. 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 GaN based HEMT or SiC based MOSFET while the second switch may be a MOSFET, BJT, or IGBT.

[0063] 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.

[0064] 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 along 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.

[0065] 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.

[0066] 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 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 while 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.

[0067] 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 and a coupled inductor.

[0068] 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.

[0069] 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.

[0070] 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 while node 123 is the non-dot end of the second communication winding 122.

[0071] 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 at node 119 with respect to 121. And transmitter current I_T is shown as positive when conducting 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 the receiver winding as shown. The receiver voltage V_R is shown as positive at node 123 with respect to node 125. The receiver current I_R is shown as positive when conducting from node 125 to node 123.

[0072] It is also noted that the dots and triangles shown on windings 104, 106, 120 and 122 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 the external circuit.

[0073] 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. For example, the second power winding 106 may conduct current I_s and produce a changing magnetic field which may inadvertently induce a voltage across the second communication winding 122 that is positive at node 125 with respect node 123. This may occur for a particular physical orientation of the windings on T1 and COM1. In particular, the second communication winding 122 is wound with respect to the second power winding 106 such that a non-zero current I_s conducted by the second power winding 106 produces a negative receiver voltage V_R across the second

communication winding 122. If the second power winding 106 conducts the current I_S from node 109 to node 107 when node 107 is positive with respect to node 109, the voltage on node 123 with respect to node 125 is substantially negative. It should be appreciated that the magnitudes and polarities of voltages unintentionally induced in the windings of communication link COM1 in response to current in a winding of energy transfer element T1 depend on the relative orientations of the windings and the direction of the current.

[0074] 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 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.

[0075] Energy transfer element T1 and communication link COM1 are included in the same magnetic assembly 124. The magnetic assembly includes a multilayer circuit. The multilayer circuit may be affixed to either rigid or flexible media. Both the energy transfer element T1 and the communication link COM1 may be implemented into the multilayer circuit.

The multilayer circuit may include an opening to receive the core of the energy transfer element T1. The first power winding 104 may be disposed on one or more layers of the multilayer circuit. The second power winding 106 may be disposed on one or more layers of the multilayer circuit. The first communication winding 120 may be disposed on one or more layers of the multilayer circuit. The second communication winding 122 may be disposed on one or more layers of the multilayer circuit. The first communication winding 120 and the second communication winding 122 may be disposed on different layers and substantially overlay each other.

[0076] The communication link COM1 may be disposed proximate to the energy transfer element T1. For example, the communication link COM1 may be disposed in layers of the multilayer circuit above the energy transfer element T1. In another example, the communication link COM1 may be disposed in layers of the multilayer circuit below the energy transfer element T1.

[0077] The communication link COM1 may also be disposed between layers of the energy transfer element T1. For example, the communication link COM1 may be disposed between the one or more layers of the first power winding 104 and the one or more layers of the second power winding 106. If the first power winding 104 is disposed on two or more layers, the communication link COM1 may be disposed between the layers of the first power winding 104. Similarly, if the second power winding 106 is disposed on two or more layers, the communication link COM1 may be disposed between the layers of the second power winding 106. While the magnetic assembly 124 illustrates one communication link, it should be appreciated that the magnetic assembly may include two or more communication links.

[0078] A cartesian coordinate system is introduced to illustrate the orientation of the various embodiments in the figures. As shown, the coordinate system includes 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 axis. 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. For FIGS. 2A and 2B, the first vertical direction (z-axis) traverses towards the top of the page, the first lateral direction (x-axis) traverses diagonally towards the top right of the page, and the second lateral direction (y-axis) traverses diagonally towards the top left of the page.

[0079] FIG. 2A illustrates a perspective view of the magnetic assembly 224, which is one example of magnetic assembly 124 shown in FIG. 1. The magnetic assembly 224 is shown

as including a multilayer circuit 226 and a core 228 of magnetic material. The multilayer circuit 226 is shown as a multilayer circuit board.

[0080] The multilayer circuit 226 comprises multiple layers. The multilayer circuit 226 is often referred to by the number of its layers which include a conductive material. For example, a fourteen layer circuit board would refer to a circuit board which includes fourteen layers of a conductive material. Copper may be one example of a conductive material. However, it should be appreciated that while a layer may have conductive material, the layer may or may not conduct current. For example, a layer may include a copper shield winding which would generally not conduct current. Between the layers of conductive material may be insulation or dielectric layers. Example materials for the insulation or dielectric include resined glass, polysilicon, ceramic or prepreg materials to be cured at a later time. In one example manufacturing technique, the conductive material is disposed upon a dielectric layer. The conductive material is then etched to form traces. As the layers are coupled together, the gaps or voids between traces in one layer may be filled with the dielectric from another layer. Multilayer circuits may also be produced by additive manufacturing techniques that deposit and cure both conductive and insulating inks on a substrate.

[0081] The multilayer circuit 226 may also have interconnects between the conductive layers to couple conductive paths in different layers. The interconnects are often referred to as vias. Examples of interconnects include a plated through hole or a micro via. The multilayer circuit 226 may include a single multilayer printed circuit board or the multilayer circuit 226 may include several printed circuit boards adhered together. In one example, the multilayer circuit 226 may have a width (first lateral direction, x-axis) of approximately 18.2 millimeters (mm), a length (second lateral direction, y-axis) of approximately 17.2 mm, and a thickness (first vertical direction, z-axis) of approximately 3.2 mm.

[0082] The core 228 provides a path for a magnetic field generated by a current in either the first power winding 104 or the second power winding 106. The core 228 is generally made from a material of relatively high magnetic permeability, e.g., ferrite or steel. The core 228 strengthens the magnetic coupling between the first power winding 104 and the second power winding 106. The core 228 may also provide shielding for the multilayer circuit 226 from external magnetic fields.

[0083] FIG. 2B illustrates an exploded view of the magnetic assembly 224 along the first axis G1. The axis G1 is parallel to the first vertical direction (z-axis) and is perpendicular to both the first lateral direction (x-axis) and the second lateral direction (y-axis).

[0084] The multilayer circuit includes multiple layers. Each layer of the multilayer circuit spans a plane defined by the first lateral direction (x-axis) and the second lateral direction

(y-axis). In other words, each layer of the multilayer circuit spans a plane perpendicular to the first vertical direction(z-axis). The dashed line illustrates a winding area 235 which encloses the conductive path or paths which form either the first power winding 104 or the second power winding 106, or both. The winding area 235 is disposed in a plane of the first lateral direction (x-axis) and the second lateral direction (y-axis). As will be further discussed, the multilayer circuit 226 includes the first power winding 104 and the second power winding 106 of the energy transfer element T1 along with the first communication winding 120 and the second communication winding 122 of the communication link COM1.

[0085] The multilayer circuit 226 includes an opening 234. The opening 234 extends through the multilayer circuit 226 in the first vertical direction (z-axis) and traverses each layer of the multilayer circuit 226. The opening 234 is configured to receive the core 228. The axis G1 is also shown as centered upon an opening 234 of the multilayer circuit 226 along the first vertical direction (z-axis). The multilayer circuit 226 may also include guides on the edge of the multilayer circuit 226 for positioning the core 228.

[0086] Core 228 is shown as an E-I core with a first portion 228a and a second portion 228b. It should be appreciated that the core 228 may only have one portion or may have more than the two portions shown and still benefit from the teachings of the present disclosure. Further, while the core 228 is shown as an E-I core, the core may be other shapes, such as an E-E core, and still benefit from the teachings of the present disclosure. The first portion 228a of the core 228 includes a center leg 229 which protrudes in a first vertical direction (z-axis). The center leg 229 of the core 228 is received in the opening 234 such that the core 228 traverses multiple layers of the multilayer circuit 226. The core 228 also includes outer legs, which may be positioned in the guides of the multilayer circuit 226. In one example, the first portion 228a of the core 228 may have a width (first lateral direction, x-axis) of approximately 5.33 mm, a length (second lateral direction, y-axis) of approximately 17.2 mm, and a thickness (first vertical direction, z-axis) of approximately 5.63 mm. The second portion 228b may have a width (first lateral direction, x-axis) of approximately 5.33 mm, a length (second lateral direction, y-axis) of approximately 17.2 mm, and a thickness (first vertical direction, z-axis) of approximately 1.25 mm.

[0087] In one embodiment, the first power winding 104 and the second power winding 106 may be air-cored. As such, the magnetic assembly 224 would not include the core 228. The opening 234 may be optional. The conductive paths which form the first power winding 104 and the second power winding 106 are laid around the first axis G1.

[0088] FIG. 2C illustrates a side view of the core 228 shown in FIGS. 2A and 2B. In particular, FIG. 2C illustrates a side view when facing the plane of the first vertical direction (z-

axis) and the second lateral direction (y-axis). The first vertical direction (z-axis) is shown as traversing the page from bottom to top. The second lateral direction (y-axis) is shown as traversing the page from right to left. The first lateral direction (x-axis) is shown as going into the page.

[0089] The first portion 228a of the core 228 includes a center leg 229. On either side of the center leg 229 is a first core window 232 and a second core window 230. The first core window 232 and the second core window 230 refer to the spaces bounded by the core 228 in which conductive paths may be placed. The first core window 232 and the second core window 230 may represent the volume in which the core 228 and the multilayer circuit 226 overlap. The first core window 232 and the second core window 230 may represent the volume in space bounded by the core 228 that may be fully or partially occupied by portions of the multilayer circuit 226. In FIG. 2C, the first core window 232 represents the volume in which the core 228 and the multilayer circuit 226 overlap to the right of the center leg 229. The second core window 230 represents the volume in which the core 228 and the multilayer circuit 226 overlap to the left of the center leg 229.

[0090] 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, typically referred to as a gap. The size 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, epoxy, or varnish. In the example shown, a gap may be placed between the center leg 229 of the first portion 228a and the second portion 228b.

[0091] FIG. 3 is an exploded view of a first power layer 326a, a second power layer 326d, a first communication layer 326c and a second communication layer 326b. The first power layer 326a, the second power layer 326d, the first communication layer 326c and the second communication layer 326b are positioned along planes in the first lateral direction (x-axis) and the second lateral direction (y-axis). In other words, the first power layer 326a, the second power layer 326d, the first communication layer 326c and the second communication layer 326b each span a plane perpendicular to the first vertical direction (z-axis). The first power layer 326a and the second power layer 326d includes conductive paths which form the energy transfer element T1. The first communication layer 326c and the second communication layer 326b include conductive paths which form the communication link COM1. FIG. 3 is illustrated in the same perspective as FIGS. 2A and 2B.

[0092] FIG. 3 also illustrates a first axis G1 and a second axis G2. Both the first and second axis G1, G2 are parallel to the first vertical direction (z-axis). Further, the second axis G2 is a different axis from the first axis G1. The conductive paths which form the energy transfer element T1 are laid around the first axis G1. The conductive paths which form the first energy transfer element T1 encircle the first axis G1. The conductive paths which form the communication link COM1 are laid around the second axis G2. The conductive paths which form the communication link COM1 encircle the second axis G2.

[0093] First Power Layer 326a

[0094] The first power layer 326a includes the first power winding 304. As shown, a conductive path which forms the first power winding 304 is disposed on the first power layer 326a. As such, conductive paths or traces disposed on the first power layer 326a would traverse in the plane of the first lateral direction (x-axis) and the second lateral direction (y-axis). The first power winding 304 is one example of the first power winding 104 shown in FIG. 1.

[0095] The first power winding 304 forms at least one turn around the opening 234. The first power winding 304 encircles the opening 234 on the first power layer 326a. Further, the first power winding 304 encircles the opening 234 an N_P number of times, to create N_P number of turns of the first power winding 304. The opening 234 is inside a turn formed by the first power winding 304.

[0096] With regards the first axis G1, the first power winding 304 is laid around the first axis G1. The first power winding 304 spirals around the first axis G1. The first power winding 304 may encircle the axis an N_P number of times to create an N_P number of turns. The first axis G1 is inside a turn formed by the first power winding 304.

[0097] The dashed line illustrates a winding area 235. The winding area 235 denotes the space which the first power winding 304 spans within the first power layer 326a.

[0098] While the first power winding 304 is shown as disposed on one layer, e.g., the first power layer 326a, it should be appreciated that the first power winding 304 may be disposed on multiple layers. The conductive paths which form the first power winding 304 in one layer may be coupled to a conductive path which forms the first power winding 304 in another layer. The conductive paths in different layers may be coupled by an interconnect. The interconnect traverses the first vertical direction (z-axis) to couple conductive paths in different layers of the multilayer circuit 226.

[0099] Second Power Layer 326d:

[0100] The second power layer 326d is parallel to the first power layer 326a. The second power layer 326d includes the second power winding 306. As shown, a conductive path which forms the second power winding 306 is disposed on the second power layer 326d.

Conductive paths or traces disposed on the second power layer 326d would traverse in the plane of the first lateral direction (x-axis) and the second lateral direction (y-axis). The second power winding 306 is one example of the second power winding 106 shown in FIG. 1.

[0101] The second power winding 306 forms at least one turn around the opening 234. The second power winding 306 encircles the opening 234 on the second power layer 326d. The second power winding 306 encircles the opening 234 an N_s number of times, to create N_s number of turns of the second power winding 306. In the example shown, the second power winding 306 encircles the opening 234 once, creating a single turn of the second power winding 306. However, it should be appreciated that the second power winding 306 may have more turns than shown in the figures. The opening 234 is inside a turn formed by the second power winding 306.

[0102] With regards the first axis G1, the second power winding 306 is laid around the first axis G1. The second power winding 306 spirals around the first axis G1. The second power winding 306 may encircle the axis an N_s number of times to create an N_s number of turns. The first axis G1 is inside a turn formed by the second power winding 306.

[0103] Both the first power winding 304 and the second power winding 306 are magnetically coupled to each other. The first power winding 304 and the second power winding 306 both encircle the opening 234. As such, the magnetic coupling between the first power winding 304 and the second power winding 306 may be strengthened by the core 228.

[0104] While the second power winding 306 is shown as disposed on one layer, e.g., the second power layer 326d, it should be appreciated that the second power winding 306 may be disposed on multiple layers. The conductive path which forms the second power winding 306 in one layer may be coupled to a conductive path which forms the second power winding 306 in another layer. The conductive paths in different layers may be coupled by an interconnect. The interconnect traverses the first vertical direction (z-axis) to couple conductive paths in different layers of the multilayer circuit 226.

[0105] First Communication Layer 326c:

[0106] The first communication layer 326c is parallel to the first power layer 326a. Conductive paths or traces disposed on the first communication layer 326c traverse in the first lateral direction (x-axis) and the second lateral direction (y-axis). The first communication layer 326c includes the first communication winding 320. As shown, a conductive path which forms the first communication winding 320 is disposed on the first communication layer 326c. The first communication winding 320 is one example of the first communication winding 120 shown in FIG. 1.

[0107] The dotted line illustrates a projection 335 of the winding area 235 upon the first communication layer 326c and the second communication layer 326b. The projection 335 is a projection of the winding area 235 of the first power winding 304 upon the other layers of the multilayer circuit 226. The projection 335 is the projection of the winding area 235 in the first vertical direction (z-axis).

[0108] The first communication winding 320 is disposed within the projection 335. The first communication winding 320 forms at least one turn within the projection 335. Unlike the first power winding 304 and the second power winding 306, the first communication winding 320 does not encircle the opening 234. In other words, the first communication winding 320 does not surround the opening 234. The turns of the first communication winding 320 are formed such that the opening 234 is outside of the first communication winding 320. The first communication winding 320 is shown with an N_T number of turns. However, it should be appreciated that the first communication winding 320 may have either more or fewer turns than what is shown in the figures. The first communication winding 320 spirals within the projection 335 to form its turns.

[0109] With respect to the second axis G2, the first communication winding 320 laid around is the second axis G2. The first communication winding 320 spirals around the second axis G2. The first communication winding 320 may encircle the axis an N_T number of times to create an N_T number of turns. The second axis G2 is inside a turn formed by the first communication winding 320.

[0110] While the first communication winding 320 is shown as disposed on one layer, e.g., the first communication layer 326c, it should be appreciated that the first communication winding 320 may be disposed on multiple layers. The conductive paths which form the first communication winding 320 in one layer may be coupled to a conductive path which forms the first communication winding 320 in another layer. The conductive paths in different layers may be coupled by an interconnect. The interconnect traverses the first vertical direction (z-axis) to couple conductive paths in different layers of the multilayer circuit 226.

[0111] Second Communication Layer 326b:

[0112] The second communication layer 326b is parallel to the first power layer 326a. Conductive paths or traces disposed on the second communication layer 326b traverse in the first lateral direction (x-axis) and the second lateral direction (y-axis). The second communication layer 326b includes the second communication winding 322. As shown, a conductive path which forms the second communication winding 322 is disposed on the second communication layer 326b. The second communication winding 322 is one example of the second communication winding 122 shown in FIG. 1.

[0113] The second communication winding 322 is disposed within the projection 335. The second communication winding 322 forms at least one turn within the projection 335. Unlike the first power winding 304 and the second power winding 306, the second communication winding 322 does not encircle the opening 234. In other words, the second communication winding 322 does not surround the opening 234. The turns of the second communication winding 322 are formed such that the opening 234 is outside of the second communication winding 322. The second communication winding 322 is shown with an N_R number of turns. The second communication winding 322 spirals within the projection 335 to form its turns.

[0114] With respect to the second axis G2, the second communication winding 322 is laid around the second axis G2. The second communication winding 322 spirals around the second axis G2. The second communication winding 322 may encircle the axis an N_R number of times to create N_R number of turns. The second axis G2 is inside a turn formed by the second communication winding 322.

[0115] While the second communication winding 322 is shown as disposed on one layer, e.g., the second communication layer 326b, it should be appreciated that the second communication winding 322 may be disposed on multiple layers. The conductive paths which form the second communication winding 322 in one layer may be coupled to a conductive path which forms the second communication winding 322 in another layer. The conductive paths in different layers may be coupled by an interconnect. The interconnect traverses the first vertical direction (z-axis) to couple conductive paths in different layers of the multilayer circuit 226.

[0116] The first communication winding 320 and the second communication winding 322 are magnetically coupled. Further, first communication winding 320 and second communication winding 322 are magnetically coupled substantially independent of the core 228. As shown, the first communication layer 326c is adjacent to the second communication layer 326b in the first vertical direction (z-axis). However, it should be appreciated that there may be intervening layers between the first communication layer 326c and the second communication layer 326b. Such layers could include for example isolation layers made of electrically insulating material, providing galvanic isolation between communication layers 326c and 326b for example in an isolated power converter. The intervening layer could also include conductive paths if the conductive paths do not lie within the projection of the communicating windings 320, 322, which could be used as jumpers or partial shields.

[0117] In one embodiment, the first communication winding 320 and the second communication winding 322 have the same number of turns, e.g., N_T is equal to N_R . However, it should be appreciated that the first communication winding and the second communication

winding may not have the same number of turns, as shown, for example, later in FIGS. 16 and 18.

[0118] The first communication winding 320 and the second communication winding 322 are positioned with respect to each other on their respective layers. In one example, the conductive path or paths of the first communication winding 320 substantially overlay the conductive path or paths of the second communication winding 322. Further, the first communication winding 320 overlays the second communication winding 322 in the first vertical direction (z-axis). By substantially overlaying the first communication winding 320 and the second communication winding 322, magnetic coupling between the first communication winding 320 and the second communication winding 322 may be strengthened.

[0119] In FIG. 3, the first power layer 326a is disposed above the second power layer 326d in the first vertical direction (z-axis). The second communication layer 326b is disposed above the first communication layer 326c in the first vertical direction (z-axis). The first communication layer 326c and second communication layer 326b are disposed between the first power layer 326a and second power layer 326d in the first vertical direction (z-axis). However, it should be appreciated that the ordering of the layers may differ from what is shown. For example, the first communication layer 326c and second communication layer 326b may be disposed above both the first power layer 326a and second power layer 326d. In another example, the first communication layer 326c and second communication layer 326b may be disposed below the first power layer 326a and second power layer 326d.

[0120] In addition, the first power winding 304 or the second power winding 306, or both, may be disposed on multiple layers. As such, the first communication layer 326c may be disposed between layers of the first power winding 304, or the second power winding 306, or both. Similarly, the second communication layer 326b may be disposed between layers of the first power winding 304, or the second power winding 306, or both.

[0121] For FIGS. 4A and FIG. 4B, the first communication layer 326c and the second communication layer 326b are viewed in the plane of the first lateral direction (x-axis) and the second lateral direction (y-axis). The first lateral direction (x-axis) is shown as pointing to the right-hand side of the page while the second lateral direction (y-axis) is shown pointing to the top of the page. The first vertical direction (z-axis) is pointing out of the page. For FIG. 4A, the solid line represents the outline or edge of the second communication layer 326b. In FIG. 4B, the solid line represents the outline or edge of the first communication layer 326c. For both FIGS. 4A and 4B, the thick dashed line illustrates the outline 436 of the core 228 from the first vertical direction (z-axis) upon the plane of the first lateral direction (x-axis) and the second lateral direction (y-axis). In other words, the thick dashed line illustrates the outline 436 of the

core 228 along the first lateral direction (x-axis) and the second lateral direction (y-axis). The thin dotted line illustrates the projection 335. The projection 335 is the projection of the winding area 235 upon the plane of the first lateral direction (x-axis) and the second lateral direction (y-axis).

[0122] For FIG. 4A and 4B, the first core window 232 and the second core window 230 are the spaces in which the outline 436 of the core (thick dotted line) overlaps the second communication layer 326b and the first communication layer 326c. As shown, the first core window 232 is the space in which the outline 436 of the core (thick dotted line) overlaps the second communication layer 326b and the first communication layer 326c below the opening 234 in the second lateral direction (y-axis). The second core window is the space in which the outline 436 of the core (thick dotted line) overlaps the second communication layer 326b and the first communication layer 326c above the opening 234 in the second lateral direction (y-axis).

[0123] For the purposes of this disclosure, an inner end of a winding may refer to an end which is inside the turns of the winding. An outer end of a winding may refer to an end which is outside of the turns formed by the winding. The winding is laid around a central axis. Further, the winding may spiral around a center axis. An inner end may refer to the end closest to the central axis while the outer end refers to the end which is farthest from the central axis. A winding may be formed by one or more conductive paths, as such an inner end of a winding may refer to an end which is inside the turns formed by the one or more conductive paths. An outer end of a winding may refer to an end which is outside of the turns formed by the one or more conductive paths. Further, the number of turns for the winding may refer to the number of times in which the one or more conductive paths is laid around the central axis. Examples of a central axis includes first axis G1 and second axis G2. The first axis G1 and the second axis G2 traverse into and out of the page, parallel with the first vertical direction (z-axis), and are shown as filled circles. In addition, an innermost conductor of a winding may refer to a conductor which is closest to the central axis while an outermost conductor of the winding may refer to a conductor which is farthest from the central axis.

[0124] FIG. 4A is an illustrative top-down view of the second communication layer 326b including the second communication winding 322 of FIG. 3. The first power winding 304 is shown for illustration purposes and it should be appreciated that the first power winding 304 is not disposed on the second communication layer 326b. FIG. 4A illustrates one example placement of the second communication winding 322 with respect to the first power winding 304.

[0125] The second communication winding 322 is disposed in the second communication layer 326b. Further, the second communication winding 322 is substantially

within the projection 335. The second communication winding 322 is substantially below the opening 234 in the second lateral direction (y-axis). The solid line which illustrates the second communication winding 322 is also representative of a conductive path of the second communication winding 322. From an inner end of the second communication winding 322, the second communication winding 322 spirals outward. The second communication winding 322 spirals outward in a clockwise direction. In FIG. 4A, the second communication winding 322 has substantially three turns. Each turn is substantially rectangular in shape. The overall shape of the second communication winding 322 is shown as rectangular. However, it should be appreciated that the second communication winding 322 may form other shapes.

[0126] The second communication winding 322 is substantially within the first core window 232. The first core window 232 is rectangular in shape. However, it should be appreciated that the first core window 232 may have other shapes, such as a square. The number of turns of the second communication winding 322, the shape, or both may be determined by the size and shape of the first core window 232. The number of turns selected for the second communication winding 322 is in part determined by the maximum number of turns which would fit in the first core window 232 given set constraints for trace spacing and width. The number of turns may also be selected to strengthen the magnetic coupling between the first communication winding 320 and the second communication winding 322.

[0127] In one example, the communication layers, 326b, 326c may have a width (first lateral direction, x-axis) of approximately 18.2 mm and a length (second lateral direction, y-axis) of approximately 17.2 mm. It should be appreciated that each of the layers of the multilayer circuit has substantially the same dimensions in the first lateral direction (x-axis) and the second lateral direction (y-axis). The first core window 232 may have a width (first lateral direction, x-axis) of approximately 5.33 mm and a length (second lateral direction, y-axis) of approximately 5.3 mm. In the example shown, the second core window 230 is substantially the same dimensions as the first core window 232. However, it should be appreciated that the dimensions may be different.

[0128] Further, the second communication winding 322 is positioned with respect to the first power winding 304. The second communication winding 322 is positioned in relation to an innermost conductor and an outermost conductor of the first power winding 304 with respect to the opening 234. An innermost conductor of the first power winding 304 refers to the conductor which is closest to the opening 234. An outermost conductor of the first power winding 304 refers to the conductor which is farthest from the opening 234. In other words, the outermost conductor of the first power winding 304 refers to the conductor which is closest to the edge of the first power layer 326a. With reference to the first axis G1, the innermost conductor of the

first power winding 304 refers to the conductor which is closest to the first axis G1 while the outermost conductor of the first power winding 306 refers to the conductor which is the farthest from the first axis G1.

[0129] A reference line may be used to refer to the positioning of the second communication winding 322. In one example, the reference line intersects the second communication winding 322 parallel with the first lateral direction (x-axis). The second communication winding 322 is positioned such that the reference line is substantially halfway between the innermost conductor and an outermost conductor of the first power winding 304 given the conductors of the first power winding 304 are substantially parallel and equidistant. In another example, the second communication winding 322 is positioned such that a voltage induced in a conductive path of the second communication winding 322 on one side of the reference line is substantially balanced by a voltage of opposite polarity in a conductive path of the second communication winding 322 on the other side of the reference line. In a further example, the second communication winding 322 is positioned such that the reference line is substantially in a line of symmetry of the magnetic flux in the first vertical direction produced by the first power winding 304 when the first power winding 304 is conducting current. One example of the reference line is shown as reference line 639 in FIGS. 6A-6G, and 9. Communication winding 322 may be positioned to minimize the net magnetic field in the first vertical direction (z-axis) enclosed by the communication winding 322 when the first power winding 304 is conducting current.

[0130] FIG. 4B is an illustrative top-down view of the first communication layer 326c including the first communication winding 320 of FIG. 3. The first power winding 304 is shown for illustration purposes and it should be appreciated that the first power winding 304 is not disposed on the first communication layer 326c. FIG. 4B illustrates one example placement of the first communication winding 320 with respect to the first power winding 304.

[0131] The first communication winding 320 is disposed in the first communication layer 326c. The first communication winding 320 is substantially within the projection 335. The first communication winding 320 is substantially below the opening 234 in the second lateral direction (y-axis). The solid line which illustrates the first communication winding 320 is also representative of a conductive path of the first communication winding 320. From an inner end of the first communication winding 320, the first communication winding 320 spirals outward. The first communication winding 320 spirals outward in a clockwise direction. In FIG. 4B, the first communication winding 320 has substantially three turns. Each turn is substantially rectangular in shape. The overall shape of the first communication winding 320 is

shown as rectangular. However, it should be appreciated that the first communication winding 320 may form other shapes.

[0132] The first communication winding 320 is substantially within the first core window 232. The number of turns of the first communication winding 320, the shape of the first communication winding 320, or both may be determined by the size and shape of the first core window 232. The number of turns selected for the first communication winding 320 is in part determined by the maximum number of turns which would fit in the first core window 232 given set constraints for trace spacing and width. The number of turns may also be selected to strengthen the magnetic coupling between the first communication winding 320 and the second communication winding 322.

[0133] Further, the first communication winding 320 is positioned with respect to the first power winding 304. The first communication winding 320 is positioned in relation to the innermost conductor and the outermost conductor of the first power winding 304 with respect to the opening 234. The reference line discussed above with FIG. 4A may also be used to refer to the positioning of the first communication winding 320. In one example, the reference line intersects the first communication winding 320 parallel with the first lateral direction (x-axis). The first communication winding 320 is positioned such that the reference line is substantially halfway between the innermost conductor and an outermost conductor of the first power winding 304 given the conductors of the first power winding 304 are substantially parallel and equidistant. In another example, the first communication winding 320 is positioned such that a voltage induced in a conductive path of the first communication winding 320 on one side of the reference line is substantially balanced by a voltage of opposite polarity in a conductive path of the first communication winding 320 on the other side of the reference line. In a further example, the first communication winding 320 is positioned such that the reference line is substantially in a line of symmetry of the magnetic flux in the first vertical direction produced by the first power winding 304 when the first power winding 304 is conducting current. One example of the reference line is shown as reference line 639 in FIGS. 6A-6G, and 9. First communication winding 320 may be positioned to minimize the net magnetic field in the first vertical direction (z-axis) enclosed by the first communication winding 320 when the first power winding 304 is conducting current.

[0134] The first communication winding 320 and the second communication winding 322 substantially overlay in the first vertical direction (z-axis). As such, each turn for the second communication winding 322 substantially overlays the respective turn of the first communication winding 320. Magnetic coupling between the first communication winding 320 and the second communication winding 322 may be strengthened by overlaying the conductive

paths which form the first communication winding 320 and the second communication winding 322.

[0135] The number of turns for the first communication winding 320 and the second communication winding 322 are selected to maximize the size of the first communication winding 320 and the second communication winding 322 within the first core window 232. The larger the enclosed area of both the first communication winding 320 and the second communication winding 322, the stronger the magnetic coupling between these windings. In one example, the first communication winding 320 and the second communication winding 322 may have a width (first lateral direction, x-axis) of approximately 4.95 mm and a length (second lateral direction, y-axis) of approximately 3.77 mm.

[0136] For FIGS. 5A, 5B, 5C, and 5D, the first power layer 326a, the second communication layer 326b, the first communication layer 326c and the second power layer 326d are viewed in the plane of the first lateral direction (x-axis) and the second lateral direction (y-axis). The first lateral direction (x-axis) is shown as pointing to the right-hand side of the page while the second lateral direction (y-axis) is shown pointing to the top of the page. The first vertical direction (z-axis) is pointing out of the page. For each figure, the thin solid line represents the outline of each layer. The winding area 235 is shown in dashed lines. The projection 335 of the winding area 235 is shown in a thin dotted line.

[0137] End-to-end reference lines 511a, 511b, 511c, and 511d are shown in each figure as a thick dashed line. The reference line traverses the plane of the of the first lateral direction (x-axis) and the second lateral direction (y-axis). The end-to-end reference line is a line which traverses from one end of a winding to the other end of the winding. The end-to-end reference line is shown as a straight line from one end to the other end of the winding. The end-to-end reference line may intersect the winding. The end-to-end reference line may be utilized to illustrate the number of turns of a winding. The number of turns is generally the number of times which the winding encircles the inner end-point on the end-to-end reference line. A turn of a winding may refer to the route traversed by the conductive path of the winding from one side of its respective end-to-end reference line and returning to the other side of the end-to-end reference line. With relation to the end-to-end reference line, the number of turns may be determined from the number of times which the winding crosses the end-to-end reference line. In one example, the number of turns may be the number of times the winding crosses the end-to-end reference line plus one. With regards to a central axis, the number of turns for the winding may refer to the number of times which the one or more conductive paths is laid around the central axis. Examples of a central axis includes first axis G1 and second axis G2. The first axis

G1 and the second axis G2 would traverse into and out of the page, parallel with the first vertical direction (z-axis), and are shown as filled circles.

[0138] For FIG. 5A, the reference line 511a is shown as traversing from end 503 to end 505. For FIG. 5B, the reference line 511b is shown as crossing from end 523 to end 525 of the second communication winding 322. For FIG. 5C, the reference line 511c is shown as crossing from end 519 to end 521 of the first communication winding 320. For FIG. 5D, the reference line 511d is shown as traversing from the end 507 to end 509.

[0139] For the purposes of this disclosure, the direction which a winding is wound is determined by the direction which a winding traverses its respective layer from the positive labeled terminal of the winding to the negative labeled terminal of the winding as shown in FIG. 1 and as viewed from the perspective of the page. However, it should be appreciated that different conventions may be utilized. For example, the direction which the winding is wound may also be determined by the direction which the winding traverses its respective layer from the negative labeled terminal to the positive labeled terminal. In another example, the direction which a winding is wound may be from an inner end to an outer end of the winding, or vice versa.

[0140] FIG. 5A illustrates a top-down view of a first power layer 326a including the first power winding 304. The first power winding 304 includes a conductive path 504a. The conductive path 504a forms the first power winding 304 and is disposed on the first power layer 326a. The conductive path 504a is one example of the first power winding 104 shown in FIG. 1. The conductive path 504a includes an end 503 and end 505. The conductive path 504a traverses the first power layer 326a from end 503 to end 505. End 503 of the conductive path 504a corresponds to the electrical node 103 shown in FIG. 1. The end 505 of the conductive path 504a corresponds to the electrical node 105 shown in FIG. 1. End 503 may be the positive labeled terminal of the voltage V_P while end 505 may be the negative labeled terminal of voltage V_P . As shown, end 503 may be coupled to the input voltage V_{IN} while end 505 may be coupled to the power switch S1. End 503 is an outer end and is outside the turns formed by the first power winding 304. End 503 is disposed near the outside edge of the first power layer 326a. End 505 is an inner end and is disposed inside turns formed by the first power winding. End 505 is disposed near the opening 234. End 505 is closer to the first axis G1 than end 503. Conductive path 504a, end 503, and end 505 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. The portion of the conductive path 504a farthest from the opening 234 and first axis G1 of the first power layer 326a may be referred to as the outer conductor of the first power winding 304. The portion of the conductive path 504a closest to the

opening 234 and first axis G1 may be referred to as the inner conductor of the first power winding 304.

[0141] The conductive path 504a traverses the first power layer 326a in a clockwise direction around the opening 234 from end 503. From end 503, the conductive path 504a traverses in a spiral from the outer edge of the first power layer 326a towards the opening 234 to end 505. The conductive path 504a inwardly spirals from the end 503 to end 505 around first axis G1. As such, the first power winding 304 may be wound in a clockwise direction from end 503 to end 505.

[0142] Each instance in which the conductive path 504a crosses the reference line 511a in FIG. 5A may be considered one turn of the first power winding 304. End 503 is shown as the beginning of reference line 511a. The conductive path 504a traverses from end 503 down the page on the right-hand side of opening 234. The conductive path 504a wraps underneath the opening and proceeds up the page on the left-hand side of the opening 234. The conductive path 504a continues to traverse above the opening and reaches the reference line 511a. For the example shown, this is one turn of the first power winding 304. It should be appreciated that the first power winding 304 is a planar winding. The conductive path 504a continues in the clockwise spiral around the opening 234 towards end 505. As the conductive path 504a traverses around the first power layer 326a to form the turns of the first power winding 304, each successive instance which the conductive path 504a reaches the reference line 511a is closer to end 505. The conductive path 504a illustrates eleven turns in the first power winding 304. However, it should be appreciated that the first power winding 304 may have either more or fewer turns than what is shown.

[0143] The opening 234 is inside the first power winding 304. The opening 234 is inside the turns formed by the conductive path 504a in the first power layer 326a of the first power winding 304. The opening 234 is substantially a stadium shape. In FIG. 5A, each turn of the conductive path 504a is substantially a stadium shape.

[0144] While the first power winding 304 is shown as disposed on a single first power layer 326a, it should be appreciated that the first power winding 304 may be disposed on multiple layers. For example, an additional power layer may include another conductive path which is coupled to the conductive path 504a.

[0145] FIG. 5B illustrates a top-down view of a second communication layer 326b including the second communication winding 322. The second communication winding 322 includes a conductive path 522a. The conductive path 522a forms the second communication winding 322 and is disposed on the second communication layer 326b. The conductive path 522a is one example of the second communication winding 122 shown in FIG. 1.

[0146] The conductive path 522a has an end 523 and end 525. The conductive path 522a traverses the second communication layer 326b from end 523 to end 525. End 523 of the conductive path 522a corresponds to the electrical node 123 shown in FIG. 1. The end 525 of the conductive path 522a corresponds to the electrical node 125 shown in FIG. 1. End 523 may be the triangle end, non-dot end of the second communication winding 322 while end 525 may be the non-triangle end, dot end of the second communication winding 322. In one example, end 523 may be the positive labeled terminal of receiver voltage V_R while end 525 may be the negative labeled terminal of receiver voltage V_R .

[0147] End 525 is an outer end. End 525 is disposed near the outside edge of the second communication layer 326b. The end 525 is disposed outside of the turns formed by the conductive path 522a of the second communication winding 322. End 523 is an inner end and is inside the turns formed by the conductive path 522a of the second communication winding 322. End 523 is closer to second axis G2 than end 525. Conductive path 522a, end 523, and end 525 may be comprised of a conductive material. The conductive path 522a traverses the second communication layer 326b in a clockwise direction from end 523 to end 525. From end 523, the conductive path 522a traverses in an outward spiral toward end 525 around second axis G2. As such, the second communication winding 322 is wound in a clockwise direction from end 523 to end 525. The conductive path 522a forms a spiral which is substantially rectangular in shape. However, it should be appreciated that the conductive path 522a may spiral in other shapes.

[0148] Each instance in which the conductive path 522a crosses the reference line 511b in FIG. 5B may be considered one turn of the second communication winding 322. End 523 is the beginning of reference line 511b of FIG. 5B. From end 523, the conductive path 522a traverses towards the left-hand side of the page. The conductive path 522a forms a ninety-degree rotation in a clockwise direction to form a first corner. The conductive path 522a then traverses the page upward. The conductive path 522a forms another ninety-degree clockwise rotation to form a second corner. Conductive path 522a then traverses towards the right-hand side of the page. The conductive path 522a forms a third ninety-degree clockwise rotation to form a third corner and then traverses the page downward. The conductive path 522a forms a fourth ninety-degree clockwise rotation to form a fourth corner such that the conductive path 522a then traverses towards the left-hand side of the page. After the fourth corner, the conductive path 522a reaches the reference line 511b. For the example shown, this is one turn of the second communication winding 322. This may also be referred to as one loop of the conductive path 522a. For the conductive path 522a shown, four rotations form one turn of the second communication winding. It should be appreciated that the second communication winding 322 is a planar winding. The conductive path 522a continues forming ninety-degree

rotations as the conductive path 522a spirals outwards to end 525. As the conductive path 522a forms the turns of second communication winding 322, each successive turn formed as the conductive path 522a reaches the reference line 511b is farther from the end 523. The conductive path 522a illustrates three turns in the second communication winding 322.

[0149] The opening 234 is outside the second communication winding 322. The opening 234 is outside the turns formed by the conductive path 522a of the second communication winding 322. The first axis G1 is outside the turns formed by the conductive path 522a of the second communication winding 322. Conductive path 522a is disposed on one side of the opening 234. The conductive path 522a is disposed below the opening 234 in the second lateral direction (y-axis). The conductive path 522a is substantially within the first core window.

[0150] While the second communication winding 322 is shown as disposed on a solitary second communication layer 326b, it should be appreciated that the second communication winding 322 may be disposed on multiple layers. For example, an additional communication layer may include another conductive path which is coupled to the conductive path 522a.

[0151] FIG. 5C illustrates a top-down view of a first communication layer 326c including the first communication winding 320. The first communication winding 320 includes a conductive path 520a. The conductive path 520a forms the first communication winding 320 and is disposed on the first communication layer 326c. The conductive path 520a may be referred to as a first conductive path while conductive path 522a may be referred to as a second conductive path. The conductive path 520a is one example of the first communication winding 120 shown in FIG. 1.

[0152] The conductive path 520a has an end 519 and end 521. The conductive path 520a traverses the first communication layer 326c from end 519 to end 521. End 519 of the conductive path 520a corresponds to the electrical node 119 shown in FIG. 1. The end 521 of the conductive path 520a corresponds to the electrical node 121 shown in FIG. 1. End 519 may be the triangle end of the first communication winding 320 while end 521 may be the non-triangle end of the first communication winding 320. In one example, end 519 may be the positive labeled terminal of transmit voltage V_T while end 521 may be the negative labeled terminal of transmit voltage V_T .

[0153] End 521 is an outer end and is disposed near the outside edge of the first communication layer 326c. The end 521 is an outer end and is disposed outside of the turns formed by the conductive path 520a. End 521 is an outer end disposed outside the turns of the first communication winding 320. End 519 is an inner end and is within the turns formed by the conductive path 520a of the first communication winding 320. Conductive path 520a, end 519,

and end 521 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.

[0154] The conductive path 520a traverses the first communication layer 326c in a clockwise direction from end 519. From end 519, the conductive path 520a traverses in an outward spiral towards end 521 around second axis G2. As such, the first communication winding 320 is wound in a clockwise direction. The conductive path 520a forms a spiral which is substantially rectangular in shape. However, it should be appreciated that the conductive path 520a may spiral in other shapes.

[0155] Each instance in which the conductive path 520a crosses the reference line 511c in FIG. 5C may be considered one turn of the first communication winding 320. End 519 is the beginning of reference line 511c of FIG. 5C. Similar to the discussion above regarding conductive path 522a, conductive path 520a traverses the first communication layer 326c and forms several ninety-degree clockwise rotations to form corners. As shown, four ninety-degree clockwise rotations form one turn of the first communication winding 320. Said differently, four corners form one turn of the first communication winding 320. It should be appreciated that the first communication winding 320 is a planar winding. The conductive path 520a continues with the ninety-degree clockwise rotations as the conductive path 520a spirals outward towards end 521. As the conductive path 520a forms the turns of first communication winding 320, each successive turn formed as the conductive path 520a reaches the reference line 511c is farther from the end 519. The conductive path 520a illustrates three turns in the first communication winding 320.

[0156] The opening 234 is outside the first communication winding 320. The opening 234 is outside the turns formed by the conductive path 520a of the first communication winding 320. The first axis G1 is outside the turns formed by the conductive path 520a of the first communication winding 320. Conductive path 520a is disposed on one side of the opening 234. The conductive path 520a is disposed below the opening 234 in the second lateral direction (y-axis). The conductive path 520a is substantially within the first core window. It should be appreciated that conductive path 522a substantially overlays the conductive path 520a.

[0157] While the first communication winding 320 is shown as disposed on a solitary first communication layer 326c, it should be appreciated that the first communication winding 320 may be disposed on multiple layers. For example, an additional communication layer may include another conductive path which is coupled to the conductive path 520a.

[0158] The widths of the conductive paths 522a, 520a and the spacing between the conductive paths 522a, 520a are determined by the manufacturing process of the multilayer circuit. However, the number of turns for conductive paths 522a, 520a are selected to maximize

the size of the first communication winding 320 and the second communication winding 322 within the first core window 232. The larger the enclosed area of both the first communication winding 320 and the second communication winding 322, the stronger the magnetic coupling between conductive paths 522a, 520a.

[0159] The conductive path 522a of the second communication winding 322 is wound in the same direction as conductive path 520a of the first communication winding 320. For the example shown, the conductive path 522a and the conductive path 520a are wound in a clockwise direction from their inner to outer ends. However, the conductive path 522a and conductive path 520a may be wound in a counter-clockwise direction. It should be appreciated that the conductive path 522a and conductive path 520a may be wound in opposite directions to each other.

[0160] FIG. 5D illustrates a top-down view of the second power layer 326d of FIG. 3 including the second power winding 306. The second power winding 306 includes a conductive path 506a. The conductive path 506a is one example of the second power winding 106 shown in FIG. 1. The conductive path 506a has an end 507 and an end 509. The conductive path 506a traverses the second power layer 326d from end 507 to end 509. End 507 of the conductive path 506a corresponds to the electrical node 107 shown in FIG. 1. The end 509 of the conductive path 506a corresponds to the electrical node 109 shown in FIG. 1. End 507 may be the dot-end while end 509 is the non-dot end of the second power winding 306. End 507 may be the positive labeled terminal of the voltage V_s while end 509 may be the negative labeled terminal of voltage V_s . As shown, end 507 may be coupled to the output capacitor C_o while end 509 may be coupled to the output rectifier S2. Conductive path 506a, end 507, and end 509 may be comprised of a conductive material.

[0161] The conductive path 506a traverses the second power layer 326d from end 507 in a counterclockwise direction around the opening 234 to end 509. The conductive path 506a is laid around the first axis G1 from end 507 to end 509. As such, the second power winding 306 may be wound in a counterclockwise direction.

[0162] For the example shown, the conductive path 506a does not cross the reference line 511d. As such, the conductive path 506a forms one turn of the second power winding 306 in FIG. 5D. It should be appreciated that the second power winding 306 is a planar winding. However, similar to the first power winding 304 shown in FIG. 5A, the second power winding 306 may include more turns than as shown. For a multiple turn embodiment, the conductive path 506a may spiral inwardly or outwardly to form the additional turns of the second power winding 306.

[0163] The opening 234 is inside the second power winding 306. The opening 234 is inside the turn formed by the conductive path 506a in the second power layer 326d of the second power winding 306. In FIG. 5D, the turn of the conductive path 506a is substantially a stadium shape.

[0164] While the second power winding 306 is shown as disposed on a single second power layer 326d, it should be appreciated that the second power winding 306 may be disposed on multiple layers. For example, an additional power layer may include another conductive path which is coupled to the conductive path 506a.

[0165] In one winding configuration, the polarity of the voltage at an inner end with respect to an outer end of one winding is the same polarity as the voltage at an inner end with respect to an outer end for the other winding. In another winding configuration, the polarity of the voltage at the inner end with respect to the outer end of one winding is opposite to the polarity of the voltage at the inner end with respect to the outer end of the other winding.

[0166] As shown, the first power winding 304 is configured with respect to the second power winding 306 such that the voltage from end 503 to end 505 is opposite polarity from the voltage from end 507 to end 509. However, it should be appreciated that the first power winding 304 and the second power winding 306 may be configured such that the voltage from end 503 to end 505 is the same polarity as the voltage from end 507 to end 509. The second communication winding 322 is configured with respect to the first communication winding 320 such that the voltage from end 523 to end 525 is the same polarity as the voltage from end 519 to end 521. However, it should be appreciated that the second communication winding 322 may be configured with respect to the first communication winding 320 such that the voltage from end 523 to end 525 is the opposite polarity from the voltage from end 519 to end 521.

[0167] In one example, the second communication winding 322 is a receiver winding. The second communication winding 322 is configured with respect to the second power winding 306 such that the voltage from end 523 to end 525 is opposite in polarity from the voltage from end 507 to end 509. The second communication winding 322 is configured with respect to the second power winding 306 such that a non-zero decreasing current conducted by the second power winding 306 from end 509 to end 507 may produce a negative voltage from end 523 to end 525.

[0168] FIGS. 6A, 6B, 6C, 6D, 6E, 6F, and 6G are viewed in the plane of the first lateral direction (x-axis) and the second lateral direction (y-axis). The first lateral direction (x-axis) is shown as pointing to the right-hand side of the page while the second lateral direction (y-axis) is shown pointing to the top of the page. The first vertical direction (z-axis) is pointing out of the page. For the example partial loops and conductive paths shown in FIGS. 6A, 6B, 6C, 6D, 6E,

6F, and 6G, the partial loops and/or conductive paths are disposed in a layer which is adjacent to another layer of the multilayer circuit which may conduct current. The arrow which points towards the left-hand side of the page illustrates the direction of current in the adjacent layer.

[0169] FIGS. 6A, 6B, 6C, and 6D are illustrative of partial loops in conductive paths which form windings and the effects of extra enclosed flux. For these figures, the inner most loop of the first communication winding 320 is shown, however it should be appreciated that other windings may have been used to illustrate the teachings of the present disclosure. FIG. 6E illustrates a second communication winding 622 including features or jogs 638. FIG. 6F and 6G illustrate a first communication winding 620 including features or jogs 638.

[0170] In one example, the reference line 639 shown in FIGs 6A, 6B, 6C, 6D, 6E, 6F, and 6G is representative of a line of symmetry between an inner conductor and an outer conductor of the winding in an adjacent layer. In another example, the reference line 639 is representative of a line of symmetry of a magnetic flux in the first vertical direction produced by the current conducted by the winding in the adjacent layer. In another example, a voltage induced in a partial loop on one side of the reference line 639 is substantially cancelled by a voltage induced in a partial loop on the opposite side of the reference line 639.

[0171] The adjacent layer may refer to the first power layer 326a and the current may be conducted by the first power winding 304. The reference line 639 is representative of a line of symmetry between an inner conductor and an outer conductor of the first power winding 304. In one example, the reference line 639 is representative of a line of symmetry of a magnetic flux in the first vertical direction produced by the first power winding 304. In another example, a voltage induced by the first power winding 304 on one side of the reference line 639 is substantially cancelled by a voltage induced by the first power winding 304 in a partial loop on the opposite side of the reference line 639.

[0172] If the direction of current in an adjacent layer is towards the left-hand side of the page, the component of the magnetic flux generated in the first vertical direction (z-axis) is generally into the page above the reference line 639 (as denoted by the “X”) and is generally out of the page below the reference line 639 (as denoted by the filled circles). For the example which the first power layer 325a is the adjacent layer, the component of the magnetic flux generated in the first vertical direction (z-axis) by current in the first power winding 304 is generally into the page above the reference line 639 (as denoted by the “X”) and is generally out of the page below the reference line 639 (as denoted by the filled circles).

[0173] FIG. 6A illustrates an example first partial loop 698 and a second partial loop 699 of the second communication winding 322. The first partial loop 698 and the second partial

loop 699 are portions of the conductive path which forms the second communication winding 322.

[0174] The first partial loop 698 is the portion of the conductive path that is below the reference line 639. The first partial loop 698 begins at terminal 613. The first partial loop 698 traverses downwards and forms a corner with a ninety-degree clockwise rotation. The first partial loop 698 then traverses to the left-hand side of the page. The first partial loop 698 then forms a second corner with a ninety-degree clockwise rotation. The first partial loop 698 then travels up the page and reaches the reference line 639.

[0175] The second partial loop 699 is the portion of the conductive path that is above the reference line 639. Beginning at the intersection of the conductive path and the reference line 639 on the left-hand side of the page, the second partial loop 699 traverses up the page and makes a ninety-degree rotation to form a corner. The second partial loop 699 then traverses to the right-hand side of the page. The second partial loop 699 then forms a second corner with another ninety-degree rotation. The second partial loop 699 then traverses down the page and reaches the terminal 617.

[0176] The terminals 613 and 617 are both disposed on the reference line 639. As such, the first partial loop 698 and the second partial loop 699 forms a turn of the second communication winding 322. However, the conductive paths to form the communication windings are disposed on circuit board layers. To form additional turns in the communication winding, the first partial loop 698 does not begin at the same location as the second partial loop 699 ends. In FIG. 6A, the area enclosed by the second partial loop 699 and the reference line 639 is greater than the area enclosed by the first partial loop 698 and the reference line 639. The diagonal lines illustrate the area E1, which represents the additional area enclosed by the second partial loop 699 and the reference line 639 as compared to the area enclosed by the first partial loop 698 and the reference line 639.

[0177] The area E1 may create issues for a communication winding. In particular, current in a winding in an adjacent layer, such as the current in the first power winding 304 in the first power layer 326a, generates magnetic flux which can interfere with the communication between the first communication winding 320 and the second communication winding 322. The area E1 encloses extra magnetic flux which produces a nonzero voltage between terminals 613 and 617. An increasing flux in the direction into the page above the reference line 639 produces a voltage V between terminals 613 and 617 with the polarity shown, the terminal 613 has a greater potential than the terminal 617. A decreasing flux in the direction into the page would reverse the polarity of the voltage between terminals 613 and 617.

[0178] In other words, current in an adjacent layer may inadvertently produce a voltage in a communication winding and affects the voltage induced in one communication winding by current in the other communication winding. For the example of the second communication winding 322, the voltage V between terminals 613 and 617 affects the receiver voltage V_R . For the first communication winding 320, voltage due to an additional enclosed area would affect the transmit voltage V_T . As such, the intended receiver voltage V_R or transmit voltage V_T may be affected by the magnetic flux produced by current in an adjacent layer.

[0179] However, in accordance with embodiments of the present disclosure, the interference by current in an adjacent layer may be minimized by shaping the conductive path of the communication windings such that the area enclosed by the first partial loop 698 and the reference line is substantially equal to the area enclosed by the second partial loop 699 and the reference line 639. The first partial loop 698 and the second partial loop 699 forms one turn of the communication winding. Further, the area enclosed by subsequent partial loops with respect to the reference line 639 are substantially equal. In other words, the area enclosed by a partial loop below reference line 639 is substantially equal to the area enclosed by the corresponding partial loop above reference line 639.

[0180] FIG. 6B illustrates the example first partial loop 698 and second partial loop 699 with feature 638. The feature 638 may also be referred to as a jog. The feature 638 may also be referred to as a discontinuity in the direction of conductive path. In the example of FIG. 6B, the feature 638 is added to the first partial loop 698.

[0181] The first partial loop 698 is the portion of the conductive path that is below the reference line 639. The first partial loop 698 begins at terminal 613. The feature 638 is formed in the first partial loop 698. As shown, feature 638 is a discontinuity in the direction of the first partial loop which adds an additional area $E2$. As shown, feature 638 inserts four ninety-degree deviations to the first partial loop 698 such that the area enclosed by the first partial loop 698 and the reference line 639 includes the additional area $E2$, shown in diagonal lines. Although a ninety-degree deviation is shown, deviations of other degrees may also be utilized. Further, the deviations could also be otherwise shaped, such as a curved deviation or arched deviation. Further, the length of the first partial loop 698 with the feature 638 is longer than the length of the first partial loop 698 without the feature.

[0182] The attributes of feature 638 may be selected such that the additional area $E2$ compensates for the area $E1$. The area $E2$ encloses magnetic flux which is opposite in direction than the magnetic flux enclosed by area $E1$. The magnetic flux in area $E2$ produces a nonzero voltage which counters the nonzero voltage produced by the magnetic flux enclosed in area $E1$ such that the net voltage due to current in an adjacent layer is substantially zero. As such, the

area enclosed by the first partial loop 698 and the reference line 639 is substantially equal to the area enclosed by the second partial loop 699 and the reference line 639.

[0183] FIG. 6C illustrates another example utilization of features to compensate for the additional area E1. FIG. 6C illustrates the first partial loop 698, second partial loop 699, and jogs 638a and 638b. Jogs 638a and 638b may also be referred to as a feature. The jogs 638a and 638b may also be referred to as a discontinuity in the direction of the conductive path. In the example of FIG. 6C, the jogs 638a and 638b are included in the second partial loop 699. Further, the jogs 638a and 638b are shown as ninety-degree indents in the second partial loop 699.

[0184] Similar to FIG. 6A, the first partial loop 698 is the portion of the conductive path that is below the reference line 639. First partial loop 698 is discussed in detail with respect to FIG. 6A. The second partial loop 699 is the portion of the conductive path which is above the reference line 639. Jogs 638a and jog 638b are several ninety-degree rotations which form a ninety-degree indent in the second partial loop.

[0185] In FIG. 6C, the jogs 638a and 638b reduce the area which encloses magnetic flux. Jog 638a forms a ninety-degree indent in the second partial loop 699 such that the second partial loop 699 encloses an area E3 less as compared to the second partial loop 699 without jog 638a. Jog 638b forms a ninety-degree indent in the second partial loop 699 such that the second partial loop 699 encloses an area E4 less as compared to the second partial loop 699 without jog 638b.

[0186] The sum of area E3 and E4 is chosen to be substantially equal to the area E1 shown in FIG. 6A. Said differently, the second partial loop 699 shown in FIG. 6C is formed such that the area enclosed by the second partial loop 699 and the reference line 639 is an area E1 less than the area enclosed by the second partial loop 699 and the reference line 639 in FIG. 6A. As such, the area enclosed by the first partial loop 698 and the reference line 639 is substantially equal to the area enclosed by the second partial loop 699 and the reference line 639.

[0187] FIG. 6D illustrates another example utilization of features added to second partial loop 699 to ensure the areas enclosed by the partial loops are substantially equal. FIG. 6D illustrates the first partial loop 698, second partial loop 699, and jogs 638c and 638d. Jogs 638c and 638d may also be referred to as a feature. The jogs 638c and 638d may also be referred to as a discontinuity in the direction of the conductive path. In the example of FIG. 6D, the jogs 638c and 638d are included in the second partial loop 699. Further, the jogs 638c and 638d are shown as ninety-degree indents in the second partial loop 699.

[0188] Similar to FIG. 6A, the first partial loop 698 is the portion of the conductive path that is below the reference line 639 and is discussed in detail above. The second partial loop 699 is the portion of the conductive path which is above the reference line 639.

[0189] In FIG. 6D, the jogs 638c and 638d reduce the area which encloses magnetic flux. Jog 638c forms a ninety-degree indent in the second partial loop 699 such that the second partial loop 699 encloses an area E5 less as compared to the second partial loop 699 without jog 638c. Jog 638d forms a ninety-degree indent in the second partial loop 699 such that the second partial loop 699 encloses an area E6 less as compared to the second partial loop 699 without jog 638d.

[0190] The sum of area E5 and E6 is chosen to be substantially equal to the area E1 shown in FIGS. 6A and 6B. Said differently, the second partial loop 699 shown in FIG. 6D is formed such the area enclosed by the second partial loop 699 and the reference line 639 is an area E1 less than the area enclosed by the second partial loop 699 and the reference line 639 in FIG. 6A. As such, the area enclosed by the first partial loop 698 and the reference line 639 is substantially equal to the area enclosed by the second partial loop 699 and the reference line 639. Removing Areas E5 and E6 from partial loop 699 allow for the enclosed flux to be balanced such that the net voltage produced is substantially zero.

[0191] The areas E5 and E6 are shown as rectangles in which the length of the rectangle in the first lateral direction (x-axis) is much longer than the length of the rectangle in the second lateral direction (y-axis). The areas E3 and E4 are also shown as rectangles, however the length of the rectangle in the first lateral direction (x-axis) is almost the same as the is the length of the rectangle in the second lateral direction (y-axis). It should be appreciated that area E3 is substantially the same as area E5. The area E4 is substantially the same as E6. However, the shape of the rectangles formed by these areas are different. The example jogs shown in FIG. 6B, FIG. 6C and 6D illustrate that the partial loops may be formed in different ways such that the area enclosed by the first partial loop 698 and the reference line 639 is substantially equal to the area enclosed by the second partial loop 699 and the reference line 639.

[0192] FIG. 6E illustrates a second communication winding 622 with jogs 638a-638l. The second communication winding 622 includes a conductive path 622a, end 623, and end 625. Jogs 638a-638l are formed in the conductive path 622a. The second communication winding 622 is one example of second communication winding 122 of FIG. 1. Jogs 638a-638s may also be referred to as features. The jogs 638a-638l may also be referred to as discontinuities in the conductive path which forms the second communication winding 622. Further, the jogs 638a-638l are shown as ninety-degree indents in the second communication winding 622. The jogs 638a-638l replace the corners of the second communication winding 322 shown in FIGS. 3, 4A,

and 5B with ninety-degree indents. Although jogs 638a-638l are shown as ninety-degree indents, it should be appreciated that indents of other degrees may also be utilized. Further, jogs 638a-638l may also have other shaped indents, such as an arched or curved indent.

[0193] The conductive path 622a which forms the second communication winding 622 includes end 623 and end 625. The conductive path 622a traverses the second communication layer from end 623 to end 625. End 623 corresponds to the electrical node 123 shown in FIG. 1. The end 625 corresponds to the electrical node 125 shown in FIG. 1. End 623 may be the triangle end, non-dot end of the second communication winding 622 while end 625 may be the non-triangle end, dot end of the second communication winding 622. In one example, end 623 may be the positive labeled terminal of receiver voltage V_R while end 625 may be the negative labeled terminal of receiver voltage V_R .

[0194] End 625 is an outer end and is disposed outside of the turns formed by the conductive path 622a of the second communication winding 622. End 623 is an inner end and is within the turns formed by the conductive path 622a of the second communication winding 622. Conductive path 622a, end 623, and end 625 may be comprised of a conductive material. The conductive path 622a traverses from end 623 to end 625 in a clockwise direction. From end 623, the conductive path 622a traverses in an outward spiral towards end 625. As such, the second communication winding 622 is wound in a clockwise direction.

[0195] In FIG. 4A and 5B, the conductive path 522a of the second communication winding 322 spirals in a rectangular shape. However, the second communication winding 622 replaces the ninety-degree corners of the second communication winding 322 with ninety-degree indentations. These ninety-degree indentations or ninety-degree deviations are labeled as jogs 638a-638l. The jogs 638a-638l may also be referred to as routing indents. However, it should be appreciated that the second communication winding 622 may spiral in other shapes.

[0196] Beginning at end 623, the conductive path 622a traverses down the page. Jog 638a is formed in the conductive path 622a which results in a ninety-degree clockwise rotation. As shown, the ninety-degree indent formed by jog 638a is a result of three ninety-degree rotations. A first ninety-degree clockwise rotation followed by a second ninety-degree counter-clockwise rotation and then followed by a third ninety-degree clockwise rotation. The overall result is a ninety-degree clockwise rotation with an indentation of the conductive path 622a. The conductive path 622a then traverses toward the left-hand side of the page. Jog 638b is formed in the conductive path 622a which results in a ninety-degree clockwise rotation with an indentation. The conductive path 622a then traverses up the page.

[0197] Jog 638c is formed in the conductive path 622a which results in another ninety-degree clockwise rotation with an indentation. The conductive path 622a then traverses towards

the right-hand side of the page. Jog 638d is formed in the conductive path 622a which results in a ninety-degree clockwise rotation with an indentation. The conductive path 622a then traverses down the page.

[0198] Jogs 638e-638l are formed in the conductive path 622a and each of these jogs result in a ninety-degree clockwise rotation with an indentation. The conductive path 622a continues with the ninety-degree rotations with indentations to spiral from end 623 to end 625. It should be appreciated that end-to-end reference line 511b may be drawn from end 623 to end 625 and is further shown in FIG. 8B. Crossings of the end-to-end reference line 511b by the conductive path 622a may be representative of the turns of the second communication winding 622. The conductive path 622a shown in FIG. 6E illustrates three turns in the second communication winding 622.

[0199] It should be appreciated that portions of the conductive path 622a may form partial loops as discussed with respect to FIGS. 6A-6D. The first partial loop may be the portion of the conductive path 622a which includes jogs 638a and 638b and is below reference line 639. The corresponding second partial loop would be the portion of the conductive path 622a which includes jogs 638c and 638d and is above reference line 639. The area enclosed by the first partial loop and reference line 639 is substantially the same as the area enclosed by the second partial loop and reference line 639.

[0200] Similarly, the first partial loop may be the portion of the conductive path 622a which includes jogs 638e and 638f and is below the reference line 639. The corresponding second partial loop would be the portion of the conductive path 622a which includes jogs 638g and 638h and is above reference line 639. The area enclosed by the first partial loop and reference line 639 is substantially the same as the area enclosed by the second partial loop and reference line 639.

[0201] The first partial loop may be the portion of the conductive path 622a which includes jogs 638i and 638j and is below reference line 639. The corresponding second partial loop would be the portion of the conductive path 622a which includes jogs 638k and 638l and is above reference line 639.

[0202] FIG. 6F illustrates an example first communication winding 620 with jogs 638m-638w. The first communication winding 620 includes a conductive path 620a, end 619, and end 621. Jogs 638m-638w are formed in the conductive path 620a. First communication winding 620 is one example of first communication winding 120 of FIG. 1. In one example, the conductive path 620a may be referred to as a first conductive path while conductive path 622a may be referred to as a second conductive path. Jogs 638m-638w may also be referred to as features. The jogs 638m-638w may also be referred to as discontinuities in the conductive path

620a which forms the first communication winding 620. Further, the jogs 638m-638w are shown as ninety-degree indents in the first communication winding 620. The jogs 638m-638w replace the corners of the first communication winding 320 shown in FIGS. 3, 4B, and 5C with ninety-degree indents. Although jogs 638m-638w are shown as ninety-degree indents, it should be appreciated that indents of other degrees may also be utilized. Further, jogs 638m-638w may also have other shaped indents, such as an arched or curved indent.

[0203] The conductive path 620a which forms the first communication winding 620 includes end 619 and end 621. The conductive path 620a traverses the first communication layer from end 619 to end 621. End 619 corresponds to the electrical node 119 shown in FIG. 1. The end 621 corresponds to the electrical node 121 shown in FIG. 1. End 619 may be the triangle end of the first communication winding 620 while end 621 may be the non-triangle end of the first communication winding 620. In one example, end 619 may be the positive labeled terminal of transmit voltage V_T while end 621 may be the negative labeled terminal of transmit voltage V_T .

[0204] End 621 is an outer end and is disposed outside of the turns formed by the conductive path 620a of the first communication winding 620. End 619 is an inner end and is within the turns formed by the conductive path 620a of first communication winding 620. Conductive path 620a, end 619, and end 621 may be comprised of a conductive material. The conductive path 620a traverses from end 619 to end 621 in a clockwise direction. From end 619, the conductive path 620a traverses in an outward spiral towards end 621. As such, the first communication winding 620 is wound in a clockwise direction.

[0205] In FIG. 4B and 5C, the conductive path 520a of the first communication winding 320 spirals in a rectangular shape. However, the first communication winding 620 replaces the ninety-degree corners of the first communication winding 320 with ninety-degree indentations. These ninety-degree indentations or ninety-degree deviations are labeled as jogs 638m-638w. The jogs 638m-638w may also be referred to as routing indents. However, it should be appreciated that the first communication winding 620 may spiral in other shapes.

[0206] An end-to-end reference line 511b may be drawn from end 619 to end 621 and is shown in FIG. 8C. Crossings of the end-to-end reference line 511b by the conductive path 620a may be representative of the turns of the first communication winding 620. The conductive path 620a shown in FIG. 6F illustrates three turns in the first communication winding 620.

[0207] It should be appreciated that portions of the conductive path 620a may form partial loops as discussed with respect to FIGS. 6A-6D. The first partial loop may be the portion of the conductive path 620a which includes jog 638m and is below reference line 639. The corresponding second partial loop would be the portion of the conductive path 620a which

includes jogs 638n and 638o and is above reference line 639. The area enclosed by the first partial loop and reference line 639 is substantially the same as the area enclosed by the second partial loop and reference line 639.

[0208] Similarly, the first partial loop may be the portion of the conductive path 620a which includes jogs 638p and 638q and is below reference line 639. The corresponding second partial loop would be the portion of the conductive path 620a which includes jogs 638r and 638s and is above reference line 639. The area enclosed by the first partial loop and reference line 639 is substantially the same as the area enclosed by the second partial loop and reference line 639.

[0209] The first partial loop may be the portion of the conductive path 620a which includes jogs 638t and 638u and is below reference line 639. The corresponding second partial loop would be the portion of the conductive path 620a which includes jogs 638v and 638w and is above reference line 639.

[0210] FIG. 6G illustrates the conductive path 620a of the first communication winding 620 shown in FIG. 6F with relation to a reference line 639. As mentioned above, the conductive path 620a which forms the first communication winding 620 spirals outwardly in a clockwise direction from the end 619. Portions of the conductive path 620a may form partial loops as discussed with respect to FIGS. 6A-6D. The first partial loop may be the portion of the conductive path 620a which includes jog 638m and is below reference line 639. The area A1 enclosed by the first partial loop is shaded with vertical lines. The corresponding second partial loop would be the portion of the conductive path 620a which includes jogs 638n and 638o and is above reference line 639. The area A2 enclosed by the second partial loop and the reference line 639 is shaded with diagonal lines. The first partial loop and second partial loop are shaped such that area A1 is substantially the same as area A2. As such, any voltage due to the magnetic flux produced by current in an adjacent layer, such as the current conducted in the first power winding 304 in the first power layer 326a, may be minimized.

[0211] For FIGS. 7A and FIG. 7B, the first communication layer 726c and the second communication layer 726b are viewed in the same perspective as FIGS. 4A and 4B. The outline or edge of each layer is shown in a thin solid line, the thick dashed line illustrates the outline 436 of the core 228, and the thin dotted line is representative of the projection 335. The first core window 232 and the second core window 230 are also shown. The corresponding description for these elements is discussed with respect to FIGS. 4A and 4B.

[0212] FIG. 7A is an illustrative top-down view of the second communication layer 726b including the second communication winding 622 of FIG. 6E. The second communication layer 726b is an alternative embodiment of the second communication layer 326b shown in FIG. 3. It

should be appreciated that similarly named and numbered elements couple and function as described above, in particular, with respect to FIGS. 4A and 4B. The first power winding 304 is shown for illustration purposes and it should be appreciated that the first power winding 304 is not disposed on the second communication layer 726b. FIG. 7A illustrates an example placement of the second communication winding 622 with respect to the first power winding 304.

[0213] The second communication winding 622 is disposed in the second communication layer 726b. Further, the second communication winding 622 is substantially within the projection 335. The second communication winding 622 is substantially below the opening 234 in the second lateral direction (y-axis). The solid line which illustrates the second communication winding 622 is also representative of a conductive path 622a of the second communication winding 622. The second communication winding 622 spirals outward in a clockwise direction from an inner end (e.g., end 623). In FIG. 7A, the second communication winding 622 has substantially three turns. The overall shape of the second communication winding 622 is shown as a rectangle with ninety-degree indents at the corners of each turn.

[0214] The second communication winding 622 is substantially within the first core window 232. The number of turns of the second communication winding 622, the shape of the second communication winding 622, or both, may be determined by the size and shape of the first core window 232. The number of turns selected for the second communication winding 622 is in part determined by the number of turns which would fit in the first core window 232 given constraints for trace spacing and width. The number of turns may also be selected to strengthen the magnetic coupling between the first communication winding 620 and the second communication winding 622.

[0215] Further, the second communication winding 622 is positioned with respect to the first power winding 304. The second communication winding 622 is positioned in relation to an innermost conductor and an outermost conductor of the first power winding 304 with respect to the opening 234. The reference line 639 shown in FIG. 7A and 7B is the same reference line 639 with respect to FIGS. 6E, 6F, and 6G. In one example, the second communication winding 622 is positioned such that reference line 639 is substantially halfway between the innermost conductor and an outermost conductor of the first power winding 304 given the conductors are substantially parallel and equidistant. In another example, the second communication winding 622 is positioned such that a voltage induced in the conductive path of the second communication winding 622 on one side of the reference line is substantially balanced by a voltage of opposite polarity in the conductive path of the second communication winding 622 on the other side of the reference line. In a further example, the second communication winding

622 is positioned such that reference line 639 is substantially in a line of symmetry of the magnetic flux in the first vertical direction produced by the first power winding 304 when the first power winding 304 is conducting current. Second communication winding 622 may be positioned to minimize the net magnetic field in the first vertical direction (z-axis) enclosed by the second communication winding 620 when the first power winding 304 is conducting current.

[0216] FIG. 7B is an illustrative top-down view of the first communication layer 726c including the first communication winding 620 of FIG. 6F and 6G. The first communication layer 726c is an alternative embodiment of the first communication layer 326c shown in FIG. 3. It should be appreciated that similarly named and numbered elements couple and function as described above, in particular, with respect to FIGS. 4A and 4B. The first power winding 304 is shown for illustration purposes and it should be appreciated that the first power winding 304 is not disposed on the first communication layer 726c. FIG. 7B illustrates one example placement of the first communication winding 620 with respect to the first power winding 304.

[0217] The first communication winding 620 is disposed in the first communication layer 726c. The first communication winding 620 is substantially within the projection 335. The first communication winding 620 is substantially below the opening 234 in the second lateral direction (y-axis). The solid line which illustrates the first communication winding 620 is also representative of a conductive path 620a of the first communication winding 620. From an inner end (e.g., end 619) of the first communication winding 620, the first communication winding 620 spirals outward. The first communication winding 620 spirals outward from an inner end in a clockwise direction. In FIG. 7B, the first communication winding 620 has substantially three turns. The overall shape of the first communication winding 620 is shown as rectangular with ninety-degree indents at each corner.

[0218] The first communication winding 620 is substantially within the first core window 232. The first core window 232 is rectangular in shape. The first core window 232 may also be other shapes, such as a square. The number of turns of the first communication winding 620, the shape of the first communication winding 620, or both, may be determined by the size and shape of the first core window 232. The number of turns selected for the first communication winding 620 is partly determined by the number of turns which would fit in the first core window 232 given constraints for trace spacing and width. The number of turns may also be selected to strengthen the magnetic coupling between the first communication winding 620 and the second communication winding 622.

[0219] Further, the first communication winding 620 is positioned with respect to the first power winding 304. The first communication winding 620 is positioned in relation to the innermost conductor and the outermost conductor of the first power winding 304 with respect to

the opening 234. In one example, the first communication winding 620 is positioned such that the reference line 639 is substantially halfway between the innermost conductor and an outermost conductor of the first power winding 304 given the conductors are substantially parallel and equidistant. In another example, the first communication winding 620 is positioned such that a voltage induced in the conductive path of the first communication winding 620 on one side of the reference line is substantially balanced by a voltage of opposite polarity in the conductive path of the first communication winding 620 on the other side of the reference line. In a further example, the first communication winding 620 is positioned such that reference line 639 is substantially in a line of symmetry of the magnetic flux in the first vertical direction produced by the first power winding 304 when the first power winding 304 is conducting current. First communication winding 620 may be positioned to minimize the net magnetic field in the first vertical direction (z-axis) enclosed by the first communication winding 620 when the first power winding 304 is conducting current.

[0220] The first communication winding 620 and the second communication winding 622 substantially overlay in the first vertical direction (z-axis). As such, each turn for the second communication winding 622 substantially overlays the respective turn of the first communication winding 620.

[0221] The number of turns for the first communication winding 620 and the second communication winding 622 are selected to maximize the size of the first communication winding 620 and the second communication winding 622 within the first core window 232. The larger the enclosed area of both the first communication winding 620 and the second communication winding 622, the stronger the magnetic coupling between these windings. In one example, the first communication winding 620 and the second communication winding 622 may have a width (first lateral direction, x-axis) of approximately 4.95 mm and a length (second lateral direction, y-axis) of approximately 3.77 mm.

[0222] FIGS. 8A, 8B, 8C, and 8D illustrate the example power layers and communication layers of the multilayer circuit 226. For FIGS. 8A, 8B, 8C, and 8D, the first power layer 326a, the second communication layer 726b, the first communication layer 726c and the second power layer 326d are viewed in the same perspective as FIGS. 5A-5D. The outline or edge of each layer is shown in a thin solid line and the thin dotted line is representative of the projection 335.

[0223] End-to-end reference lines 511a, 511b, 511c and 511c are also shown in FIGS. 8A, 8B, 8C, and 8D. For FIG. 8A, the reference line 511a is shown as traversing from end 503 to end 505. For FIG. 8B, the reference line 511b is shown as traversing from end 623 to end 625 of the second communication winding 622. For FIG. 8C, the reference line 511c is shown as

traversing from end 619 to end 621 of the first communication winding 620. For FIG. 8D, the reference line 511d is shown as traversing from the end 507 to end 509. The first axis G1 and the second axis G2 are shown in FIGS. 8A, 8B, 8C and 8D as filled circles. The first axis G1 and second axis G2 traverse into and out of the page, parallel with the first vertical direction (z-axis). The first power winding 304 and second power winding 306 are laid around first axis G1 while the first communication winding 620 and second communication winding 622 are laid around the second axis G2.

[0224] FIG. 8A illustrates a top-down view of the first power layer 326a including the first power winding 304. The first power winding 304 is formed by the conductive path 504a and has ends 503 and ends 505. FIG. 8A also illustrates the opening 234, winding area 235, and the end-to-end reference line 511a. It should be appreciated that similarly named and numbered elements couple and function as described above. In particular, FIG. 8A is substantially the same as FIG. 5A and the detailed description of the first power layer 326a and the other elements shown in FIG. 8A may be found with respect to the detailed description of FIG. 5A above.

[0225] FIG. 8B illustrates a top-down view of a second communication layer 726b including the second communication winding 622. The second communication layer 726b is an alternative embodiment of the second communication layer 326b shown in FIG. 3. The second communication winding 622 includes the conductive path 622a. The conductive path 622a forms the second communication winding 622 and is disposed on the second communication layer 726b. The conductive path 622a is one example of the second communication winding 122 shown in FIG. 1. It should be appreciated that many details of conductive path 622a of the second communication winding are discussed above with respect to FIG. 6E.

[0226] The conductive path 622a includes end 623 and end 625. The conductive path 622a traverses the second communication layer 626b from end 623 to end 625. End 623 corresponds to the electrical node 123 while end 625 corresponds to the electrical node 125 shown in FIG. 1. In one example, end 623 may be the positive labeled terminal of receiver voltage V_R while end 625 may be the negative labeled terminal of receiver voltage V_R .

[0227] End 623 is an inner end. End 625 is an outer end which is disposed near the outside edge of the second communication layer 326b. From end 623, the conductive path 622a traverses in an outward spiral in the clockwise direction from end 623 towards end 625 around second axis G2. As such, the second communication winding 622 is wound in a clockwise direction. The conductive path 622a forms a spiral which is substantially rectangular in shape with ninety-degree indentations at its corners. However, it should be appreciated that conductive path 622a may form other shapes.

[0228] End 623 is the beginning of reference line 511b of FIG. 8B. Each instance in which the conductive path 622a crosses the reference line 511b in FIG. 8B may be considered one turn of the second communication winding 622. It should be appreciated that the second communication winding 622 is a planar winding. As the conductive path 622a forms the turns of second communication winding 622, each successive turn formed by the conductive path 622a as the conductive path 622a reaches the reference line 511b is farther from the end 623. The conductive path 622a illustrates three turns in the second communication winding 622.

[0229] The opening 234 is outside the second communication winding 622. The opening 234 is outside the turns formed by the conductive path 622a. Conductive path 622a is disposed on one side of the opening 234. Conductive path 622a is disposed below opening 234 in the second lateral direction (y-axis) and substantially within the first core window. The first axis G1 is outside the turns of the second communication winding 622.

[0230] While the second communication winding 622 is shown as disposed on a solitary second communication layer 726b, it should be appreciated that the second communication winding 622 may be disposed on multiple layers. For example, an additional communication layer may include another conductive path which is coupled to the conductive path 622a.

[0231] FIG. 8C illustrates a top-down view of a first communication layer 726c including the first communication winding 620. The first communication layer 726c is an alternative embodiment of the first communication layer 326c of FIG. 3. The first communication winding 620 includes a conductive path 620a. The conductive path 620a forms the first communication winding 620 and is disposed on the first communication layer 726c. The conductive path 620a may be referred to as a first conductive path while conductive path 622a may be referred to as a second conductive path. The conductive path 620a is one example of the first communication winding 120 shown in FIG. 1. It should be appreciated that details of conductive path 620a are also discussed with respect to FIG. 6F.

[0232] The conductive path 620a includes end 619 and end 621. The conductive path 620a traverses the first communication layer 726c from end 619 to end 621. End 619 corresponds to the electrical node 119 while end 621 corresponds to the electrical node 121 shown in FIG. 1. In one example, end 619 may be the positive labeled terminal of transmit voltage V_T while end 621 may be the negative labeled terminal of transmit voltage V_T .

[0233] End 619 is an inner end. End 621 is an outer end and is disposed near the outside edge of the first communication layer 726c. The conductive path 620a traverses in an outward spiral in the clockwise direction from end 619 towards end 621 around the second axis G2. As such, the first communication winding 620 is wound in a clockwise direction. The conductive path 620a forms a spiral which is substantially rectangular in shape with ninety-degree

indentations at its corners. However, it should be appreciated that the conductive path 620a may spiral in other shapes.

[0234] End 619 is the beginning of reference line 511c of FIG. 8C. Each instance in which the conductive path 620a crosses the reference line 511c in FIG. 8C may be considered one turn of the first communication winding 620. It should be appreciated that the first communication winding 620 is a planar winding. As the conductive path 620a forms the turns of first communication winding 620, each successive turn formed as the conductive path 620a reaches the reference line 511c is farther from the end 619. The conductive path 620a illustrates three turns in the first communication winding 620.

[0235] The opening 234 is outside the first communication winding 620. The opening 234 is outside the turns formed by the conductive path 620a of the first communication winding 620. Conductive path 620a is disposed on one side of the opening 234. The conductive path 620a is disposed below the opening 234 in the second lateral direction (y-axis) and substantially within the first core window. The first axis G1 is outside the turns of the first communication winding 620. It should be appreciated that conductive path 622a substantially overlays the conductive path 620a.

[0236] While the first communication winding 620 is shown as disposed on a solitary first communication layer 726c, it should be appreciated that the first communication winding 620 may be disposed on multiple layers. For example, an additional communication layer may include another conductive path which is coupled to the conductive path 620a.

[0237] The widths of the conductive paths 622a, 620a and the spacing between the conductive paths 622a, 620a are determined by the manufacturing process of the multilayer circuit. However, the number of turns for conductive paths 622a, 620a are selected to maximize the size of the first communication winding 620 and the second communication winding 622 within the first core window 232. The larger the enclosed area of both the first communication winding 620 and the second communication winding 622, the stronger the magnetic coupling between conductive paths 622a, 620a.

[0238] The conductive path 622a of the second communication winding 622 is wound in the same direction as conductive path 620a of the first communication winding 620. For the example shown, the conductive path 622a and the conductive path 620a are wound in a clockwise direction. However, it should be appreciated that the conductive path 622a and the conductive path 620a may be wound in the counter-clockwise direction or could be wound in opposite directions from each other.

[0239] FIG. 8D illustrates a top-down view of the second power layer 326d including the second power winding 306. The second power winding 306 is formed by the conductive path

506a and has ends 507 and ends 509. FIG. 8D also illustrates the opening 234, projection 335, and the end-to-end reference line 511d. It should be appreciated that similarly named and numbered elements couple and function as described above. In particular, FIG. 8D is substantially the same as FIG. 5D and the detailed description of the second power layer 326d and the other elements shown in FIG. 8D may be found with respect to the detailed description of FIG. 5D above.

[0240] The second communication winding 622 is configured with respect to the first communication winding 320 such that the voltage from end 623 to end 625 is the same polarity as the voltage from end 619 to end 621. However, it should be appreciated that the second communication winding 622 and the first communication winding 620 may be configured such that the voltage from end 623 to end 625 is the opposite polarity as the voltage from end 619 to end 621. Similar to what has been previously discussed, the second communication winding 622 is a receiver winding. The second communication winding 622 is configured with respect to the second power winding 306 such that the voltage from end 623 to end 625 is the opposite polarity as the voltage from end 507 to end 509. The second communication winding 622 is wound with respect to the second power winding 306 such that a non-zero decreasing current conducted by the second power winding 306 from end 509 to end 507 may produce a negative voltage from end 623 to end 625.

[0241] FIG. 9A illustrates a perspective view of the first power winding 304, the second communication winding 622 of FIG. 6E, and the first communication winding 620 of FIG. 6F. For FIG. 9A, the first vertical direction (z-axis) traverses towards the top of the page, the first lateral direction (x-axis) traverses diagonally towards the bottom right of the page, and the second lateral direction (y-axis) traverses diagonally towards the top right of the page. The dotted line A-A' intersects the first power winding 304, the second communication winding 622, and the first communication winding 620. The arrow indicators for the dotted line A-A' is parallel with the first lateral direction (x-axis) and points diagonally towards the bottom right of the page. The reference line 639 is shown for both the first communication winding 620 and the second communication winding 622. The reference line 639 intersects the first communication winding 620 and the second communication winding 622. The reference line 639 is parallel with the first lateral direction (x-axis).

[0242] FIG. 9B illustrates the cross-section along the dotted line A-A' for the first power winding 304, the second communication winding 622, and the first communication winding 620 shown in FIG. 9A. For FIG. 9B, the first vertical direction (z-axis) traverses towards the top of the page, the first lateral direction (x-axis) traverses out of the page as indicated by the dot, and the second lateral direction (y-axis) traverses towards the right-hand side of the page. The cross-

section shown in FIG. 9B is viewed along the dotted line A-A' with the arrow indicators pointing out of the page as shown by the dots at the end of dotted line A-A'.

[0243] The cross-section of the first power layer 326a shows the conductive path 504a of the first power winding 304 as dark squares disposed on the substrate 940a. The first power winding 304 has eleven turns around the opening 234. As such, in FIG. 9B, there are eleven dark squares representative of the eleven cross-sections of the conductive path 504a.

[0244] An innermost conductor 504b of the first power winding 304 is shown as the portion of the conductive path 504a on the right-hand side of the page. In reference to FIG. 9A, the innermost conductor 504b is the portion of the conductive path 504a closest to the opening 234. An outermost conductor 504c of the first power winding 304 is shown as the portion of the conductive path 504a on the left-hand side of the page. In reference to FIG. 9A, the outermost conductor 504c is the portion of the conductive path 504a which is farthest from the opening 234. In other words, the innermost conductor 504b is the portion of the conductive path 504a which is inside the other turns of the first power winding 304. The outermost conductor 504c is the portion of the conductive path 504a which is outside the other turns of the first power winding 304.

[0245] The substrates 940a, 940b, and 940c are shown as solid white rectangles. The substrates 940a, 940b, and 940c are formed of an insulating material which the conductive paths 504a, 622a, and 622b, respectively, are formed upon. Example materials for the insulation or dielectric include resined glass, polysilicon, ceramic or prepreg materials to be cured at a later time. Conductive paths 504a, 622a, and 622b are formed from a conductive material, such as copper. In one example method of manufacture, the conductive material disposed upon the substrate is etched to form one or more conductive paths. As the layers are coupled together, the gaps or voids between conductive paths in one layer may be filled with substrate material from another layer.

[0246] Each cross-section of the conductive path 504a has a width W1 and a spacing P1 between each cross-section of the conductive path 504a. The minimum values of the width W1 and the spacing P1 may be selected based on the manufacturing processes of the multilayer circuit. Although the spacings P1 between each cross-section of the conductive path 504a are shown as equal, it should be appreciated that the spacing P1 need not be the same between each cross-section of the conductive path 504a.

[0247] The small dashed line 639a is shown in FIG. 9B to provide context with FIG. 9A. The small dashed line 639a indicates the position of the reference line 639 in the cross-section view of FIG. 9B. It should be appreciated that the reference line 639 traverses into and out of

the page for the first power layer 326a, the second communication layer 726b and the first communication layer 726c in FIG. 9B.

[0248] In one example, reference line 639 is representative of a line of symmetry between an inner conductor 504b and an outer conductor 504c of the conductive path 504a which forms the first power winding 304. In another example, a voltage induced in a conductive path of the communication winding on one side of the reference line 639 is substantially balanced by a voltage of opposite polarity in a conductive path of the communication winding on the other side of the reference line 639. For FIG. 9B, the reference line 639 is positioned halfway between the inner conductor 504b and the outer conductor 504c given the conductors of the first power winding 304 are substantially parallel and equidistant. In other words, the reference line 639 shown in FIG. 9B is the centerline of the first power winding 304. First communication winding 620 and second communication winding 622 may be positioned to minimize the net magnetic field in the first vertical direction (z-axis) enclosed by these windings when the first power winding 304 is conducting current.

[0249] The cross-section of the second communication layer 726b shows the conductive path 622a of the second communication winding 622 as dark squares disposed on the substrate 940b. The second communication winding 622 has three turns disposed on one side of the opening 234. As such, the cross-section of the second communication layer 726b illustrates six dark squares representative of the three turns of the second communication winding. The conductive path 622a is wound such that the conductive path 622a is symmetric along the reference line 639. The substrate 940b is an insulating material which the conductive path 622a is formed upon. Example materials for the insulation or dielectric include resined glass, polysilicon, ceramic or prepreg materials to be cured at a later time. In coupling the layers together, the gaps or voids between conductive paths in one layer may be filled with substrate material from another layer. For example, material from substrate 940a may fill the gaps between conductive path 622a when the layers are formed together.

[0250] Each cross-section of conductive path 622a has a width $W2$ and a spacing $P2$ between each cross-section of the conductive path 622a. The minimum values of the width $W2$ and the spacing $P2$ may be selected based on the manufacturing processes of the multilayer circuit. Although the spacings $P2$ between each cross-section of the conductive path 622a are shown as equal, it should be appreciated that the spacing $P2$ need not be the same between each between each cross-section of the conductive path 622a.

[0251] The cross-section of the first communication layer 726c shows the conductive path 620a of the first communication winding 620 as dark squares disposed on the substrate 940c. The first communication winding 620 has three turns disposed on one side of the opening

234. As such, the cross-section of the first communication layer 726c illustrates six dark squares representative of the three turns of the first communication winding 620. The conductive path 620a is wound such that the conductive path 620a is symmetric along the reference line 639. The substrate 940c is an insulating material which the conductive path 620a is formed upon. Example materials for the insulation or dielectric include resined glass, polysilicon, ceramic or prepreg materials to be cured at a later time. In coupling the layers together, the gaps or voids between conductive paths in one layer may be filled with substrate material from another layer. Material from substrate 940b may fill the gaps between conductive path 622b when the layers are formed together.

[0252] Each cross-section of conductive path 622a has a width $W3$ and a spacing $P3$ between each cross-section of the conductive path 622a. The minimum values of the width $W3$ and the spacing $P3$ may be selected based on the manufacturing processes of the multilayer circuit. Although the spacings $P3$ between each cross-section of the conductive path 620a are shown as equal, it should be appreciated that the spacing $P3$ need not be the same between each between each cross-section of the conductive path 620a.

[0253] In FIG. 9B, the conductive paths 622a and 620a substantially overlay each other. As shown, each dark square of conductive path 622a is directly above the corresponding dark square of conductive path 620a in the first vertical direction (z-axis). Further, the widths $W2$ and $W3$ are substantially the same. The spacings $P2$ and $P3$ are also substantially the same. Although it should be appreciated that the widths $W1$, $W2$, $W3$ may be the same or different and the spacings $P1$, $P2$, and $P3$ may be the same or different. The thicknesses of each substrate 940a, 940b, and 940c may also be substantially the same or different. Further, the thicknesses may be selected to meet safety requirements.

[0254] FIG. 10 illustrates a power converter 1000 with magnetic assembly 1024 including an energy transfer element T1 and a communication link COM2. The communication link COM2 includes a first enhancement winding 1044 and a second enhancement winding 1041, in accordance with an embodiment of the present disclosure. The illustrated power converter 1000 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 1000 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 COM2 is shown between the first controller 110 and the second controller 118.

[0255] It should be appreciated that similarly named and numbered elements couple and function as described above. In particular, FIG. 10 shares many similarities with FIG. 1 and the

detailed description for similarly named and numbered elements in FIG. 10 may be found with reference to FIG. 1. At least one difference, however, is the magnetic assembly 1024 includes a communication link COM2 including the first enhancement winding 1044 and the second enhancement winding 1041.

[0256] It is also noted that the dots, triangles, and squares shown on windings 104, 106, 120, 122, 1041, and 1044 in FIG. 10 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 which may be 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. The square denotes the polarity of voltage induced due to the magnetic coupling between the first enhancement winding 1044 and the second enhancement winding 1041. In other words, the dots and triangles help to illustrate the relationship of the windings with respect to the external circuit.

[0257] The magnetic assembly 1024 includes the energy transfer element T1 and the communication link COM2. The energy transfer element T1 includes the first power winding 104 and the second power winding 106. The first power winding 104 is an input winding of the energy transfer element T1 while the second power winding 106 is 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. Node 103 is shown as the non-dot end of the first power winding 104 while the node 105 is shown as the dot-end of the first power winding 104. Each end of the second power winding 106 is denoted by node 107 and node 109. Node 107 is shown as the dot-end of the second power winding 106 and the node 109 is the non-dot end of the second power winding 106. In the example shown, the first power winding 104 is coupled with respect to the second power winding 106 such that the voltage from node 103 to node 105 is the opposite polarity from the voltage from node 107 to node 109. However, it should be appreciated that the first power winding 104 may be configured with respect to the second power winding 106 such that the voltage from node 103 to node 105 is the same polarity as the voltage from node 107 to node 109 for another embodiment of the power converter, such as a forward converter. The solid 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 magnetic material. However, it should be appreciated that these windings may be air-cored.

[0258] The communication link COM2 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. The communication link COM2 may also be referred to as the first communication link.

[0259] 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.

[0260] 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. The first communication winding 120 is coupled with respect to the second communication winding 122 such that the voltage from node 119 to node 121 is the same polarity as the voltage from node 123 to node 125. Further, the second communication winding 122 is coupled with respect to the second power winding 106 such that the voltage from node 123 to node 125 is the opposite polarity from the voltage from node 107 to node 109. In the example shown, there are no lines between the first communication winding 120 and the second communication winding 106 indicating that the coupling between these windings is substantially an air-coupling.

[0261] The first enhancement winding 1044 is coupled to the second communication winding 122. The first enhancement winding 1044 has two ends, node 1045 and node 1046. Node 1046 is coupled to node 125 of the second communication winding 122. Node 1046 is the square end, dot end of the first enhancement winding 1044. Node 1045 is coupled to the first controller 110. Node 1045 is the non-square, non-dot end of the first enhancement winding 1044. Further, the voltage across the first enhancement winding 1044 from node 1046 to node 1045 is the opposite polarity to the voltage across the second communication winding 122 from node 123 to node 125 with respect to magnetic flux due to the second power winding 106. As shown, the first enhancement winding 1044 and the second communication winding 122 create a “figure eight” path in the illustrated example with respect to magnetic flux due to the second power winding 106. Stated in another way, the first enhancement winding 1044 wound starting at node 1046 and the second communication winding 122 wound starting at node 123 are in opposite directions with respect to each other. For instance, the first enhancement winding 1044

may be wound in a counter-clockwise starting at node 1046 and the second communication winding 122 would then be wound in a clockwise direction starting at node 123.

[0262] The second enhancement winding 1041 is coupled to the first communication winding 120. The second enhancement winding 1041 has two ends, node 1042 and node 1043. Node 1043 is coupled to node 121 of the first communication winding 120. Node 1043 is the square end of the second enhancement winding 1041. Node 1042 is coupled to the second controller 118. Node 1042 is the non-square end of the second enhancement winding 1041. The second enhancement winding 1041 is magnetically coupled to the first enhancement winding 1044. As shown, the second enhancement winding 1041 and the first communication winding 120 create a “figure eight” path in the illustrated example with respect to magnetic flux due to the second power winding 106. Stated in another way, the second enhancement winding 1041 wound starting at node 1043 and first communication winding 120 wound starting at node 119 are in opposite directions with respect to each other. For instance, the second enhancement winding 1041 may be wound in a counter-clockwise direction starting at node 1043 and the first communication winding 120 would then be wound in a clockwise direction starting at node 119. In the example shown, there are no lines between the first enhancement winding 1044 and the second enhancement winding 1042 indicating that the coupling between these windings is an air-coupling.

[0263] The first communication winding 120 and the second enhancement winding 1041 conduct a transmitter current I_T and there is a transmitter voltage V_T across the first communication winding 120 and second enhancement winding 1041. The transmitter voltage V_T is shown as positive when measured from node 119 to node 1042. The transmitter current I_T is shown as positive when flowing from node 119 to node 1042. The second communication winding 122 and the first enhancement winding 1044 conduct a receiver current I_R and there is a receiver voltage V_R . The receiver voltage V_R is shown as positive when measured from node 123 to node 1045. The receiver current I_R is shown as positive when flowing from node 1045 to node 123.

[0264] 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, and the magnetic coupling between the second enhancement winding 1041, and first enhancement winding 1044. 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. 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 and the first enhancement winding 1041 are conductors. 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.

[0265] The dotted line 111 denotes that a magnetic coupling exists between the energy transfer element T1 and the communication link COM2. Due to the proximity of the energy transfer element T1 and the communication link COM2, changing magnetic flux in the energy transfer element T1 may inadvertently induce a voltage in either the first communication winding 120 and the second communication winding 122. For example, the second power winding 106 may conduct a current I_S and produce a changing magnetic field which may inadvertently induce a voltage across the second communication winding 122 that is positive at node 125 with respect to node 123. This may occur for a particular orientation of the windings of energy transfer element T1 and communication link COM2. In particular, the second communication winding 122 is wound with respect to the second power winding 106 such that a non-zero decreasing current I_S conducted by the second power winding 106 produces a negative voltage from node 123 to node 125. If the current I_S conducts from node 109 to node 107 and current I_S is decreasing so that the magnetic field is decreasing, the induced voltage drop across node 123 to node 125 is substantially negative. It should be appreciated that the magnitudes and polarities of voltages unintentionally induced in the windings of communication link COM2 in response to current in a winding of energy transfer element T1 depend on the relative orientations of the windings and the direction of the current.

[0266] The first enhancement winding 1044 and the second enhancement winding 1041 enhance the communications between the second controller 118 and first controller 110 by supplementing the first communication winding 120 and the second communication winding 122. The first enhancement winding 1044 may function as a cancellation winding and may cancel the effects of noise, for example, noise due to external magnetic fields. The second enhancement winding 1041 may function as a strengthening winding and enhance the communications between the second controller 118 and first controller 110 by utilizing the magnetic coupling between the second enhancement winding 1041 and the first enhancement winding 1044 and electrically coupling them to the first communication winding 120 and second communication winding 122, respectively, such that the transmitted voltage V_T and received voltage V_R are substantially increased or the required transmission current I_T is substantially decreased. In the example shown in FIG. 10, the communication link COM2 includes both the first enhancement winding 1044 and the second enhancement winding 1041. However, it should be appreciated that the communication link COM2 may include either the first enhancement winding 1044 or the second enhancement winding 1041.

[0267] Noise, such as for example external magnetic fields, may induce a voltage drop in the second communication winding 122 and the first enhancement winding 1044. The noise induced receiver voltage V_R is the difference between the voltage across the second communication winding 122 from node 123 to node 125 and the first enhancement winding 1044 from node 1045 to node 1046. If the second communication winding 122 and first enhancement winding 1044 are substantially similar in size and number of turns, the receiver voltage V_R due to noise is substantially zero and there may substantially be no receiver current I_R due to noise. In other words, in the illustrated example, as the second communication winding 122 and first enhancement winding 1044 are substantially similar in size and number of turns, the noise signal component induced in the second communication winding 122 in response to the external noise is substantially equal and opposite to the noise signal component induced in the first enhancement winding 1044 in response to the external noise. As such, the noise signal components induced in each respective second communication winding 122 and first enhancement winding substantially cancel out each other. The second enhancement winding 1041 may also similarly function as a cancellation winding for the first communication winding 120.

[0268] The second enhancement winding 1041 may be utilized to improve the communication between second controller 118 and first controller 100 by supplementing the communication between the first communication winding 120 and the second communication winding 122. Magnetic coupling between the first communication winding 120 and the second

communication winding 122 is due in part to the substantial overlap of the area enclosed by both windings. When a first enhancement winding 1044 is coupled to the second communication winding 122, and no second enhancement winding 1041 is utilized nor coupled to the first communication winding 120, the first enhancement winding 1044 may acts as a short circuit which electrically couples node 125 of the second communication winding 122 to the first controller 110 when the first communication winding 120 conducts the transmission current I_T and magnetic flux is generated to induce a voltage V_R on the second communication winding 122. When the second enhancement winding 1041 is not utilized nor coupled to the first communication winding 120, the magnetic flux generated by transmission current I_T is not coupled into the first enhancement winding 1044 and does not produce a voltage across the first enhancement winding 1044. The second enhancement winding 1041, when utilized and coupled to the first communication winding 120, magnetically couples to the first enhancement winding 1044 which adds to the overall area for transmission and effectively increases the inductance seen across node 119 and node 1042. With higher inductance, transmission voltage V_T may increase for the same transmission current I_T , which may increase the received voltage V_R . The inclusion of the second enhancement winding 1041 which is similar in size and shape to the first enhancement winding 1044 may improve the communication between the second controller 118 and first controller 110.

[0269] In an alternative embodiment, the second enhancement winding 1041 may be coupled parallel to the first communication winding 120. Node 1043 of the second enhancement winding may be coupled to node 119 of the first communication winding 120. Node 1042 may be coupled to node 121. The transmit voltage V_T may be positive at nodes 119 and 1043 with respect to nodes 121 and 1042.

[0270] Energy transfer element T1 and communication link COM2 are included in the same magnetic assembly 1024. The magnetic assembly includes a multilayer circuit. Both the energy transfer element T1 and the communication link COM2 may be implemented into the multilayer circuit. The multilayer circuit includes an opening 234 to receive the core of the energy transfer element T1. The first power winding 104 may be disposed on one or more layers of the multilayer circuit. The second power winding 106 may be disposed on one or more layers of the multilayer circuit. The first communication winding 120 and the second enhancement winding 1041 may be disposed on one or more layers of the multilayer circuit. The second communication winding 122 and the first enhancement winding 1044 may be disposed on one or more layers of the multilayer circuit. The first communication winding 120 and the second communication winding 122 may be disposed on different layers and substantially overlay each other.

[0271] The communication link COM2 may be disposed proximate to the energy transfer element T1. For example, the communication link COM2 may be disposed in layers of the multilayer circuit above the energy transfer element T1. In another example, the communication link COM2 may be disposed in layers of the multilayer circuit below the energy transfer element T1.

[0272] The communication link COM2 may also be disposed between layers of the energy transfer element T1. For example, the communication link COM2 may be disposed between the one or more layers of the first power winding 104 and the one or more layers of the second power winding 106. If the first power winding 104 is disposed on two or more layers, the communication link COM2 may be disposed between the layers of the first power winding 104. Similarly, if the second power winding 106 is disposed on two or more layers, the communication link COM2 may be disposed between the layers of the second power winding 106.

[0273] For FIGS. 11A and FIG. 11B, the first communication layer 1126c and the second communication layer 1126b are viewed in the same perspective as FIGS. 4A-4B, and 7A-7B. The outline or edge of each layer is shown in a thin solid line, the thick dashed line illustrates the outline 436 of the core 228, and the thin dotted line is representative of the projection 335. The first core window 232 and the second core window 230 are also shown with respect to the second communication layer 1126b and first communication layer 1126c. The corresponding description for these elements is discussed with respect to FIGS. 4A and 4B.

[0274] FIG. 11A is an illustrative top-down view of the second communication layer 1126b including the second communication winding 1122 and first enhancement winding 1144. The second communication winding 1122 and the first enhancement winding 1144 are examples of second communication winding 122 and first enhancement winding 1044 shown in FIG. 10. The second communication layer 1126b is an alternative embodiment of second communication layer 326b shown in FIG. 3. It should be appreciated that similarly named and numbered elements couple and function as described above, in particular, with respect to FIGS. 4A, 4B, 7A and 7B. The first power winding 304 is shown for illustration purposes and it should be appreciated that the first power winding 304 is not disposed on the second communication layer 1126b. FIG. 11A illustrates one example placement of the second communication winding 1122 and the first enhancement winding 1144 with respect to the first power winding 304.

[0275] Second Communication Winding 1122:

[0276] The second communication winding 1122 is disposed in the second communication layer 1126b. Further, the second communication winding 1122 is substantially within the projection 335. The second communication winding 1122 is substantially below the

opening 234 in the second lateral direction (y-axis). The solid line which illustrates the second communication winding 1122 is also representative of a conductive path of the second communication winding 1122. From an inner end of the second communication winding 1122, the second communication winding 1122 spirals outward. The second communication winding 1122 spirals outward from an inner end in a clockwise direction. In FIG. 11A, the second communication winding 1122 has substantially three turns. The second communication winding 1122 shown in FIG. 11A has a similar shape to the second communication winding 622 shown with respect to FIGS. 6E, 7A and 8B. The overall shape of the second communication winding 1122 is shown as a rectangle with ninety-degree indents at the corners of each turn.

[0277] The second communication winding 1122 is substantially within the first core window 232. The first core window 232 is rectangular in shape. The number of turns of the second communication winding 1122, the shape of the second communication winding 1122, or both, may be determined by the size and shape of the first core window 232. The number of turns selected for the second communication winding 1122 is partially determined by the number of turns which would fit in the first core window 1132 given constraints for trace spacing and width.

[0278] Further, the second communication winding 1122 is positioned with respect to the first power winding 304. The second communication winding 1122 is positioned in relation to an innermost conductor and an outermost conductor of the first power winding 304 with respect to the opening 234. A reference line for the second communication winding 1122 may refer to a line which intersects the second communication winding 1122. In one example, the reference line may intersect the second communication winding 1122 parallel to the first lateral direction (x-axis). Reference line 639 discussed above is one example of the reference line discussed here. The second communication winding 1122 is positioned such that the reference line is substantially halfway between the innermost conductor and an outermost conductor of the first power winding 304 in the first core window 232 given the conductors are substantially parallel and equidistant. In another example, the second communication winding 1122 is positioned such that a voltage induced in a conductive path of the second communication winding 1122 on one side of the reference line is substantially balanced by a voltage of opposite polarity in a conductive path of the second communication winding 1122 on the other side of the reference line. In a further example, the second communication winding 1122 is positioned such that the reference line 639 is substantially in a line of symmetry of the magnetic flux in the first vertical direction produced by the first power winding 304 when the first power winding 304 is conducting current in the first core window 232. Second communication winding 1122 may be positioned to minimize the net magnetic field in the first vertical direction (z-axis) enclosed by

the second communication winding 1122 when the first power winding 304 is conducting current.

[0279] First Enhancement Winding 1144:

[0280] The first enhancement winding 1144 is disposed on the second communication layer 1126b. The first enhancement winding 1144 is substantially within the projection 335 and above the opening 234. The solid line which illustrates first enhancement winding 1144 is also representative of a conductive path of the first enhancement winding 1144. The first enhancement winding 1144 spirals inward to an inner end. The first enhancement winding 1144 spirals inward toward an inner end in a counter-clockwise direction. In FIG. 11A, the first enhancement winding 1144 has substantially three turns. The first enhancement winding 1144 shown in FIG. 11A has a similar shape to the second communication winding 622 shown with respect to FIGS. 6E, 7A and 8B. The overall shape of the first enhancement winding 1144 is shown as a rectangle with ninety-degree indents at the corners of each turn. However, it should be appreciated that the first enhancement winding 1144 may form other shapes.

[0281] The first enhancement winding 1144 is substantially within the second core window 230. The second core window 230 is rectangular in shape. However, the second core window 230 may have other shapes, such as a square. The number of turns of the first enhancement winding 1144, the shape of the first enhancement winding 1144, or both, may be determined by the size and shape of the second core window 230. The number of turns selected for the first enhancement winding 1144 is partially determined by the number of turns which would fit in the second core window 230 given constraints for trace spacing and width. Further, the number of turns of the first enhancement winding 1144, the shape of the first enhancement winding 1144, or both, may be selected based on the second communication winding 1122. For example, the number of turns of the first enhancement winding 1144, the shape of the first enhancement winding 1144, or both, may be selected to be substantially equal or match the second communication winding 1122. In one example, the first enhancement winding 1142 may be substantially a duplicate of the second communication winding 622. When the first power winding 306 is conducting current, the direction of current of the first power winding 306 in the first core window is opposite to the direction of current of the first power winding 306 in the second core window. For example, if current is conducting from end 503 to end 505, the direction of current of the first power winding 306 is toward the left-hand side of the page in the first core window 232. The direction of current in the second core window 230 is toward the right-hand side of the page.

[0282] Further, the first enhancement winding 1144 is positioned with respect to the first power winding 304. The first enhancement winding 1144 is positioned in relation to an

innermost conductor and an outermost conductor of the first power winding 304 with respect to the opening 234. A reference line for the first enhancement winding 1144 may refer to a line which intersects the first enhancement winding 1144. In one example, the reference line may intersect the first enhancement winding 1144 in parallel with the first lateral direction (x-axis). Reference line 639 discussed above may be one example of the reference line discussed here. The first enhancement winding 1144 is positioned such that the reference line is substantially halfway between the innermost conductor and an outermost conductor of the first power winding 304 in the second core window 230 given the conductors are substantially parallel and equidistant. In another example, the first enhancement winding 1144 is positioned such that a voltage induced in a conductive path of the first enhancement winding 1144 on one side of the reference line is substantially balanced by a voltage of opposite polarity in a conductive path of the first enhancement winding 1144 on the other side of the reference line. In a further example, the first enhancement winding 1144 is positioned such that the reference line 639 is substantially in a line of symmetry of the magnetic flux in the first vertical direction produced by the first power winding 304 when the first power winding 304 is conducting current in the second core window 230. First enhancement winding 1144 may be positioned to minimize the net magnetic field in the first vertical direction (z-axis) enclosed by the first enhancement winding 1144 when the first power winding 304 is conducting current.

[0283] The second communication winding 1122 is coupled to the first enhancement winding 1144. A conductive path is shown which traverses between the first core window 232 and the second core window 230 to couple the second communication winding 1122 to the first enhancement winding 1144. The conductive path for the second communication winding 1122 begins at its inner end and spirals outward in a clockwise direction. The conductive path of the second communication winding 1122 couples to the conductive path of the first enhancement winding 1144. From this coupling between the first core window 232 and the second core window 230, the first enhancement winding 1144 spirals inward in a counter-clockwise direction towards its inner end. As such, a “figure eight” path is created.

[0284] FIG. 11B is an illustrative top-down view of the first communication layer 1126c including the first communication winding 1120 and the second enhancement winding 1141. The first communication winding 1120 and the second enhancement winding 1141 are examples of the first communication winding 120 and the second enhancement winding 1041 shown in FIG. 10. The first communication layer 1126c is an alternative embodiment of the first communication layer 326c shown in FIG. 3. It should be appreciated that similarly named and numbered elements couple and function as described above, in particular, with respect to FIGS. 4A, 4B, 7A and 7B. The first power winding 304 is shown for illustration purposes and it

should be appreciated that the first power winding 304 is not disposed on the first communication layer 1126c. FIG. 11B illustrates one example placement of the first communication winding 1120 and the second enhancement winding 1141 with respect to the first power winding 304. It should be appreciated that the shape and placement of the first communication winding 1120 and the second enhancement winding 1141 is similar to the shape and placement of the second communication winding 1122 and the first enhancement winding 1144.

[0285] First Communication Winding 1120:

[0286] The first communication winding 1120 is disposed in the first communication layer 1126c. The first communication winding 1120 is substantially within the projection 335. The first communication winding 1120 is substantially below the opening 234 in the second lateral direction (y-axis). The solid line which illustrates the first communication winding 1120 is also representative of a conductive path of the first communication winding 1120. From an inner end of the first communication winding 1120, the first communication winding 1120 spirals outward. The first communication winding 1120 spirals outward from an inner end in a clockwise direction. In FIG. 11B, the first communication winding 1120 has substantially three turns. The shape of the first communication winding 1120 is similar to the shape of the first communication winding 620 shown in FIG. 68, 6G, 7B, and 8C. The overall shape of the first communication winding 1120 is shown as rectangular with ninety-degree indents at each corner.

[0287] The first communication winding 1120 is substantially within the first core window 232. The first core window 232 is rectangular in shape. The first core window 232 may also be other shapes, such as a square. The number of turns of the first communication winding 1120, the shape of the first communication winding 1120, or both, may be determined by the size and shape of the first core window 232. The first communication winding 1120 is designed with the number of turns which would fit in the first core window 232 given constraints for trace spacing and width to strengthen the magnetic coupling between the first communication winding 1120 and the second communication winding 1122.

[0288] Further, the first communication winding 1120 is positioned with respect to the first power winding 304. The first communication winding 1120 is positioned in relation to the innermost conductor and the outermost conductor of the first power winding 304 with respect to the opening 234. A reference line for the first communication winding 1120 may refer to a line which intersects the first communication winding 1120. In one example, the reference line may intersect the first communication winding 1120 parallel with first lateral direction (x-axis). Reference line 639 is one example of the reference line discussed here. In other words, the reference line is parallel to the first lateral direction. Further, the reference line for the first

communication winding 1120 may be the same reference line for the second communication winding 1122. The first communication winding 1120 is positioned such that the reference line is substantially halfway between the innermost conductor and an outermost conductor of the first power winding 304 in the first core window 232 given the conductors are substantially parallel and equidistant. In another example, the first communication winding 1120 is positioned such that a voltage induced in a conductive path of the first communication winding 1120 on one side of the reference line is substantially balanced by a voltage of opposite polarity in a conductive path of the first communication winding 1120 on the other side of the reference line. In a further example, the first communication winding 1120 is positioned such that the reference line 639 is substantially in a line of symmetry of the magnetic flux produced by the first power winding 304 when the first power winding 304 is conducting current in the first core window 232. First communication winding 1120 may be positioned to minimize the net magnetic field in the first vertical direction (z-axis) enclosed by the first communication winding 1120 when the first power winding 304 is conducting current.

[0289] The first communication winding 1120 and the second communication winding 1122 substantially overlay in the first vertical direction (z-axis). As such, each turn for the second communication winding 1122 substantially overlays the respective turn of the first communication winding 1120. Magnetic coupling between the first communication winding 1120 and the second communication winding 1122 may be strengthened by overlaying the conductive paths which form the first communication winding 1120 and the second communication winding 1122.

[0290] The number of turns for the first communication winding 1120 and the second communication winding 1122 are selected to maximize the size of the first communication winding 1120 and the second communication winding 1122 within the first core window 232. The larger the enclosed area of both the first communication winding 1120 and the second communication winding 1122, the stronger the magnetic coupling between these windings.

[0291] Second Enhancement Winding 1141:

[0292] The second enhancement winding 1141 is disposed in the first communication layer 1126c. The second enhancement winding 1141 is substantially within the projection 335 and above the opening 234 in the second lateral direction (y-axis). The solid line which illustrates the second enhancement winding 1141 is also representative of a conductive path of the second enhancement winding 1141. The second enhancement winding 1141 spirals inward to an inner end in a counter-clockwise direction. In FIG. 11B, the second enhancement winding 1141 has substantially three turns. The second enhancement winding 1141 shown in FIG. 11B has a similar shape to the first communication winding 620 shown with respect to FIGS. 6F, 6G,

7B and 8C. The overall shape of second enhancement winding 1141 is shown as a rectangle with ninety-degree indents at the corner of each turn. However, it should be appreciated that the second enhancement winding 1141 may take other shapes.

[0293] The second enhancement winding 1141 is substantially within the second core window 230. The second core window 230 is rectangular in shape. However, the second core window 230 may have other shapes, such as a square. The number of turns of the second enhancement winding 1141, the shape of the second enhancement winding 1141, or both, may be determined by the size and shape of the second core window 230. The second enhancement winding 1141 is designed with the number of turns which would fit in the second core window 230 given constraints for trace spacing and width. Further, the number of turns of the second enhancement winding 1141, the shape of second enhancement winding 1141, or both, may be selected based on the first communication winding. For example, the number of turns of the second enhancement winding 1141, the shape of the second enhancement winding 1141, or both may be selected to be substantially equal to or match the first communication winding 1120. In one example, the second enhancement winding 1141 may be substantially a duplicate of the first communication winding 1120.

[0294] Further, the second enhancement winding 1141 is positioned with respect to the first power winding 304. The second enhancement winding 1141 is positioned in relation to an innermost conductor and an outermost conductor of the first power winding 304 with respect to the opening 234. A reference line may refer to a line which intersects the second enhancement winding 1141. In one example, the reference line may intersect the second enhancement winding 1141 parallel with the first lateral direction (x-axis). Reference line 639 is one example of the reference line discussed here. The second enhancement winding 1141 is positioned such that the reference line 639 is substantially halfway between the innermost conductor and an outermost conductor of the first power winding 304 in the second core window 230 given the conductors are substantially parallel and equidistant. In another example, the second enhancement winding 1141 is positioned such that a voltage induced in a conductive path of the second enhancement winding 1141 on one side of the reference line is substantially balanced by a voltage of opposite polarity in a conductive path of the second enhancement winding 1141 on the other side of the reference line. In a further example, second enhancement winding 1141 is positioned such that the reference line is substantially in a line of symmetry of the magnetic flux in the first vertical direction produced by the first power winding 304 when the first power winding 304 is conducting current in the second core window 230. Second enhancement winding 1141 may be positioned to minimize the net magnetic field in the first vertical direction

(z-axis) enclosed by the second enhancement winding 1141 when the first power winding 304 is conducting current.

[0295] The first communication winding 1120 is coupled to the second enhancement winding 1141. A conductive path is shown which traverses between the first core window 232 and the second core window 230 to couple the first communication winding 1120 to the second enhancement winding 1141. The conductive path for the first communication winding 1120 begins at its inner end and spirals outward in a clockwise direction. The conductive path of the first communication winding 1120 couples to the conductive path of the second enhancement winding 1141. From this coupling between the first core window 232 and the second core window 230, the second enhancement winding 1141 spirals inward in a counter-clockwise direction towards its inner end. As such, a “figure eight” path is created.

[0296] The first enhancement winding 1144 substantially overlays the second enhancement winding 1141 in the first vertical direction (z-axis). As such, each turn for the first enhancement winding 1144 substantially overlays the respective turn of the second enhancement winding 1141. Magnetic coupling between the first enhancement winding 1144 and the second enhancement winding 1141 may be strengthened by overlaying the conductive paths which form the first enhancement winding 1144 and the second enhancement winding 1141. Further, the second communication winding 1122 and the first enhancement winding 1144 substantially overlay the first communication winding 1120 and the second enhancement winding 1141.

[0297] FIGS. 12A, 12B, 12C, and 12D illustrate the example power layers and communication layers of the multilayer circuit 226. For 12A, 12B, 12C, and 12D, the first power layer 326a, the second communication layer 1126b, the first communication layer 1126c and the second power layer 326d are viewed in the same perspective as FIGS. 5A-5D, and 8A-8D. The thin solid line represents the outline of each layer, the dashed line represents the winding area 235 of the first power winding 304, and the thin dotted line illustrates the projection 335.

[0298] End-to-end reference lines 511a, 511b, 511c, 511d, 511e, and 511f are shown FIGS. 12A, 12B, 12C, and 12D. For FIG. 12A, the reference line 511a is shown as traversing from end 503 to end 505. For FIG. 12B, the reference line 511b for the second communication winding 1122 is shown as traversing from end 1223 to end 1225. The reference line 511e for the first enhancement winding 1144 is shown as traversing from end 1246 to end 1245a. For FIG. 12C, the reference line 511c for the first communication winding 1120 is shown as traversing from end 1219 to end 1221. The reference line 511f for the second enhancement winding 1141 is shown as traversing from end 1243 to end 1242a. For FIG. 12D, the reference line 511d is shown as traversing from the end 507 to end 509. The first axis G1, the second axis

G2, and a third axis G3 are shown in FIGS. 12A, 12B, 12C and 12D as filled circles. The first axis G1, second axis G2, and third axis G3 traverse into and out of the page, parallel with the first vertical direction (z-axis). The first axis G1, the second axis G2, and third axis G3 are different axes. The first power winding 304 and second power winding 306 are laid around first axis G1. The first communication winding 1120 and second communication winding 1122 are laid around the second axis G2. The first enhancement winding 1144 and the second enhancement winding 1141 are laid around the third axis G3.

[0299] For the purposes of this disclosure, the direction in which a winding is wound is determined by the direction in which a winding traverses its respective layer from the positive labeled terminal of the winding to the negative labeled terminal of the winding as shown in FIG. 10 and as viewed from the perspective of the page. However, it should be appreciated that different conventions may be utilized. For example, the direction in which the winding is wound may also be determined by the direction in which the winding traverses its respective layer from the negative labeled terminal to the positive labeled terminal. In another example, the direction in which a winding is wound may be from an inner end to an outer end of the winding, or vice versa.

[0300] FIG. 12A illustrates a top-down view of the first power layer 326a including the first power winding 304. The first power winding 304 is formed by the conductive path 504a and has ends 503 and ends 505. FIG. 12A also illustrates the opening 234, winding area 235, and the end-to-end reference line 511a. It should be appreciated that similarly named and numbered elements couple and function as described above. In particular, FIG. 12A is substantially the same as FIG. 5A and the detailed description of the first power layer 326a and the other elements shown in FIG. 12A may be found with respect to the detailed description of FIG. 5A above.

[0301] FIG. 12B illustrates a top-down view of a second communication layer 1126b including the second communication winding 1122 and the first enhancement winding 1144. The second communication layer 1126b is an alternative embodiment of the second communication layer 326b shown in FIG. 3. It should be appreciated that similarly named and numbered elements couple and function as described above, in particular, with respect to FIGS. 5A, 5B, 8B and 8C.

[0302] Second Communication Winding 1122:

[0303] The second communication winding 1122 includes the conductive path 1122a. The conductive path 1222a forms the second communication winding 1122 and is disposed on the second communication layer 1126b. The conductive path 1222a is one example of the second communication winding 122 shown in FIG. 10.

[0304] The conductive path 1222a has an end 1223 and end 1225. The conductive path 1222a traverses the second communication layer 1126b from end 1223 to end 1225. End 1223 of the conductive path 1222a corresponds to the electrical node 123 shown in FIG. 10. The end 1225 of the conductive path 1222a corresponds to the electrical node 125 shown in FIG. 10. End 1223 may be the triangle end of the second communication winding 1122 while end 1225 may be the non-triangle end, dot end of the second communication winding 1122. In one example, end 1223 may be the positive labeled terminal of receiver voltage V_R . End 1225 may be coupled to the first enhancement winding 1144.

[0305] End 1225 is an outer end disposed outside of the turns formed by the conductive path 1222a of the second communication winding 1122. End 1223 is an inner end and is inside the turns formed by the conductive path 1222a of the second communication winding 1122. Conductive path 1222a, end 1223, and end 1225 may be comprised of a conductive material. The conductive path 1222a traverses in an outward spiral around the second axis G2 in the clockwise direction from end 1223 towards end 1225. As such, the second communication winding 1122 is wound in a clockwise direction. The conductive path 1222a forms a spiral which is substantially rectangular in shape with ninety-degree indentations at its corners.

[0306] End 1223 is the beginning of end-to-end reference line 511b of FIG. 12B. Each instance in which the conductive path 1222a crosses the reference line 511b in FIG. 12B may be considered one turn of the second communication winding 622. As the conductive path 1222a forms the turns of second communication winding 1122, each successive turn formed by the conductive path 1222a as the conductive path 1222a reaches the reference line 511b is farther from the end 1223. The conductive path 1222a illustrates three turns in the second communication winding 1122. It should be appreciated that the second communication winding 1122 is a planar winding.

[0307] The opening 234 is outside the second communication winding 1122. The opening 234 is outside the turns formed by the conductive path 1222a. The first axis G1 is outside the turns of the second communication winding 1122. Conductive path 1222a is disposed on one side of opening 234. The conductive path 1222a is disposed below opening 234 in the second lateral direction (y-axis). The conductive path 1222a is substantially within the first core window.

[0308] First Enhancement Winding 1144:

[0309] The first enhancement winding 1144 includes the conductive path 1244a. The conductive path 1244a forms the first enhancement winding 1144 and is disposed on the second communication layer 1126b. The conductive path 1244a is one example of the first enhancement winding 1044 shown in FIG. 10. In one example, the conductive path 1222a may

be referred to as the second conductive path and conductive path 1244a may be referred to as a third conductive path.

[0310] The conductive path 1244a has an end 1246 and an end 1245a. The conductive path 1244a traverses the second communication layer 1126b from end 1246 to end 1245a. End 1246 of the conductive path 1244a corresponds to the electrical node 1046 shown in FIG. 10. The end 1245a of the conductive path 1244a corresponds to the electrical node 1045 shown in FIG. 10. End 1246 may be the square end, dot end of the first enhancement winding 1144 while end 1245a may be the non-square end, non-dot end of the first enhancement winding 1144. In one example, end 1246 may be coupled to the second communication winding 1122. The end 1245a may be the negative labeled terminal of receiver voltage V_R .

[0311] End 1246 is an outer end and disposed outside of the turns formed by the conductive path 1244a of the first enhancement winding 1144. End 1245a is an inner end and is inside the turns formed by the conductive path 1244a of the first enhancement winding 1144. Conductive path 1244a, end 1246, and end 1245a may be comprised of a conductive material. The conductive path 1244a traverses the second communication layer 1126b in a counter-clockwise direction from end 1246 to end 1245a. From end 1246, the conductive path 1244a traverses in an inward spiral around the third axis G3 towards end 1245a. As such, the first enhancement winding 1144 is wound in a counter-clockwise direction. The conductive path 1244a forms a spiral which is substantially rectangular in shape with ninety-degree indentations at its corners.

[0312] End 1246 is the beginning of reference line 511e for the first enhancement winding 1144 in FIG. 12B. Each instance in which the conductive path 1244a crosses the reference line 511e in FIG. 12B may be considered one turn of the first enhancement winding 1144. As the conductive path 1244a forms the turns of first enhancement winding 1144, each successive turn formed by the conductive path 1244a as the conductive path 1244a reaches the reference line 511e is closer to end 1245a. The conductive path 1244a illustrates three turns in the first enhancement winding 1144. It should be appreciated that the first enhancement winding 1144 is a planar winding.

[0313] The opening 234 is outside the first enhancement winding 1144. The opening 234 is outside the turns formed by the conductive path 1244a. The first axis G1 is outside the turns of the first enhancement winding 1144. Conductive path 1244a is disposed on one side of opening 234. The conductive path 1244a is disposed above opening 234 in the second lateral direction (y-axis) and substantially within the second core window.

[0314] Conductive path 1222a of the second communication winding 1122 couples to conductive path 1244a of the first enhancement winding 1144. End 1225 couples to end 1246.

Conductive path 1257 is an intermediate conductive path which couples the second communication winding 1122 and the first enhancement winding 1144. As shown, a conductive path 1257 traverses across the second communication layer 1126b to couple the conductive path 1222a to conductive path 1244a. Said differently, conductive path 1257 couples end 1225 to end 1246. Conductive path 1222a and conductive path 1244a forms one trace on the second communication layer 1126b. As shown, the conductive path 1222a, 1257 and 1244a forms one trace on the second communication layer 1126b.

[0315] The conductive path 1222a for the second communication winding 1122 begins at the inner end 1223 and spirals outward in a clockwise direction to its outer end 1225. Outer end 1225 of conductive path 1222a couples to the outer end 1246 of conductive path 1244a of the first enhancement winding 1144. From outer end 1246, the first enhancement winding 1144 spirals inward in a counter-clockwise direction towards its inner end 1245a. As such, a “figure eight” path is created.

[0316] FIG. 12B also illustrates conductive path 1258 with end 1245b and end 1245c. Ends 1245b and 1245c also correspond to electrical node 1045 shown in FIG. 10. Conductive path 1258 traverses the second communication layer 1126b towards the edge of the second communication layer 1126b. End 1245a can be coupled to end 1245b through another conductive path on another communication layer (not shown). These additional ends and conductive paths may be utilized such that the first enhancement winding 1144 may terminate in the desired location on the second communication layer 1126b.

[0317] FIG. 12C illustrates a top-down view of a first communication layer 1126c including the first communication winding 1120 and the second enhancement winding 1141. The first communication layer 1126c is an alternative embodiment of the first communication layer 326c of FIG. 3. It should be appreciated that similarly named and numbered elements couple and function as described above, in particular, with respect to FIGS. 5A, 5B, 8B and 8C.

[0318] First Communication Winding 1120:

[0319] The first communication winding 1120 includes a conductive path 1220a. The conductive path 1220a forms the first communication winding 1120 and is disposed on the first communication layer 1126c. The conductive path 1220a may be referred to as a first conductive path while conductive path 1222a may be referred to as a second conductive path. The conductive path 1220a is one example of the first communication winding 120 shown in FIG. 1.

[0320] The conductive path 1220a has an end 1219 and an end 1221. The conductive path 1220a traverses the first communication layer 1126c from end 1219 to end 1221. End 1219 of the conductive path 1220a corresponds to the electrical node 119 shown in FIG. 10. The end 1221 of conductive path 1220a corresponds to the electrical node 121 shown in FIG. 10. End

1219 may be the triangle end of the first communication winding 1120 while end 1221 may be the non-triangle end of the first communication winding 1120. In one example, end 1219 may be the positive labeled terminal of transmit voltage V_T while end 1221 may couple to the second enhancement winding 1141.

[0321] End 1221 is an outer end and is disposed outside of the turns formed by the conductive path 1220a. End 1221 is an outer end and is disposed outside of the turns of the first communication winding 1120. End 1219 is an inner end and is inside the turns formed by the conductive path 1220a. In other words, end 1219 is an inner end and is disposed inside of the turns of the first communication winding 1120. Conductive path 1220a, end 1219, and end 1221 may be comprised of a conductive material.

[0322] The conductive path 1220a traverses the first communication layer 1126c in a clockwise direction from end 1219. From end 1219, the conductive path 1220a traverses in an outward spiral around the second axis G2 and reaches end 1221. As such, the first communication winding 1120 is wound in a clockwise direction. The conductive path 1220a forms a spiral which is substantially rectangular in shape with ninety-degree indentations at its corners. However, it should be appreciated that the conductive path 1220a may spiral in other shapes.

[0323] End 1219 is the beginning of reference line 511c of FIG. 12C. Each instance in which the conductive path 1220a crosses the reference line 511c in FIG. 12C may be considered one turn of the first communication winding 1120. As the conductive path 1220a forms the turns of first communication winding 1120, each successive turn formed as the conductive path 1220a reaches the reference line 511c is farther from the end 1219. The conductive path 1220a illustrates three turns in the first communication winding 1120. It should be appreciated that the first communication winding 1120 is a planar winding.

[0324] The opening 234 is outside the first communication winding 1120. The opening 234 is outside the turns formed by the conductive path 1220a of the first communication winding 1120. The first axis G1 is outside the turns of the first communication winding 1120. Conductive path 1220a is disposed on one side of opening 234. The conductive path 1220a is disposed below opening 234 in the second lateral direction (y-axis) and substantially within the first core window. It should be appreciated that conductive path 1222a substantially overlays the conductive path 1220a.

[0325] While the first communication winding 1120 is shown as disposed on a solitary first communication layer 1126c, it should be appreciated that the first communication winding 1120 may be disposed on multiple layers. For example, an additional communication layer may include another conductive path which is coupled to the conductive path 1220a.

[0326] The widths of the conductive paths 1222a, 1220a and the spacing between the conductive paths 1222a, 1220a are determined by the manufacturing process of the multilayer circuit. However, the number of turns for conductive paths 1222a, 1220a are selected to maximize the size of the first communication winding 1120 and the second communication winding 1122 within the first core window 232. The larger the enclosed area of both the first communication winding 1120 and the second communication winding 1122, the stronger the magnetic coupling between conductive paths 1122a, 1120a.

[0327] The conductive path 1222a of the second communication winding 1122 is wound in the same direction as conductive path 1220a of the first communication winding 1120 starting from their respective inner ends. For the example shown, the conductive path 1222a and the conductive path 1220a are wound in a clockwise direction starting at end 1223 and at end 1219 respectively. However, it should be appreciated that the conductive path 1222a and the conductive path 1220a may be wound in the counter-clockwise direction or may be wound in opposite directions from each other.

[0328] Second Enhancement Winding 1141:

[0329] The second enhancement winding 1141 includes the conductive path 1241a. The conductive path 1241a forms the second enhancement winding 1141 and is disposed on the first communication layer 1126c. The conductive path 1241a is one example of the second enhancement winding 1041 shown in FIG. 10. In one example, the conductive path 1220a may be referred to as the first conductive path and conductive path 1241a may be referred to as a fourth conductive path.

[0330] The conductive path 1241a has an end 1243 and an end 1242a. The conductive path 1241a traverses the second communication layer 1126b from end 1243 to end 1242a. End 1243 of the conductive path 1241a corresponds to the electrical node 1043 shown in FIG. 10. The end 1242a of the conductive path 1241a corresponds to the electrical node 1042 shown in FIG. 10. End 1243 may be the square end of the second enhancement winding 1141 while end 1242a may be the non-square end of the second enhancement winding 1141. In one example, end 1243 may be coupled to the first communication winding 1120. The end 1242a may be the negative labeled terminal of transmit voltage V_T .

[0331] End 1243 is an outer end and disposed outside of the turns formed by the conductive path 1241a of the second enhancement winding 1141. End 1242a is an inner end and is inside the turns formed by the conductive path 1241a of the second enhancement winding 1141. Conductive path 1241a, end 1243, and end 1242a may be comprised of a conductive material. The conductive path 1241a traverses the first communication layer 1126c in a counter-clockwise direction from end 1243 to end 1242a. From end 1243, the conductive path 1241a

traverses in an inward spiral around third axis G3 and reaches end 1242a. As such, the second enhancement winding 1141 is wound in a counter-clockwise direction. The conductive path 1241a forms a spiral which is substantially rectangular in shape with ninety-degree indentations at its corners.

[0332] End 1243 is the beginning of reference line 511f for the second enhancement winding 1141 in FIG. 12C. Each instance in which the conductive path 1241a crosses the reference line 511f of the second enhancement winding 1141 in FIG. 12C may be considered one turn of second enhancement winding 1141. As the conductive path 1241a forms the turns of second enhancement winding 1141, each successive turn formed by the conductive path 1241a as the conductive path 1241a reaches the reference line 511f is closer to end 1242a. The conductive path 1241a illustrates three turns in the second enhancement winding 1141. It should be appreciated that the second enhancement winding 1141 is a planar winding.

[0333] The opening 234 is outside the second enhancement winding 1141. The opening 234 is outside the turns formed by the conductive path 1241a. First axis G1 is outside the turns of the second enhancement winding 1141. Conductive path 1241a is disposed on one side of opening 234. The conductive path 1241a is disposed above opening 234 in the second lateral direction (y-axis) and substantially within the second core window.

[0334] Conductive path 1220a of the first communication winding 1120 couples to conductive path 1241a of the second enhancement winding 1141. End 1221 couples to end 1243. Conductive path 1251 is an intermediate conductive path which couples the first communication winding 1120 and the second enhancement winding 1141. As shown, a conductive path 1251 traverses across the first communication layer 1126c to couple the conductive path 1220a to conductive path 1241a. Said differently, conductive path 1251 couples end 1221 to end 1243. Conductive path 1220a and conductive path 1241a form one trace on the first communication layer 1126c. As shown, the conductive path 1220a, 1251 and 1241a form one trace on the first communication layer 1126c.

[0335] The conductive path 1220a for the first communication winding 1120 begins at the inner end 1219 and spirals outward in a clockwise direction to its outer end 1221. Outer end 1221 of conductive path 1220a couples to the outer end 1243 of conductive path 1241a of the second enhancement winding 1141. From outer end 1243, the second enhancement winding 1141 spirals inward in a counter-clockwise direction towards its inner end 1242a. As such, a “figure eight” path is created.

[0336] In the alternative embodiment regarding the parallel coupled second enhancement winding as discussed with respect to FIG. 10, the conductive paths may be formed such that end 1219 couples to end 1243 and end 1242a couples to end 1221. For example, the intermediate

conductive path 1251 may couple end 1219 to end 1243 and intermediate conductive path 1252 may couple end 1242a to end 1221. End 1219 and end 1243 would correspond to the positive labeled terminal of transmit voltage V_T and end 1221, 1242a, 1242b, and 1242c would correspond to the negative labeled terminal of transmit voltage V_T .

[0337] FIG. 12C also illustrates conductive path 1252 with end 1242b and end 1242c. Ends 1242b and 1242c also correspond to electrical node 1045 shown in FIG. 10. Conductive path 1252 traverses the first communication layer 1126c towards the edge of the first communication layer 1126c. End 1242a can couple to end 1242b through another conductive path on another communication layer (not shown). These additional ends and conductive paths may be utilized such that the second enhancement winding 1141 may terminate in the desired location on the first communication layer 1126c.

[0338] FIG. 12D illustrates a top-down view of the second power layer 326d including the second power winding 306. The second power winding 306 is formed by the conductive path 506a and has ends 507 and ends 509. FIG. 12D also illustrates the opening 234, projection 335, and the end-to-end reference line 511d. It should be appreciated that similarly named and numbered elements couple and function as described above. In particular, FIG. 12D is substantially the same as FIG. 5D and the detailed description of the second power layer 326d and the other elements shown in FIG. 12D may be found with respect to the detailed description of FIG. 5D above.

[0339] The second communication winding 1122 is coupled to the first communication winding 1120 such that the voltage from end 1223 to end 1225 is the same polarity as the voltage from end 1219 to end 1221. However, it should be appreciated that the second communication winding 1122 may be coupled to the first communication winding 1120 such that the voltage from end 1223 to end 1225 is the opposite polarity from the voltage from end 1219 to end 1221. The first enhancement winding 1144 is coupled to the second enhancement winding 1141 such that the voltage from end 1246 to end 1245a is the same polarity as the voltage from end 1243 to end 1242a. Similar to what has been previously discussed, the second communication winding 1122 is a receiver winding. Further, the second communication winding 1122 is configured with respect to the second power winding 306 such that the voltage from end 1223 to 1225 is the opposite polarity from the voltage from end 507 to end 509.

[0340] FIGS. 13A, and 13B illustrate example communication layers of the multilayer circuit 226. For 13A and 13B, the second communication layer 1326b and the first communication layer 1326c are viewed in the same perspective as FIGS. 4A-4B, 5A-5D, 8A-8D, and 12A-12D. The thin solid line represents the outline of each layer and the thin dotted line illustrates the projection 335.

[0341] FIG. 13A illustrates a top-down view of a second communication layer 1326b including another embodiment of a second communication winding 1322 and a first enhancement winding 1344. The second communication layer 1326b is an alternative embodiment of the second communication layer 326b shown in FIG. 3. The first enhancement winding 1344 and the second communication winding 1322 are substantially disposed within the projection 335. The example second communication winding 1322 and the first enhancement winding 1344 share many similarities with the other figures. However, at least one difference is the second communication winding 1322 and the first enhancement winding 1344 are both on the same side of opening 234.

[0342] Second Communication Winding 1322:

[0343] The second communication winding 1322 includes the conductive path 1322a. The conductive path 1322a forms the second communication winding 1322 and is disposed on the second communication layer 1326b. The conductive path 1322a is one example of the second communication winding 122 shown in FIG. 10.

[0344] The conductive path 1322a has an end 1323 and an end 1325. The conductive path 1322a traverses the second communication layer 1326b from end 1323 to end 1325. End 1323 of the conductive path 1322a corresponds to the electrical node 123 shown in FIG. 10. The end 1325 of the conductive path 1322a corresponds to the electrical node 125 shown in FIG. 10. End 1323 may be the triangle end of the second communication winding 1322 while end 1325 may be the non-triangle end, dot end of the second communication winding 1322. In one example, end 1323 may be the positive labeled terminal of receiver voltage V_R . End 1325 may be coupled to the first enhancement winding 1344.

[0345] Conductive path 1322a, end 1323, and end 1325 may be comprised of a conductive material. The conductive path 1322a traverses the second communication layer 1326b in clockwise direction from end 1323 and reaches end 1325. The conductive path 1322a is rectangular in shape. It should be appreciated that the conductive path 1322a may form other shapes. As such, the second communication winding 1322 is wound in a counter-clockwise direction. The conductive path 1322a forms one turn of the second communication winding 1322.

[0346] The opening 234 is outside the second communication winding 1322. The opening 234 is outside the turn formed by the conductive path 1322a. Conductive path 1322a is disposed on one side of opening 234. The conductive path 1322a is disposed below opening 234 in the second lateral direction (y-axis).

[0347] First Enhancement Winding 1344:

[0348] The first enhancement winding 1344 includes the conductive path 1344a. The conductive path 1344a forms the first enhancement winding 1344 and is disposed on the second communication layer 1326b. The conductive path 1344a is one example of the first enhancement winding 1044 shown in FIG. 10. In one example, the conductive path 1322a may be referred to as the second conductive path and conductive path 1344a may be referred to as a third conductive path.

[0349] The conductive path 1344a has an end 1346 and an end 1345a. The conductive path 1344a traverses the second communication layer 1326b from end 1346 to end 1345a. End 1346 of the conductive path 1344a corresponds to the electrical node 1046 shown in FIG. 10. The end 1345a of the conductive path 1344a corresponds to the electrical node 1045 shown in FIG. 10. End 1346 may be the square end, dot end of the first enhancement winding 1344 while end 1345a may be the non-square end, non-dot end of the first enhancement winding 1344. In one example, end 1346 may be coupled to the second communication winding 1322. The end 1345a may be the negative labeled terminal of receiver voltage V_R .

[0350] Conductive path 1344a, end 1346, and end 1345a may be comprised of a conductive material. The conductive path 1344a traverses the second communication layer 1326b in a counter-clockwise direction from end 1346 to end 1345a. The conductive path 1344a forms a shape which is substantially rectangular. However, it should be appreciated that the conductive path 1344a may form other shapes. As such, the first enhancement winding 1344 is wound in a counter-clockwise direction. The conductive path 1344a forms one turn of the first enhancement winding 1344.

[0351] The opening 234 is outside the first enhancement winding 1344. The opening 234 is outside the turn formed by the conductive path 1344a. Conductive path 1344a is disposed on one side of opening 234. The conductive path 1344a is disposed below opening 234 in the second lateral direction (y-axis).

[0352] Conductive path 1322a of the second communication winding 1122 couples to conductive path 1344a of the first enhancement winding 1344. End 1325 couples to end 1346. Conductive path 1357 is an intermediate conductive path which couples the second communication winding 1322 and the first enhancement winding 1344. As shown, conductive path 1357 traverses the second communication layer 1326b in a straight line to couple the conductive path 1322a to conductive path 1344a. Said differently, conductive path 1357 couples end 1325 to end 1346. Conductive path 1322a and conductive path 1344a form one trace on the second communication layer 1326b. As shown, the conductive path 1322a, 1357 and 1344a form one trace on the second communication layer 1326b.

[0353] The conductive path 1322a for the second communication winding 1322 begins at end 1323 and forms a rectangular shape in a clockwise direction to end 1325. End 1325 of conductive path 1322a couples to the end 1346 of the first enhancement winding 1344. From end 1346, the first enhancement winding 1344 forms a rectangular shape in a counter-clockwise direction towards end 1345a. As such, a “figure eight” path is created.

[0354] FIG. 13A also illustrates conductive path 1358 with end 1345b and end 1345c. Ends 1345b and 1345c also correspond to electrical node 1045 shown in FIG. 10. Conductive path 1358 traverses the second communication layer 1326b towards the edge of the second communication layer 1326b. End 1345a can couple to end 1345b through another conductive path on another communication layer (not shown). These additional ends and conductive paths may be utilized such that the first enhancement winding 1344 may terminate in the desired location on the second communication layer 1326b. Ends 1323 and 1345c may be utilized as testing nodes and are shown as disposed outside the outer edge of the second communication layer 1326b. It should be appreciated that ends 1323 and ends 1345c may be disposed within the edge of the second communication layer 1326b.

[0355] FIG. 13B illustrates a top-down view of a first communication layer 1326c including the first communication winding 1320 and the second enhancement winding 1341. The first communication layer 1326c is an alternative embodiment of the first communication layer 326c of FIG. 3. The first communication winding 1320 and the second enhancement winding 1341 may be disposed within the projection 335. The example first communication winding 1320 and the second enhancement winding 1341 share many similarities with the other figures. However, at least one difference is the first communication winding 1320 and the second enhancement winding 1341 are both on the same side of opening 234.

[0356] First Communication Winding 1320:

[0357] The first communication winding 1320 includes a conductive path 1320a. The conductive path 1320a forms the first communication winding 1320 and is disposed on the first communication layer 1326c. The conductive path 1320a may be referred to as a first conductive path while conductive path 1322a may be referred to as a second conductive path. The conductive path 1320a is one example of the first communication winding 120 shown in FIG. 1.

[0358] The conductive path 1320a has an end 1319 and end 1321. The conductive path 1320a traverses the first communication layer 1326c from end 1319 to end 1321. End 1319 of the conductive path 1320a corresponds to the electrical node 119 shown in FIG. 10. The end 1321 of the conductive path 1320a corresponds to the electrical node 121 shown in FIG. 10. End 1319 may be the triangle end of the first communication winding 1320 while end 1321 may be the non-triangle end of the first communication winding 1320. In one example, end 1319

may be the positive labeled terminal of transmit voltage V_T while end 1321 may couple to the second enhancement winding 1341. Conductive path 1320a, end 1319, and end 1321 may be comprised of a conductive material.

[0359] The conductive path 1320a traverses the first communication layer 1326c in a substantially clockwise direction from end 1319 and reaches end 1321. As such, the first communication winding 1320 is wound in a clockwise direction. The conductive path 1320a is substantially rectangular in shape. However, it should be appreciated that the conductive path 1320a may form other shapes. As shown, conductive path 1320a forms one turn of the first communication winding 1320.

[0360] The opening 234 is outside the first communication winding 1320. The opening 234 is outside the turn formed by the conductive path 1320a of the first communication winding 1320. Conductive path 1320a is disposed on one side of opening 234. The conductive path 1320a is disposed below opening 234 in the second lateral direction (y-axis). It should be appreciated that conductive path 1322a substantially overlays the conductive path 1320a.

[0361] While the first communication winding 1320 is shown as disposed on a solitary first communication layer 1326c, it should be appreciated that the first communication winding 1320 may be disposed on multiple layers. For example, an additional communication layer may include another conductive path which is coupled to the conductive path 1320a.

[0362] The conductive path 1322a of the second communication winding 1322 is wound in the same direction as conductive path 1320a of the first communication winding 1320 starting at end 1323 and end 1319 respectively. For the example shown, the conductive path 1322a and the conductive path 1320a are wound in a clockwise direction starting at end 1323 and end 1319 respectively. However, it should be appreciated that the conductive path 1322a and the conductive path 1320a may be wound in the counter-clockwise direction.

[0363] Second Enhancement Winding 1341:

[0364] The second enhancement winding 1341 includes the conductive path 1341a. The conductive path 1341a forms the second enhancement winding 1341 and is disposed on the first communication layer 1326c. The conductive path 1341a is one example of the second enhancement winding 1041 shown in FIG. 10. In one example, the conductive path 1320a may be referred to as the first conductive path and conductive path 1341a may be referred to as a fourth conductive path.

[0365] The conductive path 1341a has an end 1343 and an end 1342a. The conductive path 1341a traverses the second communication layer 1326b from end 1343 to end 1342a. End 1343 of the conductive path 1341a corresponds to the electrical node 1043 shown in FIG. 10. The end 1342a of the conductive path 1341a corresponds to the electrical node 1042 shown in

FIG. 10. End 1343 may be the square end of the second enhancement winding 1341 while end 1342a may be the non-square end of the second enhancement winding 1341. In one example, end 1343 may be coupled to the first communication winding 1320. The end 1342a may be the negative terminal of transmit voltage V_T .

[0366] Conductive path 1341a, end 1343, and end 1342a may be comprised of a conductive material. The conductive path 1341a traverses the first communication layer 1326c in a counter-clockwise direction from end 1343 to end 1342a. As such, the second enhancement winding 1341 is wound in a counter-clockwise direction. The conductive path 1341a forms a substantially rectangular shape. It should be appreciated that the conductive path 1341a may form other shapes. As shown, conductive path 1341a forms one turn of the second enhancement winding 1341.

[0367] The opening 234 is outside the second enhancement winding 1341. The opening 234 is outside the turn formed by the conductive path 1341a. Conductive path 1341a is disposed on one side of opening 234. The conductive path 1341a is disposed below opening 234 in the second lateral direction (y-axis).

[0368] Conductive path 1320a of the first communication winding 1320 couples to conductive path 1341a of the second enhancement winding 1341. End 1321 couples to end 1343. Conductive path 1351 is an intermediate conductive path which couples the first communication winding 1320 and the second enhancement winding 1341. As shown, a conductive path 1351 traverses across the first communication layer 1326c in a straight line to couple the conductive path 1320a to conductive path 1341a. Said differently, conductive path 1351 couples end 1321 to end 1343. Conductive path 1320a and conductive path 1341a form one trace on the first communication layer 1326c. As shown, the conductive path 1320a, 1351 and 1341a form one trace on the first communication layer 1326c.

[0369] The conductive path 1320a for the first communication winding 1320 begins at end 1319 and forms a rectangular shape in a clockwise direction to end 1321. End 1321 of conductive path 1320a couples to the end 1343 of the second enhancement winding 1341. From end 1343, the second enhancement winding 1341 forms a rectangular shape in a counter-clockwise direction towards end 1342a. As such, a “figure eight” path is created.

[0370] FIG. 13B also illustrates conductive path 1352 with end 1342b and end 1342c. Ends 1342b and 1342c also correspond to electrical node 1042 shown in FIG. 10. Conductive path 1352 traverses the first communication layer 1326c towards the edge of the first communication layer 1326c. End 1342a can couple to end 1342b through another conductive path on another communication layer (not shown). These additional ends and conductive paths may be utilized such that the second enhancement winding 1341 may terminate in the desired

location on the first communication layer 1326c. Ends 1319 and 1342c may be utilized as testing nodes and are shown as disposed outside the outer edge of the second communication layer 1326b. It should be appreciated that ends 1319 and end 1342c may be disposed within the edge of the second communication layer 1326b.

[0371] FIG. 14 illustrates an example switch controller 1400 which utilizes a magnetic assembly 1424. The magnetic assembly 1424 includes an energy transfer element T2 and communication links COM3, COM4, and COM5. The switch controller 1400 is also shown as a control interface 1418, a driver 1410, a turn-on switch Q1, and a turn-off switch Q2. The power switch S2 is also shown to provide context for the switch controller 1400. Power switch S2 is shown as an insulated-gate bipolar transistor (IGBT). However, other transistors may be used for power switch S2. Such as a metal-oxide-semiconductor field-effect transistors (MOSFETs), bipolar transistors, injection enhancement gate transistors (IEGTs) and gate turn-off thyristors (GTOs). In addition, power switches which are based on gallium nitride (GaN) semiconductors or silicon carbide (SiC) semiconductors may also be utilized.

[0372] The magnetic assembly 1424 includes the energy transfer element T2 and the communication link COM3, communication link COM4, and communication link COM5. The energy transfer element T2 includes a first power winding 1404 and a second power winding 1406. The first power winding 1404 may also be referred to as an input winding of the energy transfer element T2 while the second power winding 1406 may also be referred to as an output winding of the energy transfer element T2. As shown, energy transfer element T2 transfers energy from the interface to the driver 1410. As such, the driver 1410 is provided with operational power to operate the various circuitry of the driver 1410. As shown, the second power winding 1406 is coupled to the driver to provide a reference voltage VAUX and a reference voltage VNEG. The reference voltage VAUX is greater than reference voltage VNEG. Driver 1410 may include circuitry to generate a regulated voltage reference VIGD from the reference voltage VAUX. Regulated voltage reference VIGD may be used to supply the driver 1410. The lines between the windings of the energy transfer element T2 indicate that these windings are substantially coupled through a core of magnetic material, such as iron or ferrite. As shown, there are no lines between the windings of the communication link COM3, communication link COM4, and communication link COM5, indicating that the coupling between their respective windings is substantially an air-coupling.

[0373] The communication link COM3 includes a first communication winding 1420a and a second communication winding 1422a. Each end of the first communication winding 1420a is denoted by node 1419a and node 1421a, respectively. Each end of the second communication winding 1422a is denoted by node 1423a and node 1425a, respectively. The

second communication winding 1422a also includes a tap node 1460. A transmit voltage V_{T1} is the voltage across node 1419a and node 1421a. As shown, 1419a is the positive labeled terminal of transmit voltage V_{T1} while node 1421a is the negative labeled terminal of transmit voltage V_{T1} . A receiver voltage V_{R1} is the voltage across node 1423a and 1425a. The node 1423a is the positively labeled terminal of receiver voltage V_{R1} and node 1425a is the negatively labeled terminal of receiver voltage V_{R1} . Node 1419a is the dot end while 1421a is the non-dot end of the first communication winding 1420a. Node 1423a is the dot end while 1425a is the non-dot end of the second communication winding 1422a. The first communication winding 1420a is coupled to the second communication winding 1422a such that the voltage from node 1419a to node 1421a is the same polarity as the voltage from node 1423a to node 1425a. However, it should be appreciated that the first communication winding 1420a may be configured with respect to the second communication winding 1422a such that the voltage from node 1419a to node 1421a is the opposite polarity as the voltage from node 1423a to node 1425a. The communication link COM3 may be referred to as the first communication link.

[0374] The communication link COM4 includes a first communication winding 1420b and a second communication winding 1422b. Each end of the first communication winding 1420b is denoted by node 1419b and node 1421b, respectively. Each end of the second communication winding 1422b is denoted by node 1423b and node 1425b, respectively. The second communication winding 1422b also includes a tap node 1460. A transmit voltage V_{T2} is the voltage across node 1419b and node 1421b. As shown, 1419b is the positive labeled terminal of transmit voltage V_{T2} while node 1421b is the negative labeled terminal of transmit voltage V_{T2} . A receiver voltage V_{R2} is the voltage across node 1423b and 1425b. The node 1423b is the positively labeled terminal of receiver voltage V_{R2} and node 1425b is the negatively labeled terminal of receiver voltage V_{R2} . Node 1419b is the dot end while 1421b is the non-dot end of the first communication winding 1420b. Node 1423b is the dot end while 1425b is the non-dot end of the second communication winding 1422b. The first communication winding 1420b is coupled to the second communication winding 1422b such that the voltage from node 1419b to node 1421b is the same polarity as the voltage from node 1423b to node 1425b. However, it should be appreciated that the first communication winding 1420b may be configured with respect to the second communication winding 1422b such that the voltage from node 1419b to node 1421b is the opposite polarity as the voltage from node 1423b to node 1425b. The communication link COM4 may be referred to as the second communication link.

[0375] As shown, the tap node of the second communication winding 1422a of communication link COM3 is coupled to the tap node of the second communication winding 1422b of communication link COM4. This tap node is denoted as node 1460. The tap nodes on

the second communication windings may be used to reduce common mode noise. However, it should be appreciated that the tap nodes need not be coupled together. Node 1460 is shown as coupled to reference VIGD. As mentioned above, reference VIGD may be generated from reference VAUX. Within driver 1410, the reference VIGD may be coupled to one end of a capacitor. The other end of the capacitor is coupled to reference VNEG. The internal capacitor may be used as a blocking capacitor.

[0376] The communication link COM5 includes a first communication winding 1420c and a second communication winding 1422c. Each end of the first communication winding 1420c is denoted by node 1419c and node 1421c, respectively. Each end of the second communication winding 1422c is denoted by node 1423c and node 1425c, respectively. The second communication winding 1422c also includes a tap node 1461. A transmit voltage V_{T3} is the voltage across node 1419c and node 1421c. As shown, 1419c is the positive labeled terminal of transmit voltage V_{T3} while node 1421c is the negative labeled terminal of transmit voltage V_{T3} . A receiver voltage V_{R3} is the voltage across node 1423c and 1425c. The node 1423c is the positively labeled terminal of receiver voltage V_{R3} and node 1425c is the negatively labeled terminal of receiver voltage V_{R3} . Node 1419c is the dot end while 1421c is the non-dot end of the first communication winding 1420c. Node 1423c is the dot end while 1425c is the non-dot end of the second communication winding 1422c. The first communication winding 1420c is coupled to the second communication winding 1422c such that the voltage from node 1419c to node 1421c is the same polarity as the voltage from node 1423c to node 1425c. However, it should be appreciated that the first communication winding 1420c may be coupled to the second communication winding 1422b such that the voltage from node 1419c to node 1421c is the opposite polarity as the voltage from node 1423c to node 1425c. The communication link COM5 may be referred to as the third communication link.

[0377] The tap node on the second communication windings may be used to reduce common mode noise. Node 1461 is coupled to reference VCC2. Within control interface 1418 is a capacitor. One end of the capacitor is coupled to reference VCC2, the other end is coupled to reference GND. This capacitor may be used as a blocking capacitor. The reference VCC2 may be a supply potential for circuitry of the control interface 1418. The reference GND refers to the lowest potential for the control interface 1418.

[0378] As shown, the first communication winding 1420a of communication link COM3 is coupled to the control interface 1418. The second communication winding 1422a of communication link COM3 couples to the driver 1410. The first communication winding 1420b of communication link COM4 is coupled to the control interface 1418. The second communication winding 1422b of communication link COM4 couples to the driver 1410. The

direction of communication for communication links COM3 and COM4 is from the control interface to the driver 1410.

[0379] The first communication winding 1420c of communication link COM5 is coupled to driver 1410. The second communication winding 1422c of communication link COM5 is coupled to control interface 1418. The direction of communication for communication link COM5 is from the driver 1410 to the control interface 1418. As such, the communication between the control interface 1418 and the driver 1410 is bidirectional. However, it should be appreciated that the communication may be unidirectional.

[0380] The magnetic assembly 1424 provides galvanic isolation between an interface side and a driver side of the switch controller 1400. Communication links COM3, COM4, and COM5, along with energy transfer element T2 provide galvanic isolation between the interface side and the driver side of the switch controller 1400. The interface side of switch controller 1400 includes the control interface 1418. The driver side of the switch controller 1400 includes the driver 1410. The interface side is sometimes referred to as the primary side while the driver side is sometimes referred to as the secondary side. The control interface 1418 is referenced to a reference voltage GND while the driver 1410 is referenced to reference voltage VNEG.

[0381] Control interface 1418 is coupled to receive one or more control signals 1417. The one or more control signal 1417 may be received from a system controller which determines whether the power switch S2 should be turned ON or OFF. One example of a control signal 1417 includes a command to turn ON or OFF the power switch S2. Another example includes an adjustment which adjusts a delay time for turning ON or turning OFF the power switch. It should be understood that the switch controller 1400 may receive any number of different types of control signals which characterize how to control the power switch S2.

[0382] Control interface 1418 interprets the one or more control signal 1417 to drive the power switch S2 ON or OFF. The control interface 1418 communicates the interpreted one or more control signals 1417 to the driver 1410. The control interface 1418 may communicate information as a voltage signal and/or a current signal and the driver 1410 may receive the information as a voltage signal and/or current signal.

[0383] Communication links COM3 and COM4 are utilized by the control interface 1418 to transmit information to driver 1410. The control interface 1418 may communicate information utilizing the transmitter current I_{T1} and transmitter current I_{T2} . Properties of the transmitter currents I_{T1} , I_{T2} may be controlled to communicate information. These properties may include the magnitude and the rate of change of the transmitter current I_{T1} and transmitter current I_{T2} . 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. Other communication techniques may be utilized which take advantage of the relationship between the transmitter currents I_{T1} , I_{T2} and the resultant induced receiver voltages V_{R1} and receiver voltage V_{R2} and/or induced receiver currents I_{R1} , I_{R2} received by the driver 1410. Information sent to the driver 1410 from the control interface 1418 may include: clock signal frequency, turn-on commands for power switch S2, turn-off commands for power switch S2 or adjustment times to turn ON or turn OFF the power switch S2. However, it should be appreciated that other information may be communicated.

[0384] Driver 1410 receives the information from the control interface 1418 and outputs drive signals to control the power switch S2. Further, the driver 1410 may output the drive signals to control the turn ON and turn OFF properties of the power switch S2. These properties may include how quickly and/or how often the power switch S2 turns ON or OFF. The driver 1410 turns ON the turn-on switch Q1 to turn ON the power switch S2. When turn-on switch Q1 is ON, the reference VPOS is applied to the control terminal of power switch S2. The value of reference VPOS as referenced to the emitter of power switch S2 is chosen such that power switch S2 conducts when reference VPOS is applied to the control terminal of power switch S2. The driver 1410 turns ON the turn-off switch S2 to turn OFF the power switch S2. When turn-off switch S2 is ON, the reference VNEG is applied to the control terminal of power switch S2. The value of reference VNEG as referenced to the emitter of power switch S2 is chosen such that the power switch S2 does not conduct when reference VNEG is applied to the control terminal of power switch S2.

[0385] Driver 1410 is also coupled to communicate to the control interface 1418. Driver 1410 utilizes communication link COM5 to communicate to the control interface 1418. The driver 1410 may communicate information utilizing the transmitter current I_{T3} . Properties of the transmitter current I_{T3} may be controlled to communicate information. These properties may include the magnitude and the rate of change of the transmitter current I_{T3} . 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. Other communication techniques may be utilized which take advantage of the relationship between the transmitter current I_{T3} and the resultant induced receiver voltage V_{R3} and/or induced receiver current I_{R3} received by the control interface 1418. Information sent to the control interface 1418 from the driver 1410 may include but is not limited to: fault detection, measured propagation delay, and handshaking between

communication link COM5 to communication links COM3 and COM4. However, it should be appreciated that other information may be communicated.

[0386] Further, the control interface 1418 and driver 1410 may use differential communication. As such, the second communication windings 1422a, 1422b, and 1422c have a differential receiver structure.

[0387] Although FIG. 14 illustrates the switch controller 1400 as including one control interface 1418 and one driver 1410. It should be appreciated that the switch controller 1400 may include any number of drivers or interfaces. For example, the control interface 1418 may be coupled to communicate with one or more drivers, with each driver controlling its own power switch. The driver 1410 may be coupled to communicate with one or more control interfaces.

[0388] Energy transfer element T2 and communication links COM3, COM4, and COM5 are included in the same magnetic assembly 1424. The magnetic assembly 1424 includes a multilayer circuit. In one example, one multilayer circuit board may be utilized for the multilayer circuit. In another example, two or more multilayer circuit boards may be utilized for the multilayer circuit. The energy transfer element T2 and the communication links COM3, COM4, and COM5 may be implemented into the multilayer circuit. The multilayer circuit may include an opening to receive a core of the energy transfer element T2. The first power winding 1404 may be disposed on one or more layers of the multilayer circuit. The second power winding 1406 may be disposed on one or more layers of the multilayer circuit. The first communication windings 1420a, 1420b, and 1420c may each be disposed on one or more layers of the multilayer circuit. The second communication windings 1422a, 1422b, and 1422c may each be disposed on one or more layers of the multilayer circuit. The first communication windings 1420a, 1420b, and 1420c overlay their respective second communication windings 1422a, 1422b, and 1422c. Further, the first communication winding and the second communication winding of each communication link may be disposed on different layers than the first communication winding and the second communication winding of the other communication links.

[0389] The communication links COM3, COM4, and COM5 may be disposed proximate to the energy transfer element T2. For example, the communication links COM3, COM4, COM5 may be disposed in layers of the multilayer circuit above the energy transfer element T2. In another example, the communication links COM3, COM4, COM5 may be disposed in layers of the multilayer circuit below the energy transfer element T2.

[0390] The communication links COM3, COM4, COM5 may also be disposed between layers of the energy transfer element T2. For example, the communication links COM3, COM4, COM5 may be disposed between the one or more layers of the first power winding 1404 and the

one or more layers of the second power winding 1406. If the first power winding 1404 is disposed on two or more layers, the communication links COM3, COM4, COM5 may be disposed between the layers of the first power winding 1404. Similarly, if the second power winding 1406 is disposed on two or more layers, the communication links COM3, COM4, COM5 may be disposed between the layers of the second power winding 1406. While the magnetic assembly 1424 illustrates three communication links, it should be appreciated that the magnetic assembly may include less or more communication links than what is shown.

[0391] FIG. 15 illustrates an exploded view of example communication layers 1526a, 1526b, 1526c, 1526d, 1526e, and 1526f of a portion 1526 of the multilayer circuit along axis G. The communication layers 1526a, 1526b, 1526c, 1526d, 1526e, and 1526f include communication links COM3, COM4, and COM5. It should be appreciated that the communication layers 1526a, 1526b, 1526c, 1526d, 1526e, and 1526f, are an alternative embodiment of communication layers 326b and 326c of FIG. 3.

[0392] Communication layers 1526a, 1526b, 1526c, 1526d, 1526e, and 1526f of FIG. 15 are shown in the same perspective as FIGS. 2A-2B, and 3. Communication layers 1526a, 1526b, 1526c, 1526d, 1526e, and 1526f are positioned along planes in the first lateral direction (x-axis) and the second lateral direction (y-axis). In other words, the communication layers 1526a, 1526b, 1526c, 1526d, 1526e, and 1526f each span planes which are perpendicular with the first vertical direction (z-axis). As such, conductive paths or traces disposed on communication layers 1526a, 1526b, 1526c, 1526d, 1526e, and 1526f traverse in the plane of the first lateral direction (x-axis) and the second lateral direction (y-axis). Axis G is shown as parallel with the first vertical direction (z-axis).

[0393] Interface Side Communication Layers 1526a, 1526b, and 1526c:

[0394] Communication layers 1526a, 1526b, and 1526c are on the interface side of the switch controller 1400. The conductive paths disposed on the communication layers 1526a, 1526b, and 1526c correspond with the communication windings on the interface side of the switch controller 1400 for each communication link COM3, COM4, and COM5. In the example shown, conductive paths disposed on communication layers 1526a, 1526b, and 1526c correspond with the first communication winding 1420a, the first communication winding 1420b, and the second communication winding 1422c.

[0395] First Communication Winding 1520a

[0396] The first communication winding 1520a is disposed on communication layers 1526a and 1526b. The first communication winding 1520a is one example of the first communication winding 1420a of the communication link COM3 shown in FIG. 14. As will be further discussed, the first communication winding 1520a is formed by a conductive path on

communication layer 1526a and a conductive path on communication layer 1526b. The openings 234 on communication layers 1526a and 1526b are outside of the turns formed by the first communication winding 1520a. The axis G is outside the turns formed by the first communication winding 1520a.

[0397] First Communication Winding 1520b

[0398] The first communication winding 1520b is disposed on communication layers 1526a and 1526b. The first communication winding 1520b is one example of the first communication winding 1420b of the communication link COM4 shown in FIG. 14. As will be further discussed, the first communication winding 1520b is formed by a conductive path on communication layer 1526a and a conductive path on communication layer 1526b. The openings 234 on communication layers 1526a and 1526b are outside of the turns formed by the first communication winding 1520b. The axis G is outside the turns formed by the first communication winding 1520b.

[0399] When viewing the communication layers 1526a, 1526b towards the first lateral direction (x-axis), the first communication windings 1520a and 1520b are disposed on the right-hand side of opening 234. When viewing the communication layers 1526a, 1526b towards the second lateral direction (y-axis), the first communication winding 1520a is on the right-hand side of the first communication winding 1520b.

[0400] Second Communication Winding 1522c

[0401] The second communication winding 1522c is disposed on communication layers 1526a, 1526b and 1526c. The second communication winding 1522c is one example of the second communication winding 1422c of the communication link COM5 shown in FIG. 14. As will be further discussed, the second communication winding 1522c is formed by several conductive paths on communication layer 1526a, several conductive paths on communication layer 1526b and a conductive path on communication layer 1526c. Each conductive path on communication layers 1526a and 1526b forms one turn of the second communication winding 1522c.

[0402] The openings 234 on communication layers 1526a, 1526b and 1526c are outside of the turns formed by the second communication winding 1522c. The axis G is outside the turns formed by the second communication winding 1522c. When viewing the communication layers 1526a, 1526b and 1526c towards the first lateral direction (x-axis), the second communication winding 1522c is disposed on the left-hand side of the opening 234. As shown, the second communication winding 1522c is on the opposite side of opening 234 as the first communication windings 1520a, 1520b. However, it should be appreciated that the first

communication windings 1520a, 1520b and the second communication winding 1522c may be disposed on other locations within the communication layers 1526a, 1526b, and 1526c.

[0403] The first communication windings 1520a, 1520b are shown on the same communication layers. Portions of the second communication winding 1522c are shown on the same communication layers as the first communication windings 1520a, 1520b. However, it should be appreciated that these communication windings may be on different layers or a mix of the same and different layers.

[0404] The second communication winding 1522c is an interleaved winding. For an interleaved winding, the conductive paths which form the interleaved winding are wound in alternating layers of the magnetic assembly. As will be further discussed, the conductive paths which form the turns of the second communication winding 1522c are alternately disposed between the communication layers 1526a, 1526b. For example, a conductive path to form the first turn of the second communication winding may be disposed on a first communication layer. The next conductive path to form the second turn is disposed on a second communication layer. Another conductive path to form the third turn is disposed on the first communication layer, and so on. The second communication winding 1522c may be interleaved to balance the capacitive coupling between windings. In one example, the second communication winding 1522c may be interleaved to balance the capacitive coupling between the second communication winding 1522c and its corresponding first communication winding 1520c. In addition, capacitively coupled noise may not be converted into a differential signal for an interleaved winding. The turns of the second communication winding 1522c are substantially symmetric. While the examples illustrate that the second communication winding is an interleaved winding, it should be appreciated that the first communication winding may also be an interleaved winding.

[0405] Driver Side Communication Layers 1526d, 1526e, 1526f

[0406] Communication layers 1526d, 1526e, and 1526f are on the driver side of the switch controller 1400. The conductive paths disposed on the communication layers 1526d, 1526e, and 1526f correspond with the communication windings on the driver side of the switch controller 1400 for each communication link COM3, COM4, and COM5. In the example shown, conductive paths disposed on communication layers 1526d, 1526e, and 1526f correspond with the second communication winding 1422a, the second communication winding 1422b, and the first communication winding 1420c.

[0407] Second Communication Winding 1522a:

[0408] The second communication winding 1522a is disposed on communication layers 1526d, 1526e, and 1526f. The second communication winding 1522a is one example of the second communication winding 1422a of the communication link COM3 shown in FIG. 14. As

will be further discussed, the second communication winding 1522a is formed by several conductive paths on communication layer 1526d and 1526d and a conductive path on communication layer 1526f. The openings 234 on communication layers 1526d, 1526e, and 1526f are outside of the turns formed by the second communication winding 1522a. The axis G is outside the turns formed by the second communication winding 1522a.

[0409] The second communication winding 1522a is an interleaved winding. As will be further discussed, the conductive paths which form the turns of the second communication winding 1522a are alternately disposed between communication layers 1526d and 1526e. The second communication winding 1522a may be interleaved to balance the capacitive coupling between the second communication winding 1522a and its corresponding first communication winding 1520a. In addition, the turns of the second communication winding 1522a are substantially symmetric.

[0410] Second Communication Winding 1522b:

[0411] The second communication winding 1522b is disposed on communication layers 1526d, 1526e, and 1526f. The second communication winding 1522b is one example of the second communication winding 1422b of the communication link COM4 shown in FIG. 14. As will be further discussed, the second communication winding 1522b is formed by several conductive paths on communication layer 1526d, 1526e and a conductive path on communication layer 1526f. The openings 234 on communication layers 1526d, 1526e, and 1526f are outside of the turns formed by the second communication winding 1522b. The axis G is outside the turns formed by the second communication winding 1522b.

[0412] The second communication winding 1522b is an interleaved winding. As will be further discussed, the conductive paths which form the turns of the second communication winding 1522b are alternately disposed between communication layers 1526d and 1526e. In addition, the turns of the second communication winding 1522b are substantially symmetric. The second communication winding 1522b may be interleaved to balance the capacitive coupling between the second communication winding 1522b and its corresponding first communication winding 1520b.

[0413] When viewing the communication layers 1526d, 1526e, and 1526f towards the first lateral direction (x-axis), the second communication windings 1522a and 1522b are disposed on the right-hand side of opening 234. When viewing the communication layers 1526d, 1526e, and 1526f towards the second lateral direction (y-axis), the second communication winding 1522a is on the right-hand side of the second communication winding 1522b. The first communication winding 1520a substantially overlays the second communication winding 1522a in the first vertical direction (z-axis). The first communication

winding 1520b substantially overlays the second communication winding 1522b in the first vertical direction (z-axis).

[0414] First Communication Winding 1520c:

[0415] The first communication winding 1520c is disposed on communication layers 1526d and 1526e. The first communication winding 1520c is one example of the first communication winding 1420c of the communication link COM5 shown in FIG. 14. As will be further discussed, the first communication winding 1520c is formed by a conductive path on communication layer 1526d and a conductive path on communication layer 1526e.

[0416] The openings 234 on communication layers 1526d and 1526e are outside of the turns formed by the first communication winding 1520c. The axis G is outside the turns formed by the first communication winding 1520c. When viewing the communication layers 1526d and 1526e towards the first lateral direction (x-axis), the first communication winding 1520c is disposed on the left-hand side of the opening 234. The second communication winding 1522c substantially overlays the first communication winding 1520c in the first vertical direction (z-axis). As shown, the first communication winding 1520c is on the opposite side of opening 234 as the second communication windings 1522a, 1522b. However, it should be appreciated that the second communication windings 1522a, 1522b and the first communication winding 1520c may be disposed on other locations within the communication layers 1526d, 1526e, and 1526f.

[0417] The second communication windings 1522a, 1522b are shown on the same communication layers. The first communication winding 1520c are shown on the same communication layers as portions of the second communication windings 1522a, 1522b. However, it should be appreciated that these communication windings may be on different layers or a mix of the same and different layers.

[0418] Communication layers 1526a, 1526b, 1526c, 1526d, 1526e, and 1526f are portions 1526 of the multilayer circuit. In one example, the communication layers 1526a, 1526b, 1526c, 1526d, 1526e, and 1526f are layers in the same printed multilayer circuit board. In another example, the interface side communication layers, e.g., communication layers 1526a, 1526b, and 1526c, are layers of a first printed multilayer circuit board. The drier side communication layers, e.g., communication layers 1526d, 1526e, and 1526f are layers of a second printed multilayer circuit board. The first printed multilayer circuit board and the second printed multilayer circuit board may be adhered together to form the multilayer circuit. A layer of insulation may be placed between the first printed multilayer circuit board and the second printed multilayer circuit board.

[0419] For FIG. 16, the communication layers 1526a, 1526b, and 1526c are viewed in the same perspective as FIGS. 5A-5D, 8A-8D, 12A-12D, and 13A-13B. The thin solid line represents the outline for each layer and the thin dotted line illustrates the projection 335.

[0420] FIG. 16 is an illustrative top-down view of communication layers 1526a, 1526b, and 1526c of FIG. 15. Communication layers 1526a, 1526b include first communication windings 1520a, 1520b and portions of the second communication winding 1522c. Communication layer 1526c includes a portion of the second communication winding 1522c. FIG. 16 illustrates placement of the first communication windings 1520a, 1520b and second communication winding 1522c with respect to the projection 335.

[0421] First Communication Winding 1520a:

[0422] The first communication winding 1520a is disposed in the communication layer 1526a and 1526b. The first communication winding 1520a is substantially within the projection 335 for both communication layers 1526a, 1526b. The first communication winding 1520a is substantially below the opening 234 in the second lateral direction (y-axis) for both communication layers 1526a, 1526b. The first communication winding 1520a is disposed on the right-hand side of the first communication winding 1520b for both communication layers 1526a, 1526b.

[0423] The solid lines which illustrate the first communication winding 1520a on both communication layers 1526a, 1526b are also representative of the conductive paths which form the first communication winding 1520a. The circles represent ends of the conductive paths which may couple to other layers with vias. On communication layer 1526a, the first communication winding 1520a spirals inward from an outer end to an inner end. On communication layer 1526a, the first communication winding 1520a spirals inward in a clockwise direction from an outer end to an inner end. The portion of the first communication winding 1520a disposed on communication layer 1526a is coupled to the portion of the first communication winding 1520a disposed on communication layer 1526b. As shown, the inner end of the first communication winding 1520a disposed on communication layer 1526a is coupled to the inner end of first communication winding 1520a disposed on communication layer 1526b. On communication layer 1526b, the first communication winding 1520a spirals outwards in a clockwise direction from the inner end to an outer end. It should be appreciated that the first communication winding 1520a may spiral in a counter-clockwise direction.

[0424] The first communication winding 1520a has substantially three turns on communication layer 1526a and three turns on communication layer 1526b. As such, the first communication winding 1520a has a total of six turns over two communication layers. However, it should be appreciated that the first communication winding 1520a may have any

number of turns. Further, while the first communication winding 1520a has the same number of turns in each communication layer, it should be appreciated that the number of turns per communication layer may not be the same.

[0425] The shape of the turns of first communication winding 1520a is substantially square. The overall shape of the first communication winding 1520a is shown as a square spiral. However, it should be appreciated that that first communication winding 1520a may form other shapes, such as a rectangle or a circle. The first communication winding 1520a may also include jogs as shown and discussed with respect to FIGS. 6B-9.

[0426] The conductive path of the first communication winding 1520a on communication layer 1526a substantially overlays the conductive paths of the first communication winding 1520a on communication layer 1526b in the first vertical direction (z-axis). As such, each turn for the first communication winding 1520a on communication layer 1526a substantially overlays the respective turn of the first communication winding 1520a on communication layer 1526b.

[0427] First Communication Winding 1520b:

[0428] The first communication winding 1520b is disposed in the communication layer 1526a and 1526b. The first communication winding 1520b is substantially within the projection 335 for both communication layers 1526a, 1526b. The first communication winding 1520b is substantially below the opening 234 in the second lateral direction (y-axis) for both communication layers 1526a, 1526b. The first communication winding 1520b is disposed on the left-hand side of the first communication winding 1520a for both communication layers 1526a, 1526b.

[0429] The solid lines which illustrate the first communication winding 1520b on both communication layers 1526a, 1526b are also representative of the conductive paths which form the first communication winding 1520b. The circles represent ends of the conductive paths which may couple to other layers with vias. On communication layer 1526a, the first communication winding 1520b spirals inward from an outer end to an inner end. On communication layer 1526a, the first communication winding 1520b spirals inward in a clockwise direction from an outer end to an inner end. The portion of the first communication winding 1520b disposed on communication layer 1526b is coupled to the portion of the first communication winding 1520b disposed on communication layer 1526a. As shown, the inner end of the first communication winding 1520b disposed on communication layer 1526a is coupled to the inner end of first communication winding 1520b disposed on communication layer 1526b. On communication layer 1526b, the first communication winding 1520b spirals

outwards in a clockwise direction from the inner end to an outer end. It should be appreciated that the first communication winding 1520b may spiral in a counter-clockwise direction.

[0430] The first communication winding 1520b has substantially three turns on communication layer 1526a and three turns on communication layer 1526b. As such, the first communication winding 1520b has a total of six turns over two communication layers. However, it should be appreciated that the first communication winding 1520b may have any number of turns. Further, while the first communication winding 1520b has the same number of turns in each communication layer, it should be appreciated that the number of turns per communication layer may not be the same.

[0431] The shape of the turns of first communication winding 1520b is substantially square. The overall shape of the first communication winding 1520b is shown as a square spiral. However, it should be appreciated that that first communication winding 1520b may form other shapes, such as a rectangle or a circle. The first communication winding 1520b may also include jogs as shown and discussed with respect to FIGS. 6B-9.

[0432] The conductive path of the first communication winding 1520b on communication layer 1526a substantially overlays the conductive paths of the first communication winding 1520b on communication layer 1526b in the first vertical direction (z-axis). As such, each turn for the first communication winding 1520b on communication layer 1526a substantially overlays the respective turn of the first communication winding 1520b on communication layer 1526b.

[0433] Second Communication Winding 1522c:

[0434] The second communication winding 1522c is disposed in the communication layer 1526a, 1526b, and 1526c. The second communication winding 1522c is substantially within the projection 335 for communication layers 1526a, 1526b and 1526c. The second communication winding 1522c is substantially within the projection 335 and above the opening 234 in the second lateral direction (y-axis) for communication layers 1526a, 1526b, and 1526c.

[0435] The solid lines which illustrate the second communication winding 1522c on communication layers 1526a, 1526b, and 1526c are also representative of the conductive paths which form the second communication winding 1522c. The circles represent ends of the conductive paths which may couple to other layers with vias.

[0436] The conductive paths which form the second communication winding 1522c are interleaved between communication layers 1526a and 1526b. An outer conductive path refers to a conductive path which substantially surrounds another conductive path. An inner conductive path refers to a conductive path which is substantially surrounded by another conductive path. On communication layer 1526b, the outer conductive path of the second communication

winding 1522c is wound in a clockwise direction. The outer conductive path of the second communication winding 1522c on communication layer 1526b couples to an inner conductive path on the communication layer 1526a. On communication layer 1526a, the inner conductive path of the second communication winding 1522c is wound in a clockwise direction. The inner conductive path of the second communication winding 1522c on the communication layer 1526a couples to a conductive path of the second communication winding 1522c on communication layer 1526c. The conductive path of the second communication winding 1522c on the communication layer 1526c couples to an outer conductive path of the second communication winding 1522c on communication layer 1526a. The outer conductive path of the second communication winding 1522c on communication layer 1526a is wound in a clockwise direction. The outer conductive path of the second communication winding 1522c on communication layer 1526a couples to an inner conductive path of the second communication winding 1522c on communication layer 1526b. On communication layer 1526b, the inner conductive path of the second communication winding 1522c is wound in a clockwise direction. It should be appreciated that the second communication winding 1522c may be wound in a counter-clockwise direction.

[0437] The second communication winding 1522c has substantially two turns on communication layer 1526a and two turns on communication layer 1526b. As such, the second communication winding 1522c has a total of four turns over three communication layers. However, it should be appreciated that the second communication winding 1522c may have any number of turns. Further, while the second communication winding 1522c has the same number of turns in each communication layer, it should be appreciated that the number of turns per communication layer may not be the same.

[0438] The shape of the turns of second communication winding 1522c is substantially square. The overall shape of the second communication winding 1522c is shown as a square. However, it should be appreciated that that second communication winding 1522c may form other shapes, such as a rectangle or a circle. The second communication winding 1522c may also include jogs as shown and discussed with respect to FIGS. 6B-9.

[0439] The conductive path of the second communication winding 1522c on communication layer 1526a substantially overlays the conductive paths of second communication winding 1522c on communication layer 1526b in the first vertical direction (z-axis). As such, each turn for the second communication winding 1522c on communication layer 1526a substantially overlays the respective turn of the second communication winding 1522c on communication layer 1526b. For the example shown, an outer conductive path on communication layer 1526a substantially overlays an outer conductive path on communication

layer 1526b. Similarly, an inner conductive path on communication layer 1526a substantially overlays an inner conductive path on communication layer 1526b.

[0440] The first communication windings 1520a, 1520b and the second communication winding 1522c are shown as wound in a clockwise direction. However, it should be appreciated that these windings may be wound in a counter-clockwise direction. In addition, these windings need not all be wound in the same direction. For example, the first communication winding 1520a may be wound in a clockwise direction while first communication winding 1520b and second communication winding 1522c may be wound in a counter-clockwise direction.

[0441] In FIG. 17, the communication layers 1526a, 1526b, and 1526c are a zoomed-in view of the layers shown in FIG. 16. The communication layers 1526a, 1526b, and 1526c are viewed in the plane of the first lateral direction (x-axis) and the second lateral direction (y-axis). The first lateral direction (x-axis) is shown as traversing the page from left to right while the second lateral direction (y-axis) is shown as traversing the page from bottom to top. The first vertical direction (z-axis) is pointing out of the page.

[0442] Further, FIG. 17 is utilized to illustrate an example coupling of the conductive paths of the first communication winding 1520a, first communication winding 1520b, and second communication winding 1522c. In FIG. 17, solid lines represent conductive paths. The circles, triangles, and squares are representative of ends of the conductive paths. In some cases, an end is coupled to another end on another communication layer by an interconnect, such as a via. A square represents a coupling down to the next layer in the first vertical direction (z-axis). A triangle represents a coupling which goes up to the next layer in the first vertical direction (z-axis). The hashed circles 1777c are ends which do not traverse their respective layer. It should be appreciated that the hashed circles may couple to ends in other communication layers through interconnects.

[0443] For the purposes of this disclosure, the direction in which a winding is wound is determined by the direction which a winding traverses its respective layer from the positive labeled terminal of the winding to the negative labeled terminal of the winding as shown in FIG. 14 and as viewed from the perspective of the page. However, it should be appreciated that different conventions may be utilized. For example, the direction in which the winding is wound may also be determined by the direction which the winding traverses its respective layer from the negative labeled terminal to the positive labeled terminal. In another example, the direction in which a winding is wound may be from an inner end to an outer end of the winding, or vice versa.

[0444] First Communication Winding 1520a:

[0445] The first communication winding 1520a includes conductive path 1762 and conductive path 1764. Conductive path 1762 is disposed on communication layer 1526a. Conductive path 1764 is disposed on communication layer 1526b. Conductive path 1762 includes end 1719a and end 1763a. Conductive path 1764 includes end 1763b and end 1721a. End 1719a corresponds with electrical node 1419a of the first communication winding 1420a of communication link COM3 shown in FIG. 14. End 1721a corresponds with electrical node 1421a of the first communication winding 1420a of communication link COM3 shown in FIG. 14. End 1719a is the positive labeled terminal of transmitter voltage V_{T1} while end 1721a is the negative labeled terminal of transmitter voltage V_{T1} .

[0446] For the example shown of the first communication winding 1520a, the communication layer 1526a may be referred to as a first communication layer and communication layer 1526b may be referred to as a third communication layer. Either of communication layers 1526d, 1526e, or 1526f may be referred to as a second communication layer. Further, the conductive path 1762 may be referred to as the first conductive path and conductive path 1764 may be referred to as a third conductive path.

[0447] Beginning on communication layer 1526a and end 1719a, the conductive path 1762 spirals inward from end 1719a to end 1763a. End 1719a is an outer end while end 1763a is an inner end. From end 1719a, the conductive path 1762 spirals inward in a clockwise direction to end 1763a. Each turn of conductive path 1762 is substantially square in shape. As shown, conductive path 1762 forms three turns of the first communication winding 1520a on communication layer 1526a.

[0448] End 1763a is shown as a square, indicating that the first communication winding 1520a continues downward (e.g., into the page) in the first vertical direction (z-axis) to communication layer 1526b. Conductive path 1762 couples to conductive path 1764. As shown, end 1763a of conductive path 1762 couples to end 1763b of conductive path 1764. End 1763a and end 1763b may be coupled through an interconnect. The interconnect is also often referred to as a via. Examples of interconnects include a plated through hole or a micro via. The interconnect traverses between communication layer 1526a and communication layer 1526b in the first vertical direction (z-axis).

[0449] On communication layer 1526b, the conductive path 1764 spirals outward from end 1763b towards end 1721a. End 1763b is an inner end while end 1721a is an outer end. Conductive path 1764 spirals outward in a clockwise direction from end 1763b to end 1721a. Each turn of conductive path 1764 is substantially square in shape. As shown, conductive path

1764 forms three turns of the first communication winding 1520a on communication layer 1526b. In total, first communication winding 1520a is shown with six turns.

[0450] First Communication Winding 1520b:

[0451] The first communication winding 1520b includes conductive path 1765 and conductive path 1767. Conductive path 1765 is disposed on communication layer 1526a. Conductive path 1767 is disposed on communication layer 1526b. Conductive path 1765 includes end 1719b and end 1766a. Conductive path 1767 includes end 1766b and end 1721b. End 1719b corresponds with electrical node 1419b of the first communication winding 1420b of communication link COM4 shown in FIG. 14. End 1721b corresponds with electrical node 1421b of the first communication winding 1420b of communication link COM4 shown in FIG. 14. End 1719b is the positive labeled terminal of transmitter voltage V_{T2} while end 1721b is the negative labeled terminal of transmitter voltage V_{T2} .

[0452] For the example shown of the first communication winding 1520b, the communication layer 1526a may be referred to as a first communication layer and communication layer 1526b may be referred to as a third communication layer. Either of communication layers 1526d, 1526e, or 1526f may be referred to as a second communication layer. Further, the conductive path 1765 may be referred to as the first conductive path and conductive path 1767 may be referred to as a third conductive path.

[0453] Beginning on communication layer 1526a and end 1719b, the conductive path 1765 spirals inward from end 1719b to end 1766a. End 1719b is an outer end while end 1766a is an inner end. From end 1719b, the conductive path 1765 spirals inward in a clockwise direction to end 1766a. Each turn of conductive path 1765 is substantially square in shape. As shown, conductive path 1765 forms three turns of the first communication winding 1520b on communication layer 1526a.

[0454] End 1766a is shown as a square, indicating that the first communication winding 1520b continues downward (e.g., into the page) in the first vertical direction (z-axis) to communication layer 1526b. Conductive path 1765 couples to conductive path 1767. As shown, end 1766a of conductive path 1765 couples to end 1766b of conductive path 1767. End 1766a and end 1766b may be coupled through an interconnect. The interconnect is also often referred to as a via. Examples of interconnects include a plated through hole or a micro via. The interconnect traverses between communication layer 1526a and communication layer 1526b in the first vertical direction (z-axis).

[0455] On communication layer 1526b, the conductive path 1767 spirals outward from end 1766b towards end 1721b. End 1766b is an inner end while end 1721b is an outer end. Conductive path 1767 spirals outward in a clockwise direction from end 1766b to end 1721b.

Each turn of conductive path 1767 is substantially square in shape. As shown, conductive path 1767 forms three turns of the first communication winding 1520ba on communication layer 1526b. In total, first communication winding 1520b is shown with six turns.

[0456] Second Communication Winding 1522c:

[0457] The second communication winding 1522c includes conductive paths 1768, 1770, 1772, 1774, and 1776. Conductive paths 1768 and 1776 are disposed on communication layer 1526b. Conductive path 1768 includes end 1723c and end 1769b. End 1723c corresponds with electrical node 1423c of second communication winding 1422c of communication link COM5 shown in FIG. 14. End 1723c corresponds with the positive labeled terminal of receiver voltage V_{R3} . Conductive path 1776 includes end 1775b and end 1777b. As will be further discussed, end 1777b corresponds with electrical node 1425c of the second communication winding 1422c of communication link COM5 shown in FIG. 14. End 1777b corresponds with the negative labeled terminal of receiver voltage V_{R3} .

[0458] Conductive paths 1770 and 1774 are disposed on communication layer 1526a. Conductive path 1770 includes end 1769a and 1771a. Conductive path 1774 includes end 1773a and end 1775a.

[0459] Conductive path 1772 is disposed on communication layer 1526c. Conductive path 1772 includes end 1771c and end 1773c. Further, a portion of the conductive path 1772 forms the tap for the second communication winding 1522c. As shown, conductive path 1772 couples to end 1761. End 1761 corresponds with electrical node 1461 of second communication winding 1422c of communication link COM5 shown in FIG. 14.

[0460] Conductive path 1778 is disposed on communication layer 1526a. Conductive path 1778 includes ends 1777a and end 1725c. End 1725c corresponds to electrical node 1425c of second communication winding 1422c of communication link COM5 shown in FIG. 14. End 1725c corresponds with the negative terminal of receiver voltage V_{R3} . End 1777b couples to end 1777a of conductive path 1776. As such, ends 1777a, end 1777b, and end 1725c correspond to the electrical node 1425c shown in FIG. 14. End 1777a, end 1777b, and end 1725c corresponds with the negative labeled terminal of receiver voltage V_{R3} . Conductive path 1778 traverses the communication layer 1526a towards the edge of communication layer 1526a. The additional ends and conductive path 1778 may be utilized such that the second communication winding 1522c may terminate in the desired location on communication layer 1526a or any other layer.

[0461] For the example shown, communication layer 1526b may be referred to as a second communication layer, communication layer 1526a may be referred to as a third communication layer and communication layer 1526c may be referred to as a fourth

communication layer. Either of communication layers 1526d or 1526e may be referred to as the first communication layer. Conductive path 1768 may be referred to as the second conductive path, conductive path 1770 may be referred to as the third conductive path, conductive path 1772 may be referred to as the fourth conductive path, conductive path 1774 may be referred to as the fifth conductive path, and conductive path 1776 may be referred to as the sixth conductive path.

[0462] The second communication winding 1522c is an interleaved winding. As will be discussed, the conductive paths which form the second communication winding 1522c are wound on alternate communication layers. An outer conductive path refers to a conductive path which substantially surrounds another conductive path. An inner conductive path refers to a conductive path which is substantially surrounded by another conductive path.

[0463] Beginning on communication layer 1526b and end 1723c, conductive path 1768 traverses the communication layer 1526b from end 1723c and is wound in a clockwise direction to end 1769b. The conductive path 1768 is an outer conductive path and substantially surrounds conductive path 1776. Conductive path 1768 substantially forms a square with an additional tail which traverses to the edge of communication layer 1526b. The square portion of conductive path 1768 substantially surrounds conductive path 1776. Conductive path 1768 forms one turn of the second communication winding 1522c.

[0464] End 1769b is shown as a triangle, indicating that the second communication winding 1522c continues up (e.g., out of the page) to the next communication layer 1526a. Conductive path 1768 couples to conductive path 1770 on communication layer 1526a. End 1769b couples to end 1769a. End 1769b and end 1769a couple through an interconnect. The interconnect traverses between communication layer 1526b and communication layer 1526a in the first vertical direction (z-axis).

[0465] On communication layer 1526a, conductive path 1770 is wound in a clockwise direction from end 1769a to end 1771a. The conductive path 1770 is an inner conductive path and is substantially inside conductive path 1774. Conductive path 1770 substantially forms a square. Conductive path 1770 forms one turn of the second communication winding 1522c.

[0466] Conductive path 1770 couples to conductive path 1772. End 1771a of conductive path 1770 is shown as a square, indicating that the second communication winding 1522c continues down (into the page) to next communication layer 1526b. End 1771a couples to end 1771b on communication layer 1526b. End 1771a and end 1771b couple through an interconnect which traverses between communication layer 1526a and 1526b. End 1771b is further shown as a square, indicating the second communication winding 1522c continues down (into the page) to the next communication layer 1526c. End 1771b couples to end 1771c on

communication layer 1526c. End 1771b and end 1771c couple through an interconnect which traverses between communication layer 1526b and 1526c.

[0467] On communication layer 1526c, conductive path 1772 diagonally traverses from end 1771c to end 1773c. Conductive path 1772 is coupled to conductive path 1774 on communication layer 1526a. End 1773c is shown as triangle, indicating that the second communication winding 1522c continues up (out of the page) to the next communication layer 1526b. End 1773c couples to end 1773b on communication layer 1526b. End 1773c and end 1773b couples through an interconnect which traverses between communication layer 1526c and 1526b. End 1773b is also shown as a triangle indicating that the second communication winding 1522c continues up (out of the page) to the next communication layer 1526a. End 1773b couples to end 1773a on communication layer 1526a. End 1773b and end 1773a couple through an interconnect which traverses between communication layer 1526b and 1526a.

[0468] Returning to communication layer 1526a, conductive path 1774 is wound in a clockwise direction from end 1773a to end 1775a. The conductive path 1774 is an outer conductive path and is substantially outside of conductive path 1770. Conductive path 1774 substantially forms a square. Conductive path 1774 forms one turn of the second communication winding 1522c.

[0469] End 1775a is shown as a square, indicating the second communication winding 1522c continues down (into the page) to the next communication layer 1526b. Conductive path 1774 is coupled to conductive path 1776. End 1775a couples to end 1775b on communication layer 1526b. End 1775a and end 1775b couple through an interconnect which traverses between communication layer 1526a and 1526b.

[0470] Returning to communication layer 1526b, conductive path 1776 is wound in a clockwise direction from end 1775b to end 1777b. The conductive path 1776 is an inner conductive path and is substantially inside conductive path 1768. Conductive path 1776 substantially forms a square. Conductive path 1776 forms one turn of the second communication winding 1522c. As shown, there are two turns on communication layer 1526a and two turns on communication layer 1526b. As such, the second communication winding 1522c is shown as having four turns.

[0471] End 1777b is shown as a triangle, indicating the second communication winding 1522c continues up (out the page) to the next communication layer 1526a. As discussed above, conductive path 1776 couples to conductive path 1778. End 1777b couples to end 1776a on communication layer 1526a. End 1777b and end 1777a couple through an interconnect which traverses between communication layer 1526b and 1526a. Conductive path 1778 traverses the communication layer 1526a towards the edge of communication layer 1526a. The additional

ends and conductive path 1778 may be utilized such that the second communication winding 1522c may terminate in the desired location on communication layer 1526a. It should be appreciated that the ends and conductive paths may be added or removed such that the second communication winding 1522c may be terminated on another communication layer. Conductive path 1778 may also be positioned such that noise immunity is increased and capacitive coupling is reduced.

[0472] As discussed, the direction of coupling is shown as beginning at end 1723c and completing at end 1725c. It should be appreciated that the description of the direction of coupling could have begun at end 1725c and completed at end 1723c.

[0473] Conductive path 1774 substantially overlays the square portion of conductive path 1768. Conductive path 1770 substantially overlays conductive path 1776. End 1769a substantially overlays end 1769b. End 1771a substantially overlays end 1771b and end 1771c. End 1773a substantially overlays end 1773b and end 1773c. End 1775a substantially overlays end 1775b. End 1777a substantially overlays end 1777b.

[0474] As mentioned above, the second communication winding 1522c is a receiver winding and may utilize a differential receiver structure. As such, noise experienced by the receiver windings (e.g., the second communication winding 1522a, 1522b, and 1522c) is likely common mode noise. The common mode noise may be magnetic or electric. An example magnetic noise may be noise which originates from the power windings 1404, 1406. Electric noise may include noise due to the power windings and to the voltage changes (dv/dt) on the driver side of the switch controller. The noise may also be noise external from the system controller. The interleaved structure may balance the parasitic coupling capacitance between windings. In one example, the interleaved structure may balance the parasitic coupling capacitance between the second communication winding 1522c and its corresponding first communication winding 1520c. Interleaved windings in a multilayer circuit may be difficult to implement due to the physical size of the interconnects.

[0475] For FIG. 18, the communication layers 1526d, 1526e, and 1526f are viewed in the same perspective as FIGS. 5A-5D, 8A-8D, 12A-12D, 13A-13B, and 16. The thin solid line illustrates the outline of each layer and thin dotted line illustrates the projection 335.

[0476] FIG. 18 is an illustrative top-down view of communication layers 1526d, 1526e, and 1526f of FIG. 15. Communication layers 1526d, 1526e include first communication winding 1520c and portions of the second communication windings 1522a, 1522b. Communication layer 1526f includes portions of the second communication windings 1522a, 1522b. FIG. 18 illustrates placement of the second communication windings 1522a, 1522b, and first communication winding 1520c with respect to the projection 335.

[0477] First Communication Winding 1520c:

[0478] The first communication winding 1520c is disposed in the communication layer 1526d and 1526e. The first communication winding 1520c is substantially within the projection 335 for both communication layers 1526d, 1526e. The first communication winding 1520c is substantially within the projection 335 and above the opening 234 in the second lateral direction (y-axis) for both communication layers 1526d, 1526e.

[0479] The solid lines which illustrate the first communication winding 1520c on both communication layers 1526d, 1526e are also representative of the conductive paths which form the first communication winding 1520c. The circles represent ends of the conductive paths which may couple to other layers with interconnects. On communication layer 1526d, the first communication winding 1520c spirals inward from an outer end to an inner end. On communication layer 1526e, the first communication winding 1520c spirals inward in a clockwise direction from an outer end to an inner end. The portion of the first communication winding 1520c disposed on communication layer 1526d is coupled to the portion of the first communication winding 1520c disposed on communication layer 1526e. As shown, the inner end of the first communication winding 1520c disposed on communication layer 1526d is coupled to the inner end of first communication winding 1520c disposed on communication layer 1526e. On communication layer 1526e, the first communication winding 1520c spirals outwards in a clockwise direction from the inner end to an outer end. It should be appreciated that the first communication winding 1520c may spiral in a counter-clockwise direction.

[0480] The first communication winding 1520c has substantially three turns on communication layer 1526d and three turns on communication layer 1526e. As such, the first communication winding 1520c has a total of six turns over two communication layers. However, it should be appreciated that the first communication winding 1520c may have any number of turns. Further, while the first communication winding 1520c has the same number of turns in each communication layer, it should be appreciated that the number of turns per communication layer may not be the same.

[0481] The shape of the turns of first communication winding 1520c is substantially square. The overall shape of the first communication winding 1520c is shown as a square spiral. However, it should be appreciated that that first communication winding 1520c may form other shapes, such as a rectangle or a circle. The first communication winding 1520c may also include jogs as shown and discussed with respect to FIGS. 6B-9.

[0482] The conductive path of the first communication winding 1520c on communication layer 1526d substantially overlays the conductive paths of the first communication winding 1520c on communication layer 1526e in the first vertical direction (z-

axis). As such, each turn for the first communication winding 1520c on communication layer 1526d substantially overlays the respective turn of the first communication winding 1520c on communication layer 1526e.

[0483] Second Communication Winding 1522a:

[0484] The second communication winding 1522a is disposed in the communication layer 1526d, 1526e, and 1526f. The second communication winding 1522a is substantially within the projection 335 for communication layers 1526d, 1526e, and 1526f. The second communication winding 1522a is substantially below the opening 234 in the second lateral direction (y-axis) for communication layers 1526d, 1526e, and 1526f. The second communication winding 1522a is shown on the right-hand side of second communication winding 1522b on communication layers 1526d, 1526e, and 1526f.

[0485] The solid lines which illustrate the second communication winding 1522a on communication layers 1526d, 1526e, and 1526f are also representative of the conductive paths which form the second communication winding 1522a. The circles represent ends of the conductive paths which may couple to other layers with interconnects.

[0486] The conductive paths which form the second communication winding 1522a are interleaved between communication layers 1526d and 1526e. An outer conductive path refers to a conductive path which substantially surrounds another conductive path. An inner conductive path refers to a conductive path which is substantially surrounded by another conductive path. On communication layer 1526d, the outer conductive path of the second communication winding 1522a is wound in a clockwise direction. The outer conductive path of the second communication winding 1522a on communication layer 1526d couples to an inner conductive path on the communication layer 1526e. On communication layer 1526e, the inner conductive path of the second communication winding 1522a is wound in a clockwise direction. The inner conductive path of the second communication winding 1522a on the communication layer 1526e couples to a conductive path of the second communication winding 1522a on communication layer 1526f. The conductive path of the second communication winding 1522a on the communication layer 1526f couples to an outer conductive path of the second communication winding 1522a on communication layer 1526e. The outer conductive path of the second communication winding 1522a on communication layer 1526e is wound in a clockwise direction. The outer conductive path of the second communication winding 1522a on communication layer 1526e couples to an inner conductive path of the second communication winding 1522a on communication layer 1526d. On communication layer 1526d, the inner conductive path of the second communication winding 1522a is wound in a clockwise direction. It should be

appreciated that the second communication winding 1522a may be wound in a counter-clockwise direction.

[0487] The second communication winding 1522a has substantially two turns on communication layer 1526d and two turns on communication layer 1526e. As such, the second communication winding 1522a has a total of four turns over three communication layers. However, it should be appreciated that the second communication winding 1522a may have any number of turns. Further, while the second communication winding 1522a has the same number of turns in each communication layer, it should be appreciated that the number of turns per communication layer may not be the same.

[0488] The shape of the turns of second communication winding 1522a is substantially square. The overall shape of the second communication winding 1522a is shown as a square. However, it should be appreciated that that second communication winding 1522a may form other shapes, such as a rectangle or a circle. The second communication winding 1522a may also include jogs as shown and discussed with respect to FIGS. 6B-9.

[0489] The conductive path of the second communication winding 1522a on communication layer 1526d substantially overlays the conductive paths of second communication winding 1522a on communication layer 1526e in the first vertical direction (z-axis). As such, each turn for the second communication winding 1522a on communication layer 1526d substantially overlays the respective turn of the second communication winding 1522a on communication layer 1526e. For the example shown, an outer conductive path on communication layer 1526d substantially overlays an outer conductive path on communication layer 1526e. Similarly, an inner conductive path on communication layer 1526d substantially overlays an inner conductive path on communication layer 1526e.

[0490] Second Communication Winding 1522b:

[0491] The second communication winding 1522b is disposed in the communication layer 1526d, 1526e, and 1526f. The second communication winding 1522b is substantially within the projection 335 for communication layers 1526d, 1526e, and 1526f. The second communication winding 1522b is substantially below the opening 234 in the second lateral direction (y-axis) for communication layers 1526d, 1526e, and 1526f. The second communication winding 1522b is shown on the left-hand side of second communication winding 1522a on communication layers 1526d, 1526e, and 1526f.

[0492] The solid lines which illustrate the second communication winding 1522b on communication layers 1526d, 1526e, and 1526f are also representative of the conductive paths which form the second communication winding 1522b. The circles represent ends of the conductive paths which may couple to other layers with interconnects.

[0493] The conductive paths which form the second communication winding 1522b are interleaved between communication layers 1526d and 1526e. On communication layer 1526d, the outer conductive path of the second communication winding 1522b is wound in a clockwise direction. The outer conductive path of the second communication winding 1522b on communication layer 1526d couples to an inner conductive path on the communication layer 1526e. On communication layer 1526e, the inner conductive path of the second communication winding 1522b is wound in a clockwise direction. The inner conductive path of the second communication winding 1522b on the communication layer 1526e couples to a conductive path of the second communication winding 1522b on communication layer 1526f. The conductive path of the second communication winding 1522b on the communication layer 1526f couples to an outer conductive path of the second communication winding 1522b on communication layer 1526e. The outer conductive path of the second communication winding 1522b on communication layer 1526e is wound in a clockwise direction. The outer conductive path of the second communication winding 1522b on communication layer 1526e couples to an inner conductive path of the second communication winding 1522b on communication layer 1526d. On communication layer 1526d, the inner conductive path of the second communication winding 1522b rotates in a clockwise direction. It should be appreciated that the second communication winding 1522a may be wound in a counter-clockwise direction.

[0494] The second communication winding 1522b has substantially two turns on communication layer 1526d and two turns on communication layer 1526e. As such, the second communication winding 1522b has a total of four turns over three communication layers. However, it should be appreciated that the second communication winding 1522b may have any number of turns. Further, while the second communication winding 1522b has the same number of turns in each communication layer, it should be appreciated that the number of turns per communication layer may not be the same.

[0495] The shape of the turns of second communication winding 1522b is substantially square. The overall shape of the second communication winding 1522b is shown as a square. However, it should be appreciated that that second communication winding 1522b may form other shapes, such as a rectangle or a circle. The second communication winding 1522b may also include jogs as shown and discussed with respect to FIGS. 6B-9.

[0496] The conductive path of the second communication winding 1522b on communication layer 1526d substantially overlays the conductive paths of second communication winding 1522b on communication layer 1526e in the first vertical direction (z-axis). As such, each turn for the second communication winding 1522b on communication layer 1526d substantially overlays the respective turn of the second communication winding 1522b on

communication layer 1526e. For the example shown, an outer conductive path on communication layer 1526d substantially overlays an outer conductive path on communication layer 1526e. Similarly, an inner conductive path on communication layer 1526d substantially overlays an inner conductive path on communication layer 1526e. Further, the second communication winding 1522a couples to the second communication winding 1522b on communication layer 1526f.

[0497] The second communication windings 1522a, 1522b and the first communication winding 1520c are shown as wound in a clockwise direction. However, it should be appreciated that these windings may be wound in a counter-clockwise direction. In addition, these windings need not all be wound in the same direction. For example, the second communication winding 1522a may be wound in a clockwise direction while second communication winding 1522b and first communication winding 1520c may be wound in a counter-clockwise direction.

[0498] For FIG. 19, the communication layers 1526d, 1526e, and 1526f are a zoomed in view of the layers in FIG. 18. Communication layers 1526d, 1526e, and 1526f are viewed in the plane of the first lateral direction (x-axis) and the second lateral direction (y-axis). The first lateral direction (x-axis) is shown as traversing the page from left to right while the second lateral direction (y-axis) is shown as traversing the page from bottom to top. The first vertical direction (z-axis) is pointing out of the page.

[0499] Further, FIG. 19 is utilized to illustrate an example coupling of the conductive paths of the first communication winding 1520c, second communication winding 1522a, and second communication winding 1522b. In FIG. 19, solid lines represent conductive paths. The circles, triangles, and squares are representative of ends of the conductive paths. In some cases, an end is coupled to another end on another communication layer utilizing an interconnect, such as a via. A square represents a coupling down to the next layer in the first vertical direction (z-axis). A triangle represents a coupling which goes up to the next layer in the first vertical direction (z-axis). The hashed circles are ends which do not traverse their respective layer. It should be appreciated that the hashed circles may couple to ends in other communication layers through interconnects.

[0500] First Communication Winding 1520c:

[0501] The first communication winding 1520c includes conductive path 1997 and conductive path 1999. Conductive path 1997 is disposed on communication layer 1526d. Conductive path 1999 is disposed on communication layer 1526e. Conductive path 1997 includes end 1919c and end 1998a. Conductive path 1999 includes end 1998b and end 1921c. End 1919c corresponds with electrical node 1419c of the first communication winding 1420c of communication link COM5 shown in FIG. 14. End 1921c corresponds with electrical node

1421c of the first communication winding 1420c of communication link COM5 shown in FIG.

14. End 1919c is the positive labeled terminal of transmitter voltage V_{T3} while end 1921c is the negative labeled terminal of transmitter voltage V_{T3} .

[0502] For the example shown of the first communication winding 1520c, the communication layer 1526d may be referred to as a first communication layer and communication layer 1526e may be referred to as a third communication layer. Either of communication layers 1526a, 1526b, or 1526c may be referred to as a second communication layer. Further, the conductive path 1997 may be referred to as the first conductive path and conductive path 1999 may be referred to as a third conductive path.

[0503] Beginning on communication layer 1526d and end 1919c, the conductive path 1997 spirals inward from end 1919c to end 1998a. End 1919c is an outer end while end 1763a is an inner end. Conductive path 1997 substantially forms a square with an additional tail which traverses to the edge of communication layer 1526d. From end 1919c, the conductive path 1997 travels toward the spiral and then spirals inward in a clockwise direction to end 1998a. Each turn of the conductive path 1997 is substantially square in shape. As shown, conductive path 1997 forms three turns of the first communication winding 1520c on communication layer 1526d.

[0504] End 1998a is shown as a square, indicating that the first communication winding 1520c continues downward (e.g., into the page) in the first vertical direction (z-axis) to communication layer 1526e. Conductive path 1997 couples to conductive path 1999. As shown, end 1998a of conductive path 1997 couples to end 1998b of conductive path 1999. End 1998a and end 1998b may be coupled through an interconnect. The interconnect traverses between communication layer 1526d and communication layer 1526e in the first vertical direction (z-axis).

[0505] On communication layer 1526e, the conductive path 1999 spirals outward from end 1998b towards end 1921c. End 1998b is an inner end while end 1921c is an outer end. Conductive path 1999 spirals outward in a clockwise direction from end 1998b to end 1921c. Conductive path 1999 substantially forms a square with an additional tail which traverses to the edge of communication layer 1526e. As shown, conductive path 1999 forms three turns of the first communication winding 1520c on communication layer 1526e. In total, first communication winding 1520c is shown with six turns. Each turn of conductive path 1999 is substantially square in shape.

[0506] Second Communication Winding 1522a:

[0507] The second communication winding 1522a includes conductive paths 1979, 1981, 1983, 1985, and 1987. Conductive paths 1979 and 1987 are disposed on communication

layer 1526d. Conductive path 1979 includes end 1923a and end 1980a. End 1923a corresponds with electrical node 1423a of second communication winding 1422a of communication link COM3 shown in FIG. 14. End 1923a corresponds with the positive labeled terminal of receiver voltage V_{R1} . Conductive path 1987 includes end 1986a and end 1925a. End 1925a corresponds with electrical node 1425a of the second communication winding 1422a of communication link COM3 shown in FIG. 14. End 1925a corresponds with the negative labeled terminal of receiver voltage V_{R1} . It should be appreciated that additional ends and conductive paths may be utilized such that the second communication winding 1522a may terminate in the desired location on communication layer 1526d or any other communication layer.

[0508] Conductive paths 1981 and 1985 are disposed on communication layer 1526e. Conductive path 1981 includes end 1980b and 1982b. Conductive path 1985 includes end 1984b and end 1986b.

[0509] Conductive path 1983 is disposed on communication layer 1526f. Conductive path 1983 includes end 1982c and end 1984c. Further, a portion of the conductive path 1983 forms the tap for the second communication winding 1522a. As shown, conductive path 1983 couples to end 1960. End 1960 corresponds with electrical node 1460 of second communication winding 1422a of communication link COM3 and second communication winding 1422b of communication link COM4 shown in FIG. 14. Further, conductive path 1983 may also form the tap for the second communication winding 1522b of communication link COM4 shown in FIG. 14. As shown, the conductive path 1983 traverses along the first lateral direction to couple the second communication winding 1522a and the second communication winding 1522b. The conductive path 1983 also traverses down the page towards end 1960.

[0510] For the example shown, communication layer 1526d may be referred to as a second communication layer, communication layer 1526e may be referred to as a third communication layer and communication layer 1526f may be referred to as a fourth communication layer. Either of communication layers 1526a or 1526b may be referred to as the first communication layer. Conductive path 1979 may be referred to as the second conductive path, conductive path 1981 may be referred to as the third conductive path, conductive path 1983 may be referred to as the fourth conductive path, conductive path 1985 may be referred to as the fifth conductive path, and conductive path 1987 may be referred to as the sixth conductive path.

[0511] The second communication winding 1522a is an interleaved winding. For an interleaved winding, the conductive paths which form the interleaved winding are wound in alternating layers. The conductive paths which form the second communication winding 1522a are wound on alternate communication layers.

[0512] Beginning on communication layer 1526d and end 1923a, conductive path 1979 traverses the communication layer 1526d from end 1923a and is wound in a clockwise direction to end 1980a. The conductive path 1979 is an outer conductive path and substantially surrounds conductive path 1987. Conductive path 1979 substantially forms a square with an additional tail which traverses to the edge of communication layer 1526d. The square portion of conductive path 1979 substantially surrounds the square portion of conductive path 1987. Conductive path 1979 forms one turn of the second communication winding 1522a.

[0513] End 1980a is shown as a square, indicating that the second communication winding 1522a continues down (e.g., into the page) to the next communication layer 1526e. Conductive path 1979 couples to conductive path 1981 on communication layer 1526e. End 1980a couples to end 1980b. End 1980a and end 1980b couple through an interconnect. The interconnect traverses between communication layer 1526d and communication layer 1526e in the first vertical direction (z-axis).

[0514] On communication layer 1526e, conductive path 1981 is wound in a clockwise direction from end 1980b to end 1982b. The conductive path 1981 is an inner conductive path and is substantially inside conductive path 1985. Conductive path 1981 substantially forms a square. Conductive path 1981 forms one turn of the second communication winding 1522a.

[0515] Conductive path 1981 couples to conductive path 1983. End 1982b of conductive path 1981 is shown as a square, indicating that the second communication winding 1522a continues down (into the page) to next communication layer 1526f. End 1982b couples to end 1982c on communication layer 1526f. End 1982b and end 1982c couple through an interconnect which traverses between communication layer 1526e and 1526f.

[0516] On communication layer 1526f, conductive path 1983 diagonally traverses from end 1982c to end 1984c. Conductive path 1983 is coupled to conductive path 1985 on communication layer 1526e. End 1984c is shown as triangle, indicating that the second communication winding 1522a continues up (out of the page) to the next communication layer 1526e. End 1984c couples to end 1984b on communication layer 1526e. End 1984c and end 1984b couples through an interconnect which traverses between communication layer 1526f and 1526e.

[0517] Returning to communication layer 1526e, conductive path 1985 is wound in a clockwise direction from end 1984b to end 1986b. The conductive path 1985 is an outer conductive path and is substantially outside of conductive path 1981. Conductive path 1985 substantially forms a square. Conductive path 1985 forms one turn of the second communication winding 1522a.

[0518] End 1986b is shown as a triangle, indicating the second communication winding 1522a continues up (out of the page) to the next communication layer 1526d. Conductive path 1985 is coupled to conductive path 1987. End 1986b couples to end 1986a on communication layer 1526d. End 1986b and end 1986a couple through an interconnect which traverses between communication layer 1526e and 1526d.

[0519] Returning to communication layer 1526d, conductive path 1987 is wound in a clockwise direction from end 1986a to end 1925a. The conductive path 1987 is an inner conductive path and is substantially inside conductive path 1979. Conductive path 1987 substantially forms a square with an additional tail which traverses to the edge of communication layer 1526d. The square portion of conductive path 1987 is substantially inside the square portion of conductive path 1979. Conductive path 1987 forms one turn of the second communication winding 1522a. As shown, there are two turns on communication layer 1526d and two turns on communication layer 1526e. As such, the second communication winding 1522a is shown as having four turns.

[0520] As discussed, the direction of coupling is shown as beginning at end 1923a and completing at end 1925a. It should be appreciated that the description of the direction of coupling could have begun at end 1925a and completed at end 1923a.

[0521] The square portion of conductive path 1979 substantially overlays conductive path 1985. The square portion of Conductive path 1987 substantially overlays conductive path 1981. End 1980a substantially overlays end 1980b. End 1982b substantially overlays end 1982c. End 1984b substantially overlays end 1984c. End 1986a substantially overlays end 1986b.

[0522] As mentioned above, the second communication winding 1522a is a receiver winding and may utilize a differential receiver structure. As such, noise experienced by the receiver winding is likely common mode noise. The common mode noise may be due to the power windings, dv/dt noise on the driver side of the switch controller, or external from the switch controller. The interleaved structure may balance the parasitic coupling capacitance between windings. In particular, the interleaved structure may balance the parasitic coupling capacitance between the second communication winding 1522a and its corresponding first communication winding 1520a.

[0523] Second Communication Winding 1522b:

[0524] The second communication winding 1522b includes conductive paths 1988, 1990, 1983, 1994, and 1996. Conductive paths 1988 and 1996 are disposed on communication layer 1526d. Conductive path 1988 is an outer conductive path while conductive 1996 is an inner conductive path. Conductive path 1988 includes end 1923b and end 1989a. End 1923b

corresponds with electrical node 1423b of second communication winding 1422b of communication link COM4 shown in FIG. 14. End 1923b corresponds with the positive labeled terminal of receiver voltage V_{R2} . Conductive path 1996 includes end 1995a and end 1925b. End 1925b corresponds with electrical node 1425b of the second communication winding 1422b of communication link COM4 shown in FIG. 14. End 1925b corresponds with the negative labeled terminal of receiver voltage V_{R2} . It should be appreciated that additional ends and conductive paths may be utilized such that the second communication winding 1522b may terminate in the desired location on communication layer 1526d or any other communication layer.

[0525] Conductive paths 1990 and 1994 are disposed on communication layer 1526e. Conductive path 1990 is an inner conductive path while conductive path 1994 is an outer conductive path. Conductive path 1990 includes end 1989b and 1991b. Conductive path 1994 includes end 1993b and end 1995b.

[0526] Conductive path 1983 is disposed on communication layer 1526f. Conductive path 1983 includes end 1991c and end 1993c.

[0527] For the example shown, communication layer 1526d may be referred to as a second communication layer, communication layer 1526e may be referred to as a third communication layer and communication layer 1526f may be referred to as a fourth communication layer. Either of communication layers 1526a or 1526b may be referred to as the first communication layer. Conductive path 1988 may be referred to as the second conductive path, conductive path 1990 may be referred to as the third conductive path, conductive path 1983 may be referred to as the fourth conductive path, conductive path 1994 may be referred to as the fifth conductive path, and conductive path 1996 may be referred to as the sixth conductive path.

[0528] The second communication winding 1522b is an interleaved winding. For an interleaved winding, the conductive paths which form the interleaved winding are wound in alternating layers. The conductive paths which form the second communication winding 1522b are wound on alternate communication layers.

[0529] As shown in the illustrated example, the conductive paths of second communication winding 1522b are laid out and intercouple in substantially the same manner as discussed with regard to the conductive paths of second communication winding 1522a.

[0530] As mentioned above, the second communication winding 1522b is a receiver winding and may utilize a differential receiver structure. As such, noise experienced by the receiver winding is likely common mode noise. The common mode noise may be due to the power windings, dv/dt noise on the driver side of the switch controller, or external from the

switch controller. The interleaved structure may balance the parasitic coupling capacitance between the second communication winding 1522b and its corresponding first communication winding 1520b.

[0531] FIG. 20 is a perspective view of the second communication winding 1522a illustrated in FIG. 18 and 19. Second communication winding 1522c is one example of communication winding 1422a of communication link COM3 shown in FIG. 14. It should be appreciated that FIG. 20 reproduces a portion of communication link COM3 for reference.

[0532] For FIG. 20, the conductive paths of the second communication winding 1522a are viewed in a perspective which the first lateral direction (x-axis) is pointing towards the bottom right of the page, the first lateral direction (y-axis) is pointing into and diagonally up the page, and the first vertical direction (z-axis) is pointing a little to the right towards the top of the page. Further, the tails of conductive path 1979 and 1989 are shown in this perspective for simplicity. Interconnects which couple ends between communication layers are also not shown for simplicity.

[0533] In each communication layer 1526d, 1526e, and 1526f, the various ends of the conductive paths are clustered together in substantially a square shape, with each end at one corner of the square. Although a square shape is shown, it should be appreciated that the various ends may be clustered in different shapes.

[0534] For communication layer 1526d, end 1980a is disposed on the bottom left corner, end 1982a is disposed on the bottom right corner, end 1984a is disposed on the top left corner, and end 1986a is disposed on top right corner. In other words, a line drawn from end 1984a to end 1986a is substantially parallel to a line drawn from end 1980a to 1982a.

[0535] For communication layer 1526e, end 1980b is disposed on the bottom left corner, end 1982b is disposed on the bottom right corner, end 1984b is disposed on the top left corner, and end 1986b is disposed on top right corner. In other words, a line drawn from end 1984b to end 1986b is substantially parallel to a line drawn from end 1980b to 1982b.

[0536] For communication layer 1526f, end 1980c is disposed on the bottom left corner, end 1982c is disposed on the bottom right corner, end 1984c is disposed on the top left corner, and end 1986c is disposed on top right corner. In other words, a line drawn from end 1984c to end 1986c is substantially parallel to a line drawn from end 1980c to 1982c.

[0537] As mentioned above, conductive path 1768 may be referred to as the second conductive path, conductive path 1770 may be referred to as the third conductive path, conductive path 1772 may be referred to as the fourth conductive path, conductive path 1774 may be referred to as the fifth conductive path, and conductive path 1776 may be referred to as the sixth conductive path.

[0538] Beginning on communication layer 1526d and end 1923a, conductive path 1979 substantially forms a square from end 1923a to end 1980a. Conductive path 1979 substantially surrounds conductive path 1987. Conductive path 1979 forms one turn of the second communication winding 1522a.

[0539] Conductive path 1979 couples to conductive path 1981 on communication layer 1526e. End 1980a and end 1980b couple through an interconnect which traverses between the communication layer 1526d and 1526e.

[0540] On communication layer 1526e, conductive path 1981 substantially forms a square from end 1980b to end 1982b. End 1980b and end 1982b are on the same reference line and as such conductive path 1981 substantially forms one turn of the second communication winding 1522a.

[0541] Conductive path 1981 couples to conductive path 1983 on communication layer 1526f. End 1982b couples to end 1982c through an interconnect which traverses between communication layer 1526e and 1526f.

[0542] On communication layer 1526f, conductive path 1983 diagonally traverses from end 1982c to end 1984c. As shown, conductive path 1983 diagonally traverses from the bottom right to the top left of the grouped ends 1980c, 1982c, 1984c, and 1986c.

[0543] Conductive path 1983 is coupled to conductive path 1985 on communication layer 1526e. End 1984c and end 1984b couple through an interconnect which traverses between communication layer 1526f and 1526e.

[0544] Returning to communication layer 1526e, conductive path 1985 substantially forms a square from end 1984b to end 1986b. End 1984b and end 1986b are on the same reference line and as such conductive path 1985 substantially forms one turn of the second communication winding 1522a.

[0545] Conductive path 1985 is coupled to conductive path 1987 on communication layer 1526d. End 1986b and end 1986a couple through an interconnect which traverses between communication layer 1526e and 1526d.

[0546] Returning to communication layer 1526d, conductive path 1987 substantially forms a square from end 1986a to end 1925a. Conductive path 1987 forms one turn of the second communication winding 1522a.

[0547] Various embodiments of an integrated energy transfer element and communication link in the same magnetic assembly have been discussed here. It should be appreciated that one portion of one embodiment may be used with another portion of another embodiment. For example, the first communication winding 620 of FIG. 8C may be used with the second communication winding 1122 and first enhancement winding 1144 of FIG. 12B.

[0548] 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.

[0549] 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.

[0550] 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.

[0551] 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:

[0552] Example 1. A multilayer circuit for a magnetic assembly comprising an opening configured to receive a core of the magnetic assembly; a first power layer comprising at least a portion of a first power winding, wherein the portion of the first power winding spans a winding area and the opening is inside the portion of the first power winding; a second power layer comprising at least a portion of a second power winding magnetically coupled to the portion of the first power winding, wherein the opening is inside the portion of the second power winding; a first communication layer comprising a first conductive path arranged substantially within a projection of the winding area, wherein the opening is outside the first conductive path; and a second communication layer disposed proximate to the first communication layer and comprising a second conductive path arranged substantially within the projection of the winding area, wherein the opening is outside the second conductive path and the first conductive path and the second conductive path are magnetically coupled to provide a communication link.

[0553] Example 2. The multilayer circuit of example 1, wherein the portion of the first power winding and the portion of the second power winding are configured to be magnetically coupled such that the core increases the magnetic coupling; and the first conductive path and the second conductive path are configured to be magnetically coupled substantially independent of the core.

[0554] Example 3. The multilayer circuit of example 1 or 2, wherein the portion of the first power winding is an input winding of an energy transfer element and the portion of the second power winding is an output winding of an energy transfer element.

[0555] Example 4. The multilayer circuit of any one of examples 1 to 3, wherein the opening is inside a first turn formed by the portion of the first power winding; the opening is inside a second turn formed by the portion of the second power winding; and the first conductive path and the second conductive path do not surround the opening.

[0556] Example 5. The multilayer circuit of any one of examples 1 to 4, wherein the first conductive path and the second conductive path substantially overlay one another.

[0557] Example 6. The multilayer circuit of any one of examples 1 to 5, wherein the first conductive path and the second conductive path are arranged substantially in a first core window.

[0558] Example 7. The multilayer circuit of any one of examples 1 to 6, wherein the second conductive path is coupled with respect to the second power winding such that a voltage from a non-dot end to a dot-end of the second conductive path is opposite in polarity to a voltage from a dot-end to a non-dot end of the second power winding.

[0559] Example 8. The multilayer circuit of any one of examples 1 to 7, wherein the first conductive path comprises: a first partial loop disposed on a side of a reference line; and a second partial loop disposed on a opposite side of the reference line.

[0560] Example 9. The multilayer circuit of any one of examples 1 to 8, wherein a first area enclosed by the first partial loop and a reference line is substantially equal to a second area enclosed by the second partial loop and the reference line.

[0561] Example 10. The multilayer circuit of any one of examples 1 to 9, wherein a voltage induced in the first partial loop on the side of the reference line is substantially cancelled by a voltage induced on the second partial loop on the opposite side of the reference line.

[0562] Example 11. The multilayer circuit of any one of examples 1 to 10, wherein the reference line is substantially halfway between an inner conductor and an outer conductor of the portion of the first power winding.

[0563] Example 12. The multilayer circuit of any one of examples 1 to 11, wherein the first partial loop comprises at least one jog.

[0564] Example 13. The multilayer circuit of any one of examples 1 to 12, the second communication layer further comprising: a third conductive path wound in an opposite direction to the second conductive path to form a first enhancement winding.

[0565] Example 14. The multilayer circuit of any one of examples 1 to 13, wherein the second conductive path and the third conductive path form a first trace.

[0566] Example 15. The multilayer circuit of any one of examples 1 to 14, wherein the second communication winding is arranged substantially within a first core window and the first enhancement winding is arranged substantially within a second core window.

[0567] Example 16. The multilayer circuit of any one of examples 1 to 15, the first communication layer further comprising: a fourth conductive path wound in the opposite direction of the first conductive path to form a second enhancement winding, wherein the third conductive path and the fourth conductive path substantially overlay one another.

[0568] Example 17. The multilayer circuit of any one of examples 1 to 16, wherein the first conductive path and the fourth conductive path form a second trace.

[0569] Example 18. The multilayer circuit of any one of examples 1 to 18, wherein the first communication winding is arranged substantially within a first core window and the second enhancement winding is arranged substantially within a second core window.

[0570] Example 19. The multilayer circuit of any one of examples 1 to 18, wherein, the first communication layer further comprises: a third conductive path arranged substantially within the projection of the winding area to form a third communication winding; and the second communication layer further comprises: a fourth conductive path arranged substantially

within the projection of the winding area to form a fourth communication winding, wherein the third conductive path and the fourth conductive path are magnetically coupled to provide a second communication link.

[0571] Example 20. The multilayer circuit of any one of examples 1 to 19, wherein the third conductive path and the fourth conductive path substantially overlay one another.

[0572] Example 21. The multilayer circuit of any one of examples 1 to 20, further comprising: a third communication layer comprising a third conductive path arranged substantially within the projection of the winding area, wherein the third conductive path is coupled to the first conductive path to form the first communication winding.

[0573] Example 22. The multilayer circuit of any one of examples 1 to 21, wherein the first conductive path and the third conductive path substantially overlay one another.

[0574] Example 23. The multilayer circuit of any one of examples 1 to 22, further comprising: a third communication layer comprising a third conductive path arranged substantially within the projection of the winding area and the second conductive path is coupled to the third conductive path; and a fourth communication layer comprising a fourth conductive path arranged substantially within the projection of the winding area and the third conductive path is coupled to the fourth conductive path, wherein the third communication layer further comprises a fifth conductive path arranged substantially within the projection of the winding area and the fourth conductive path is coupled to the fifth conductive path; and the second communication layer further comprises a sixth conductive path arranged substantially within the projection of the winding area and the fifth conductive path is coupled to the sixth conductive path.

[0575] Example 24. The multilayer circuit of any one of examples 1 to 23, wherein: the second conductive path substantially overlays the fifth conductive path; and the third conductive path substantially overlays the sixth conductive path.

[0576] Example 25. The multilayer circuit of any one of examples 1 to 24, wherein: the second conductive path substantially surrounds the sixth conductive path; and the fifth conductive path substantially surrounds the third conductive path.

[0577] Example 26 The multilayer circuit of claim 1, wherein the core comprises a material of relatively high magnetic permeability.

[0578] Example 27. A planar energy transfer element comprising: a magnetic core; a multilayer circuit, comprising: an opening configured to receive the magnetic core; a first power winding, wherein the first power winding spans a winding area and the opening is inside the first power winding; a second power winding magnetically coupled to the first power winding and the opening is inside the second power winding; and a first communication link arranged

substantially within a projection of the winding area of the first power winding, wherein the first communication link comprises: a first communication winding arranged substantially within the projection of the winding area, wherein the opening is outside of the first communication winding; and a second communication winding arranged substantially within the projection of the winding area, wherein the first communication winding and the second communication winding are magnetically coupled and the opening is outside of the second communication winding.

[0579] Example 28. The planar energy transfer element of example 27, wherein the first power winding and the second power winding are magnetically coupled such that the magnetic core increases the magnetic coupling and the first communication winding and the second communication winding are magnetically coupled substantially independent of the magnetic core.

[0580] Example 29. The planar energy transfer element of example 27 or 28, wherein the first power winding is an input winding of the planar energy transfer element and the second power winding is an output winding of the planar energy transfer element.

[0581] Example 30. The planar energy transfer element of any one of examples 27 to 29, wherein: the opening is inside a first turn formed by the first power winding; the opening is inside a second turn formed by the second power winding; and the first communication winding and the second communication winding do not encircle the opening.

[0582] Example 31. The planar energy transfer element of any one of examples 27 to 30, wherein the first communication winding and the second communication winding substantially overlay one another.

[0583] Example 32. The planar energy transfer element of any one of examples 27 to 31, wherein the first communication winding and the second communication winding are arranged substantially in a first core window.

[0584] Example 33. The planar energy transfer element of any one of examples 27 to 32, wherein the second communication winding is coupled with respect to the second power winding such that a voltage from a non-dot end to a dot-end of the second communication winding is opposite in polarity to a voltage from a dot-end to a non-dot end of the second power winding.

[0585] Example 34. The planar energy transfer element of any one of examples 27 to 33, wherein the first communication winding comprises a plurality of partial loops, wherein a first partial loop is on a side of a reference line and a second partial loop is on an opposite side of the reference line.

[0586] Example 35. The planar energy transfer element of any one of examples 27 to 34, wherein a first area enclosed by the first partial loop and the reference line is substantially equal to a second area enclosed by the second partial loop and the reference line.

[0587] Example 36. The planar energy transfer element of any one of examples 27 to 35, wherein a voltage induced in the first partial loop on the side of the reference line is substantially cancelled by a voltage induced on the second partial loop on the opposite side of the reference line.

[0588] Example 37. The planar energy transfer element of any one of examples 27 to 36, wherein the reference line is substantially halfway between an inner conductor and an outer conductor of the first power winding.

[0589] Example 38. The planar energy transfer element of any one of examples 27 to 37, further comprising: a first enhancement winding coupled to the second communication winding, wherein the first enhancement winding is wound in an opposite direction of the second communication winding.

[0590] Example 39. The planar energy transfer element of any one of examples 27 to 38, wherein the second communication winding is arranged substantially within a first core window and the first enhancement winding is arranged substantially within a second core window.

[0591] Example 40. The planar energy transfer element of any one of examples 27 to 39, further comprising: a second enhancement winding coupled to the first communication winding, wherein the second enhancement winding is wound in the opposite direction of the first communication winding and the second enhancement winding and the first enhancement winding substantially overlay one another.

[0592] Example 41. The planar energy transfer element of any one of examples 27 to 40, wherein the first communication winding is arranged substantially in a first core window and the second enhancement winding is arranged substantially within a second core window.

[0593] Example 42. The planar energy transfer element of any one of examples 27 to 41, further comprising: a second communication link arranged substantially within the projection of the winding area of the first power winding, wherein the second communication link comprises: a third communication winding arranged substantially within the projection of the winding area, wherein the opening is outside the third communication winding; and a fourth communication winding arranged substantially within the projection of the winding area, wherein the third communication winding and the fourth communication winding are magnetically coupled and the opening is outside the fourth communication winding.

[0594] Example 43. The planer energy transfer element of any one of examples 27 to 42, wherein the second communication winding is disposed on at least two layers of the

multilayer circuit board and turns of the second communication winding are substantially symmetric and interleaved between the at least two layers of the multilayer circuit board.

[0595] Example 44. The planar energy transfer element of any one of examples 27 to 43, wherein: the first communication winding comprises a first conductive path disposed on a first layer of the multilayer circuit; and the second communication winding comprises a second conductive path disposed on a second layer of the multilayer circuit.

[0596] Example 45. The planar energy transfer element of any one of examples 27 to 44, wherein the first communication winding further comprises: a third conductive path disposed on a third layer of the multilayer circuit, wherein the first conductive path is coupled to the third conductive path.

[0597] Example 46. The planar energy transfer element of any one of examples 27 to 45, wherein the first conductive path and the third conductive path substantially overlay one another.

[0598] Example 47. The planar energy transfer element of any one of examples 27 to 46, wherein the second communication winding further comprises: a third conductive path disposed on a third layer of the multilayer circuit and coupled to the second conductive path; a fourth conductive path disposed on a fourth layer of the multilayer circuit and coupled to the third conductive path; a fifth conductive path disposed on the third layer and coupled to the fourth conductive path; and a sixth conductive path disposed on the second layer and coupled to the fifth conductive path.

[0599] Example 48. The planar energy transfer element of any one of examples 27 to 47, wherein: the second conductive path substantially overlays the fifth conductive path; and the third conductive path substantially overlays the sixth conductive path.

[0600] Example 49. The planar energy transfer element of any one of examples 27 to 48, wherein: the second conductive path substantially surrounds the sixth conductive path; and the fifth conductive path substantially surrounds the third conductive path.

CLAIMS

What is claimed is:

1. A multilayer circuit for a magnetic assembly comprising:
 - an opening configured to receive a core of the magnetic assembly;
 - a first power layer comprising at least a portion of a first power winding, wherein the portion of the first power winding spans a winding area and the opening is inside the portion of the first power winding;
 - a second power layer comprising at least a portion of a second power winding magnetically coupled to the portion of the first power winding, wherein the opening is inside the portion of the second power winding;
 - a first communication layer comprising a first conductive path arranged substantially within a projection of the winding area, wherein the opening is outside the first conductive path; and
 - a second communication layer disposed proximate to the first communication layer and comprising a second conductive path arranged substantially within the projection of the winding area, wherein the opening is outside the second conductive path and the first conductive path and the second conductive path are magnetically coupled to provide a communication link.
2. The multilayer circuit of claim 1, wherein:
 - the portion of the first power winding and the portion of the second power winding are configured to be magnetically coupled such that the core increases the magnetic coupling; and
 - the first conductive path and the second conductive path are configured to be magnetically coupled substantially independent of the core.
3. The multilayer circuit of claim 1, wherein the portion of the first power winding is an input winding of an energy transfer element and the portion of the second power winding is an output winding of an energy transfer element.
4. The multilayer circuit of claim 1, wherein:
 - the opening is inside a first turn formed by the portion of the first power winding;
 - the opening is inside a second turn formed by the portion of the second power winding; and
 - the first conductive path and the second conductive path do not surround the opening.

5. The multilayer circuit of claim 1, wherein the first conductive path and the second conductive path substantially overlay one another.
6. The multilayer circuit of claim 1, wherein the first conductive path and the second conductive path are arranged substantially in a first core window.
7. The multilayer circuit of claim 1, wherein the second conductive path is coupled with respect to the second power winding such that a voltage from a non-dot end to a dot-end of the second conductive path is opposite in polarity to a voltage from a dot-end to a non-dot end of the second power winding.
8. The multilayer circuit of claim 1, wherein the first conductive path comprises:
a first partial loop disposed on a side of a reference line; and
a second partial loop disposed on a opposite side of the reference line.
9. The multilayer circuit of claim 8, wherein a first area enclosed by the first partial loop and a reference line is substantially equal to a second area enclosed by the second partial loop and the reference line.
10. The multilayer circuit of claim 8, wherein a voltage induced in the first partial loop on the side of the reference line is substantially cancelled by a voltage induced on the second partial loop on the opposite side of the reference line.
11. The multilayer circuit of claim 8, wherein the reference line is substantially halfway between an inner conductor and an outer conductor of the portion of the first power winding.
12. The multilayer circuit of claim 8, wherein the first partial loop comprises at least one jog.
13. The multilayer circuit of claim 1, the second communication layer further comprising:
a third conductive path wound in an opposite direction to the second conductive path to form a first enhancement winding.

14. The multilayer circuit of claim 13, wherein the second conductive path and the third conductive path form a first trace.

15. The multilayer circuit of claim 13, wherein the second communication winding is arranged substantially within a first core window and the first enhancement winding is arranged substantially within a second core window.

16. The multilayer circuit of claim 13, the first communication layer further comprising:

a fourth conductive path wound in the opposite direction of the first conductive path to form a second enhancement winding, wherein the third conductive path and the fourth conductive path substantially overlay one another.

17. The multilayer circuit of claim 16, wherein the first conductive path and the fourth conductive path form a second trace.

18. The multilayer circuit of claim 16, wherein the first communication winding is arranged substantially within a first core window and the second enhancement winding is arranged substantially within a second core window.

19. The multilayer circuit of claim 1, wherein,
the first communication layer further comprises:

a third conductive path arranged substantially within the projection of the winding area to form a third communication winding; and

the second communication layer further comprises:

a fourth conductive path arranged substantially within the projection of the winding area to form a fourth communication winding, wherein the third conductive path and the fourth conductive path are magnetically coupled to provide a second communication link.

20. The multilayer circuit of claim 19, wherein the third conductive path and the fourth conductive path substantially overlay one another.

21. The multilayer circuit of claim 1, further comprising:
a third communication layer comprising a third conductive path arranged substantially within the projection of the winding area, wherein the third conductive path is coupled to the first conductive path to form the first communication winding.
22. The multilayer circuit of claim 21, wherein the first conductive path and the third conductive path substantially overlay one another.
23. The multilayer circuit of claim 1, further comprising:
a third communication layer comprising a third conductive path arranged substantially within the projection of the winding area and the second conductive path is coupled to the third conductive path; and
a fourth communication layer comprising a fourth conductive path arranged substantially within the projection of the winding area and the third conductive path is coupled to the fourth conductive path, wherein
the third communication layer further comprises a fifth conductive path arranged substantially within the projection of the winding area and the fourth conductive path is coupled to the fifth conductive path; and
the second communication layer further comprises a sixth conductive path arranged substantially within the projection of the winding area and the fifth conductive path is coupled to the sixth conductive path.
24. The multilayer circuit of claim 23, wherein:
the second conductive path substantially overlays the fifth conductive path; and
the third conductive path substantially overlays the sixth conductive path.
25. The multilayer circuit of claim 23, wherein:
the second conductive path substantially surrounds the sixth conductive path; and
the fifth conductive path substantially surrounds the third conductive path.
26. The multilayer circuit of claim 1, wherein the core comprises a material of relatively high magnetic permeability.

27. A planar energy transfer element comprising:
a magnetic core;
a multilayer circuit, comprising:
an opening configured to receive the magnetic core;
a first power winding, wherein the first power winding spans a winding area and the opening is inside the first power winding;
a second power winding magnetically coupled to the first power winding and the opening is inside the second power winding; and
a first communication link arranged substantially within a projection of the winding area of the first power winding, wherein the first communication link comprises:
a first communication winding arranged substantially within the projection of the winding area, wherein the opening is outside of the first communication winding; and
a second communication winding arranged substantially within the projection of the winding area, wherein the first communication winding and the second communication winding are magnetically coupled and the opening is outside of the second communication winding.

28. The planar energy transfer element of claim 27, wherein the first power winding and the second power winding are magnetically coupled such that the magnetic core increases the magnetic coupling and the first communication winding and the second communication winding are magnetically coupled substantially independent of the magnetic core.

29. The planar energy transfer element of claim 27, wherein the first power winding is an input winding of the planar energy transfer element and the second power winding is an output winding of the planar energy transfer element.

30. The planar energy transfer element of claim 27, wherein:
the opening is inside a first turn formed by the first power winding;
the opening is inside a second turn formed by the second power winding; and
the first communication winding and the second communication winding do not encircle the opening.

31. The planar energy transfer element of claim 27, wherein the first communication winding and the second communication winding substantially overlay one another.

32. The planar energy transfer element of claim 27, wherein the first communication winding and the second communication winding are arranged substantially in a first core window.

33. The planar energy transfer element of claim 27, wherein the second communication winding is coupled with respect to the second power winding such that a voltage from a non-dot end to a dot-end of the second communication winding is opposite in polarity to a voltage from a dot-end to a non-dot end of the second power winding.

34. The planar energy transfer element of claim 27, wherein the first communication winding comprises a plurality of partial loops, wherein a first partial loop is on a side of a reference line and a second partial loop is on an opposite side of the reference line.

35. The planar energy transfer element of claim 34, wherein a first area enclosed by the first partial loop and the reference line is substantially equal to a second area enclosed by the second partial loop and the reference line.

36. The planar energy transfer element of claim 34, wherein a voltage induced in the first partial loop on the side of the reference line is substantially cancelled by a voltage induced on the second partial loop on the opposite side of the reference line.

37. The planar energy transfer element of claim 34, wherein the reference line is substantially halfway between an inner conductor and an outer conductor of the first power winding.

38. The planar energy transfer element of claim 27, further comprising:
a first enhancement winding coupled to the second communication winding, wherein the first enhancement winding is wound in an opposite direction of the second communication winding.

39. The planar energy transfer element of claim 38, wherein the second communication winding is arranged substantially within a first core window and the first enhancement winding is arranged substantially within a second core window.

40. The planar energy transfer element of claim 38, further comprising:
a second enhancement winding coupled to the first communication winding, wherein the second enhancement winding is wound in the opposite direction of the first communication winding and the second enhancement winding and the first enhancement winding substantially overlay one another.

41. The planar energy transfer element of claim 40, wherein the first communication winding is arranged substantially in a first core window and the second enhancement winding is arranged substantially within a second core window.

42. The planar energy transfer element of claim 27, further comprising:
a second communication link arranged substantially within the projection of the winding area of the first power winding, wherein the second communication link comprises:

a third communication winding arranged substantially within the projection of the winding area, wherein the opening is outside the third communication winding; and

a fourth communication winding arranged substantially within the projection of the winding area, wherein the third communication winding and the fourth communication winding are magnetically coupled and the opening is outside the fourth communication winding.

43. The planar energy transfer element of claim 27, wherein the second communication winding is disposed on at least two layers of the multilayer circuit board and turns of the second communication winding are substantially symmetric and interleaved between the at least two layers of the multilayer circuit board.

44. The planar energy transfer element of claim 27, wherein:
the first communication winding comprises a first conductive path disposed on a first layer of the multilayer circuit; and
the second communication winding comprises a second conductive path disposed on a second layer of the multilayer circuit.

45. The planar energy transfer element of claim 44, wherein the first communication winding further comprises:
a third conductive path disposed on a third layer of the multilayer circuit, wherein the first conductive path is coupled to the third conductive path.

46. The planar energy transfer element of claim 45, wherein the first conductive path and the third conductive path substantially overlay one another.

47. The planar energy transfer element of claim 44, wherein the second communication winding further comprises:

a third conductive path disposed on a third layer of the multilayer circuit and coupled to the second conductive path;

a fourth conductive path disposed on a fourth layer of the multilayer circuit and coupled to the third conductive path;

a fifth conductive path disposed on the third layer and coupled to the fourth conductive path; and

a sixth conductive path disposed on the second layer and coupled to the fifth conductive path.

48. The planar energy transfer element of claim 47, wherein:
the second conductive path substantially overlays the fifth conductive path; and
the third conductive path substantially overlays the sixth conductive path.

49. The planar energy transfer element of claim 47, wherein:
the second conductive path substantially surrounds the sixth conductive path; and
the fifth conductive path substantially surrounds the third conductive path.

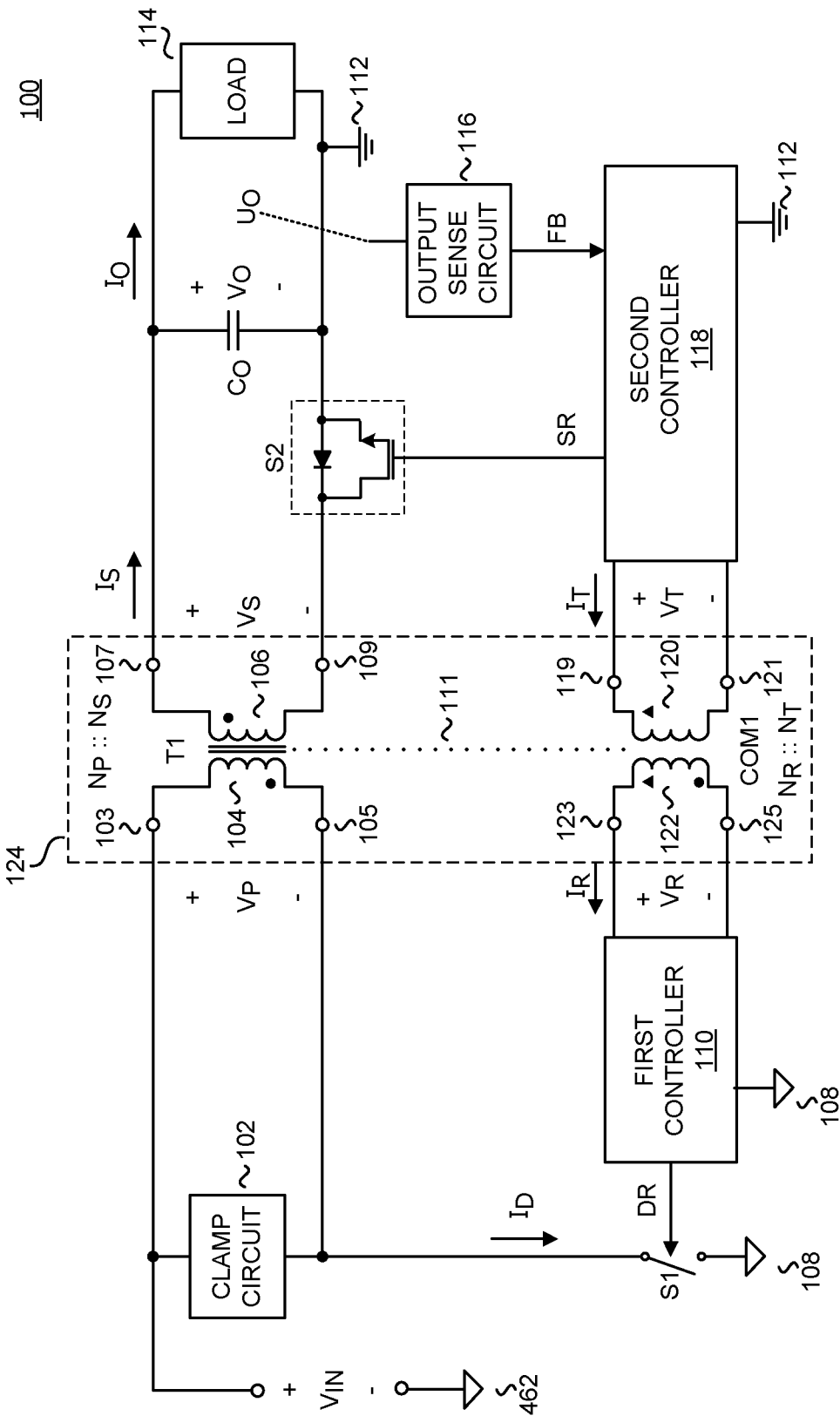


FIG. 1

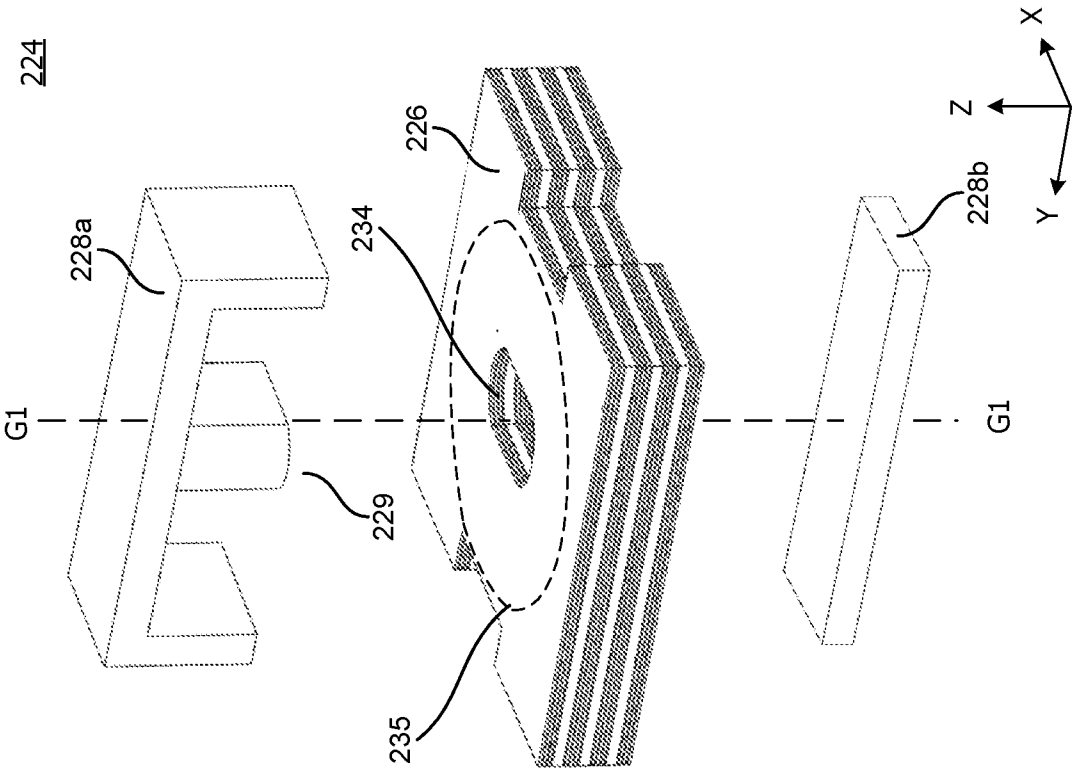


FIG. 2B

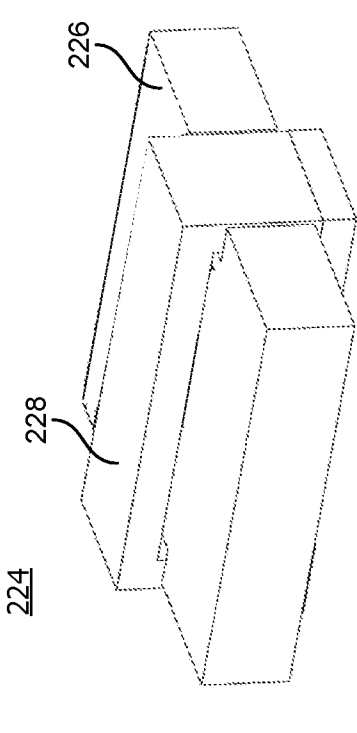


FIG. 2A

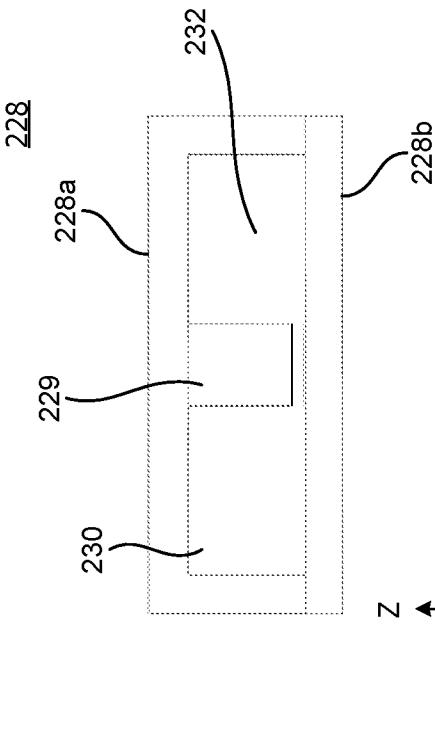


FIG. 2C

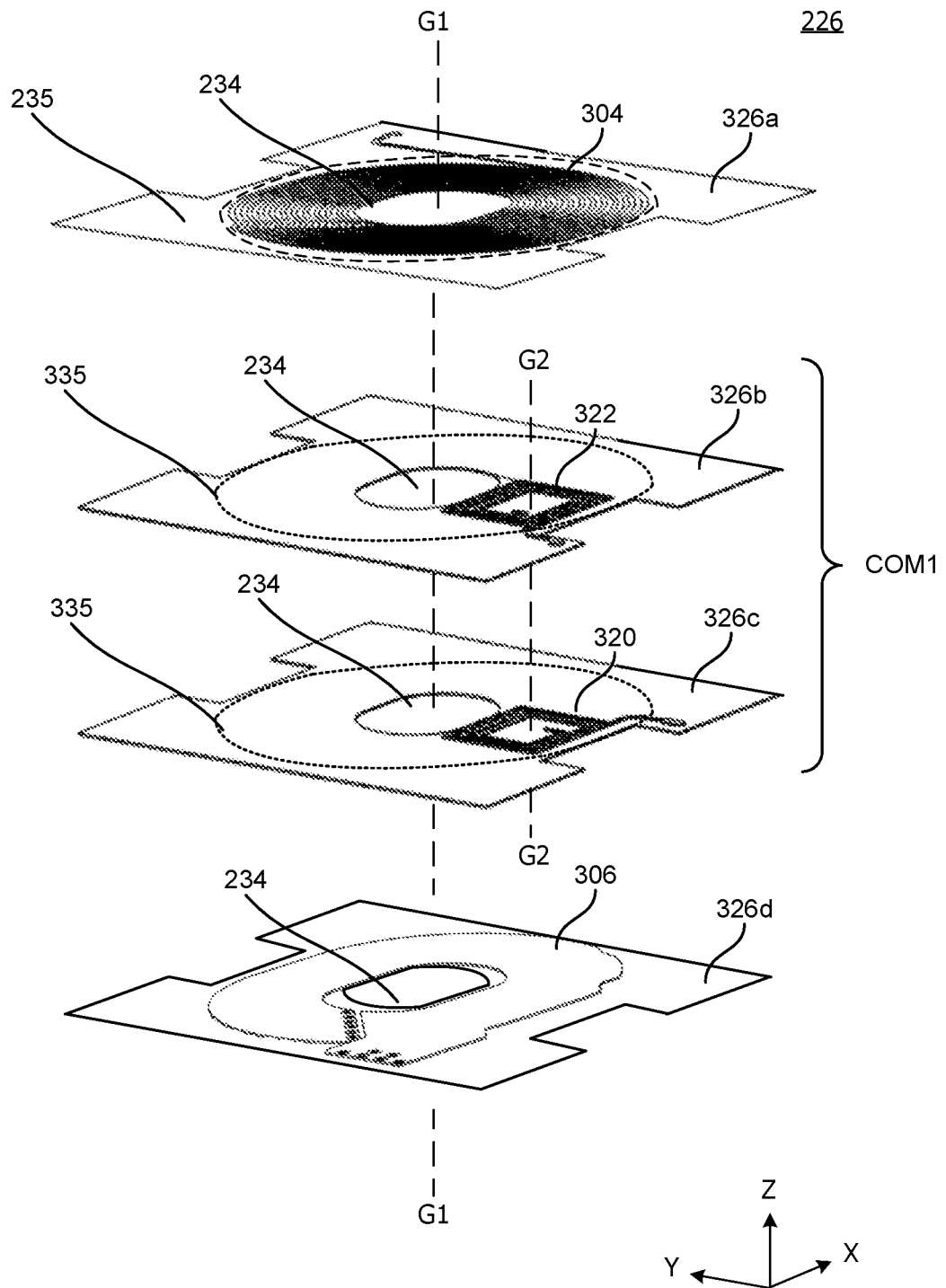


FIG. 3

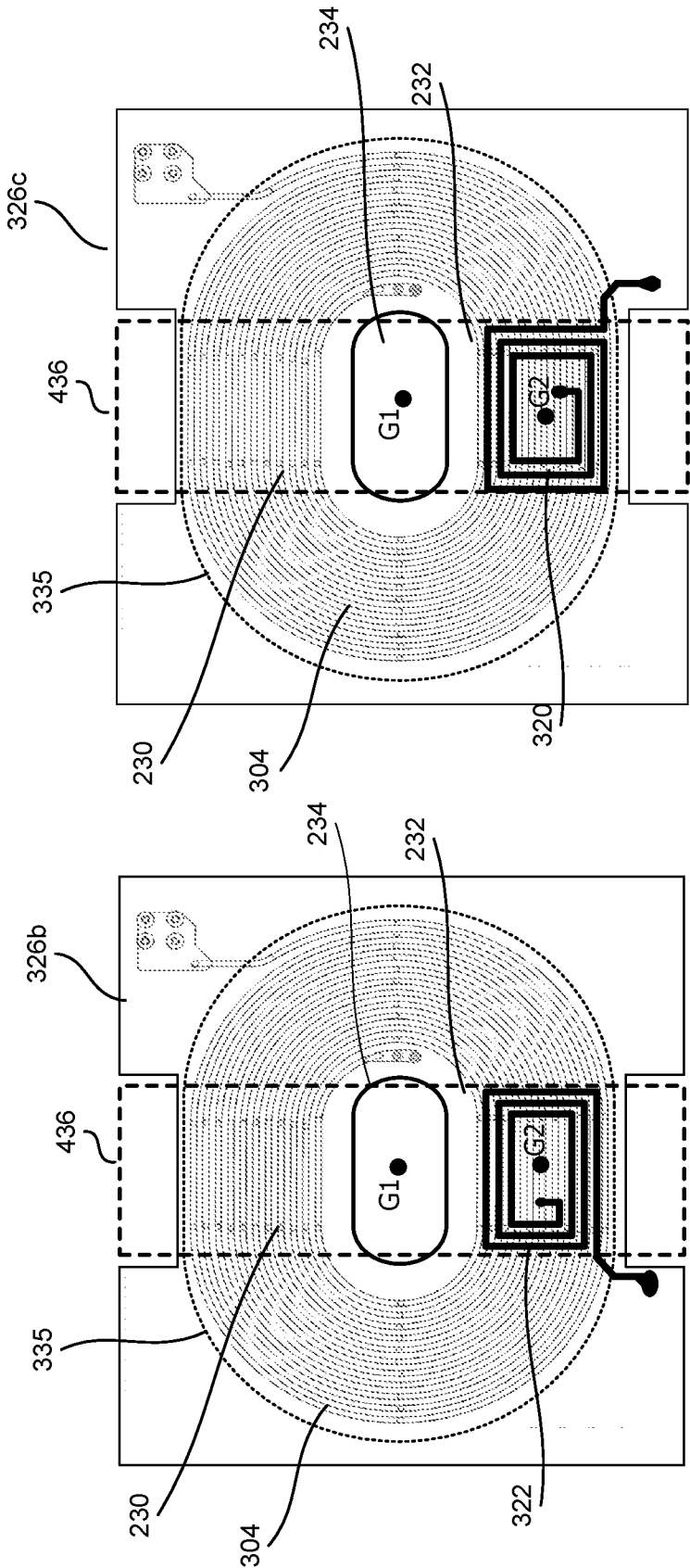
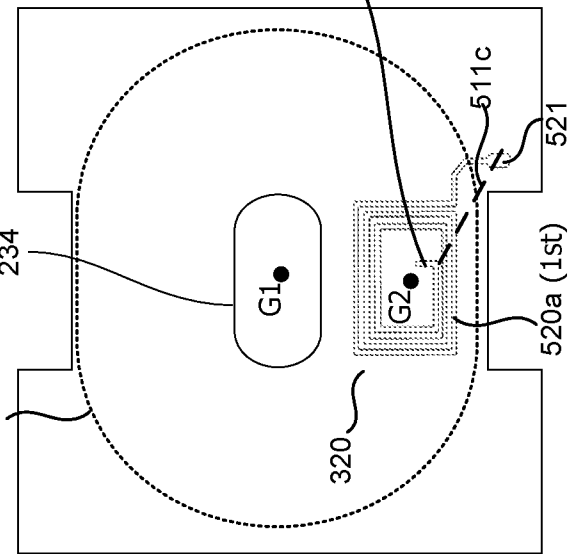
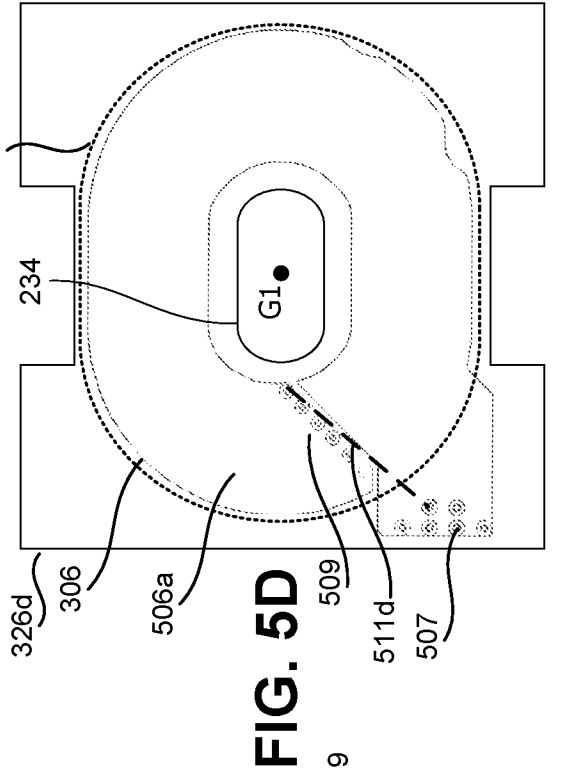
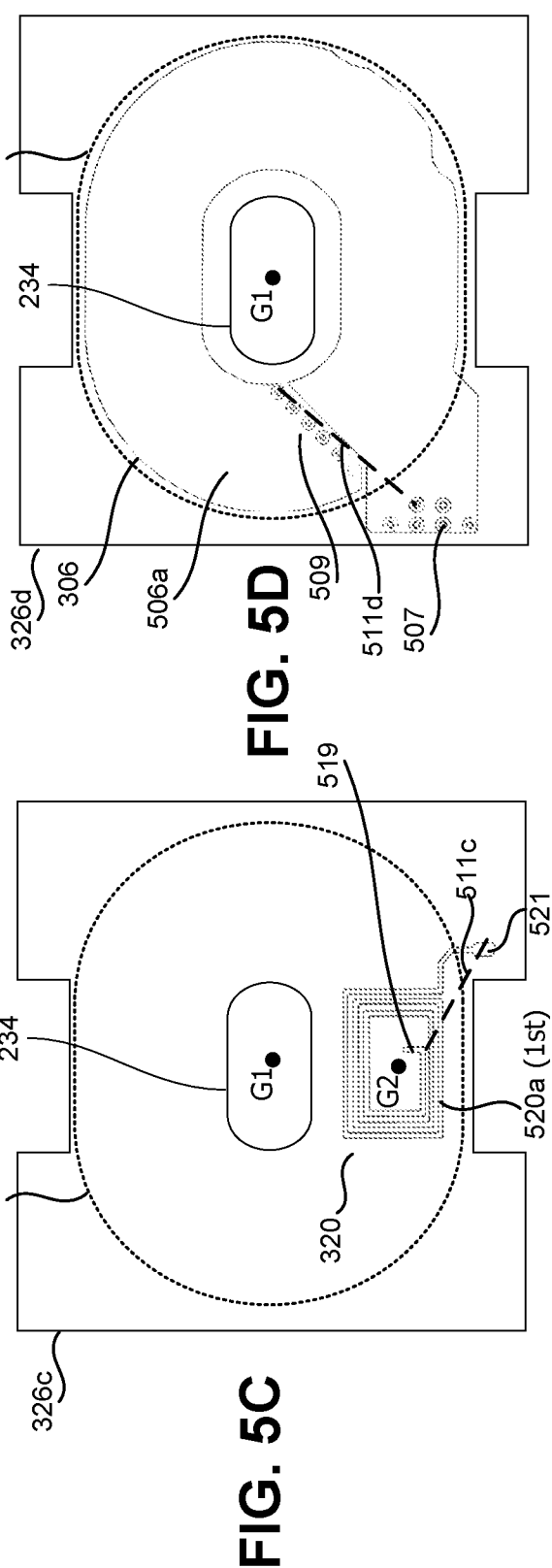
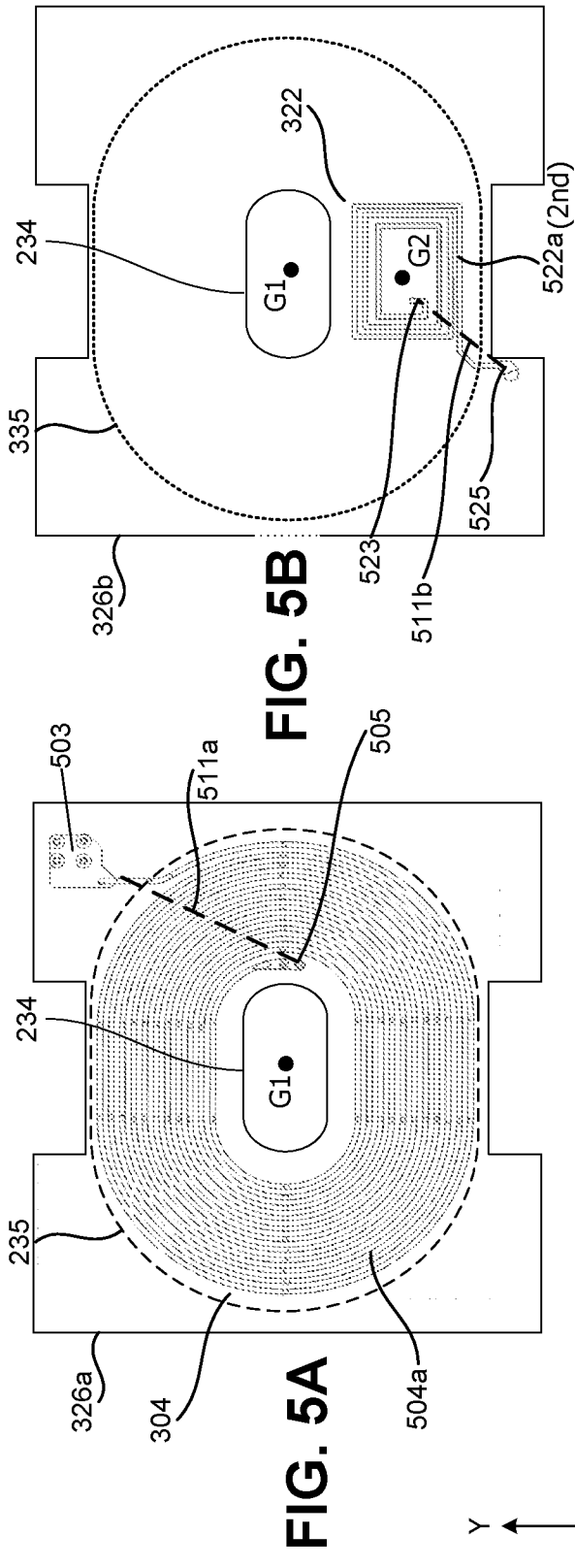


FIG. 4B

FIG. 4A



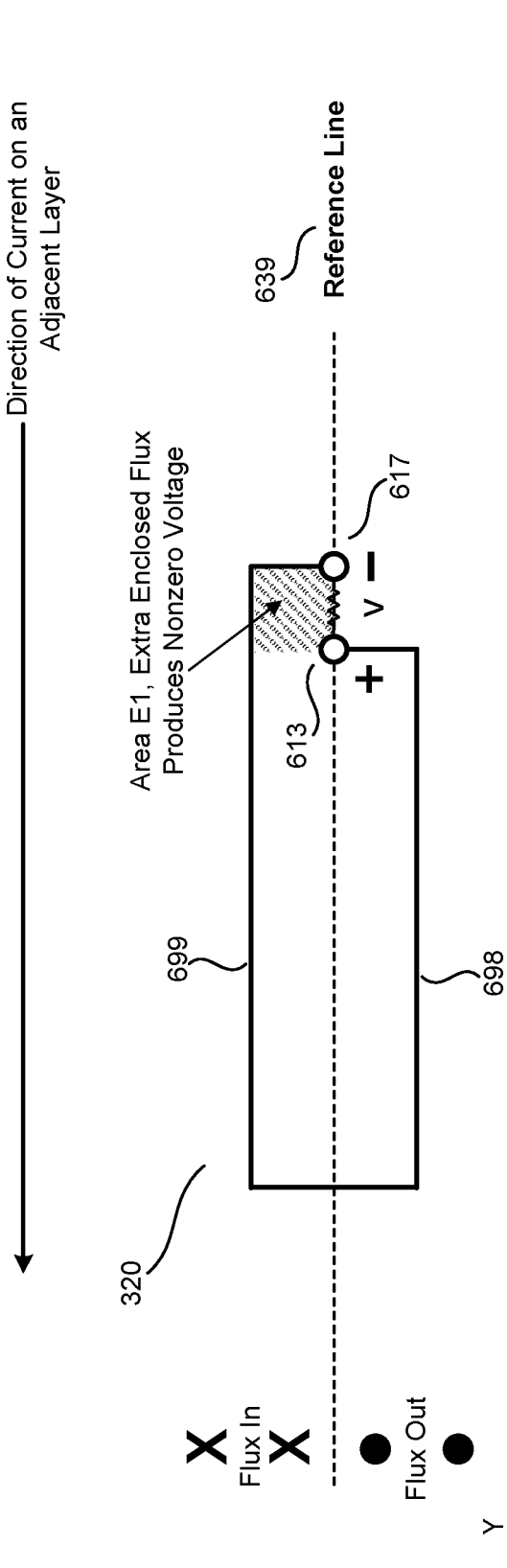


FIG. 6A

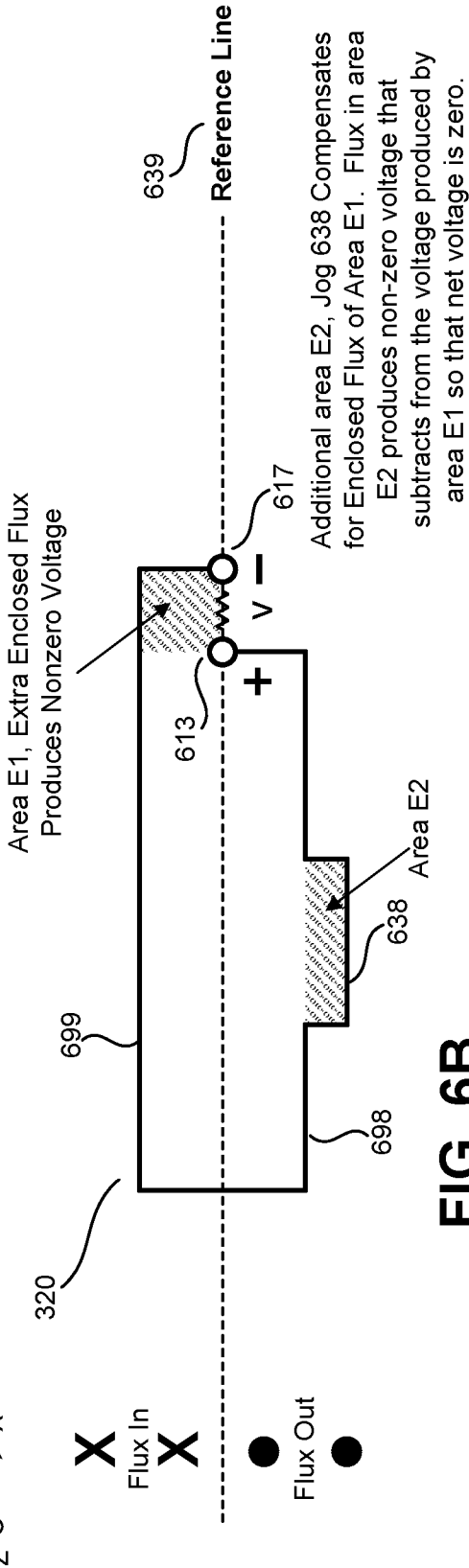


FIG. 6B

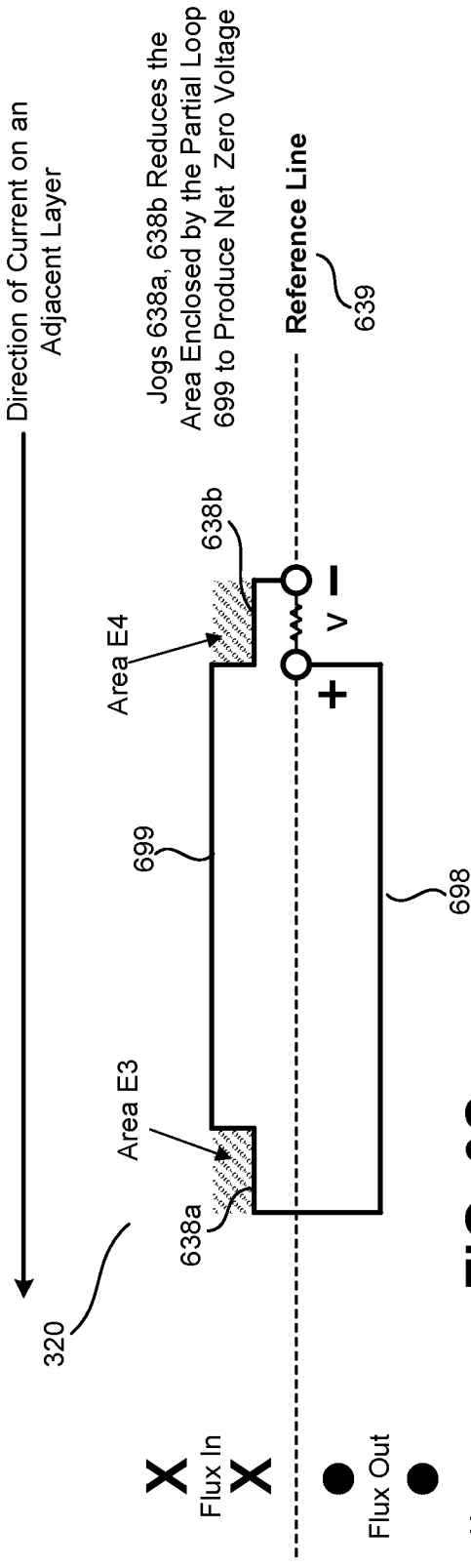


FIG. 6C

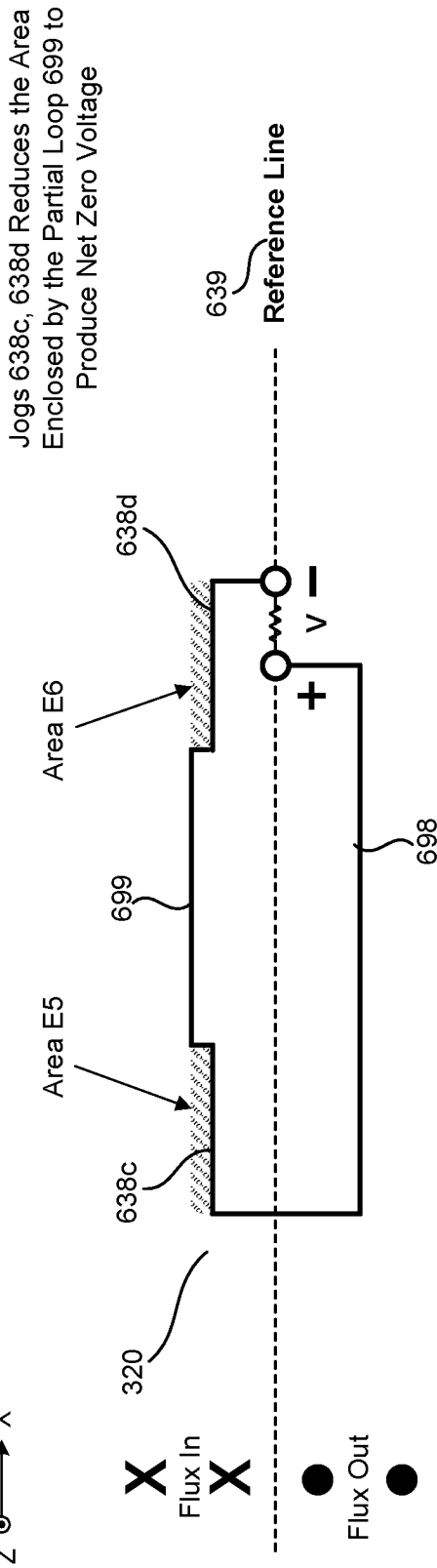


FIG. 6D

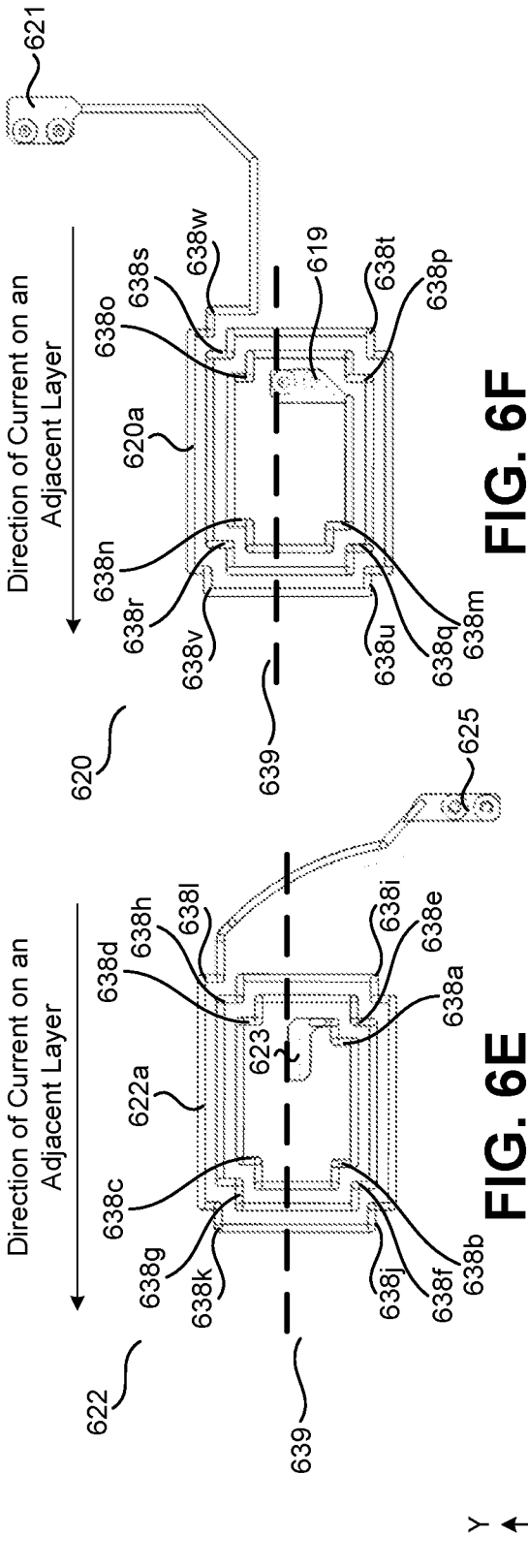


FIG. 6F

FIG. 6E

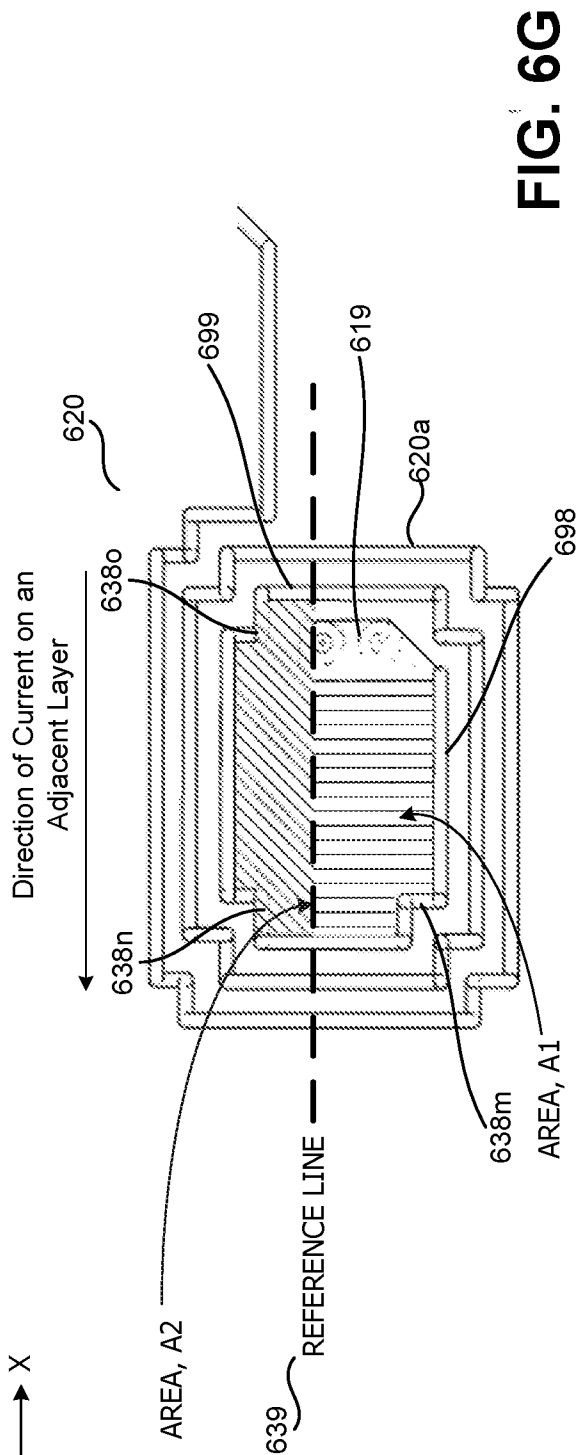


FIG. 6G

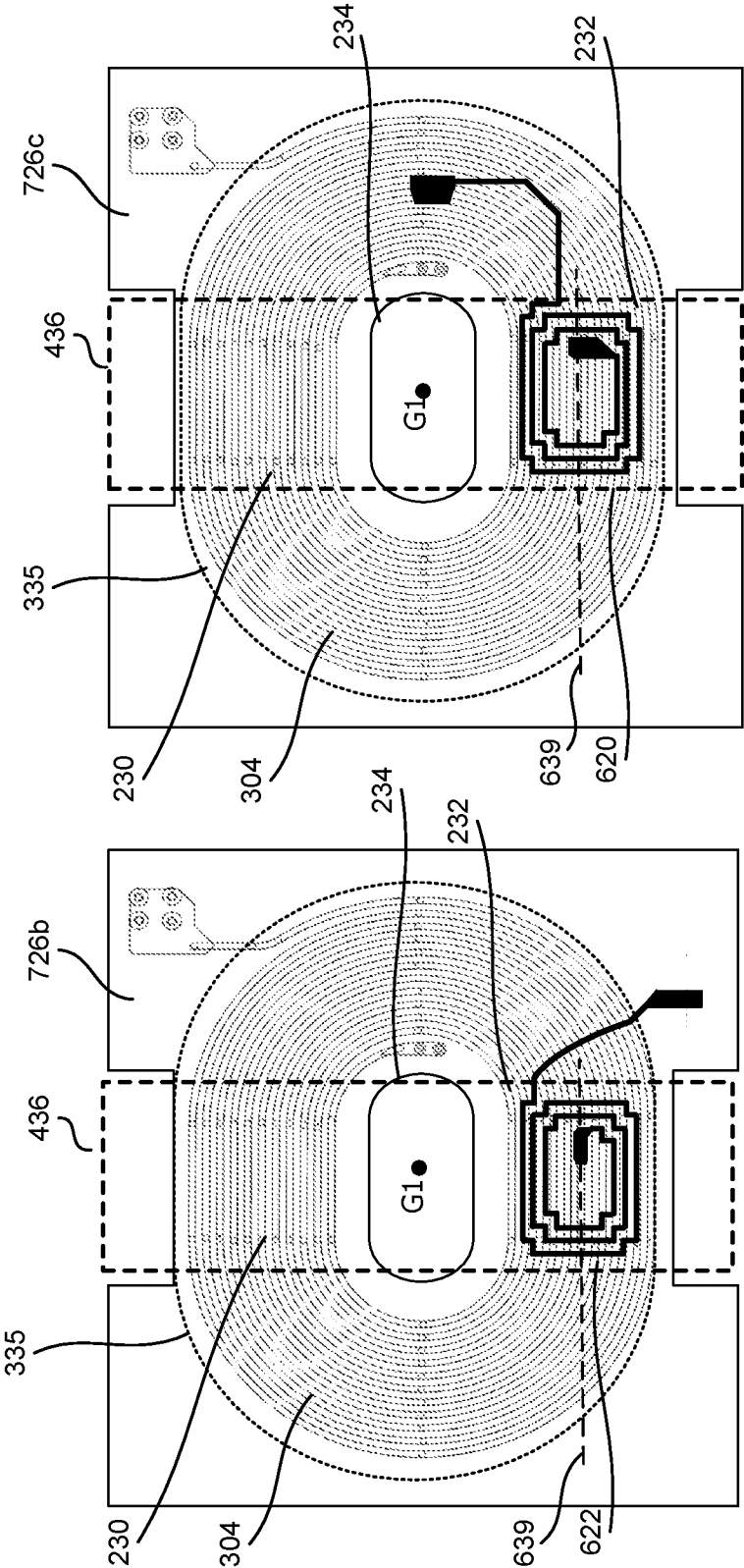
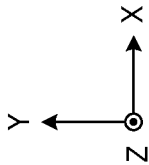


FIG. 7A

FIG. 7B



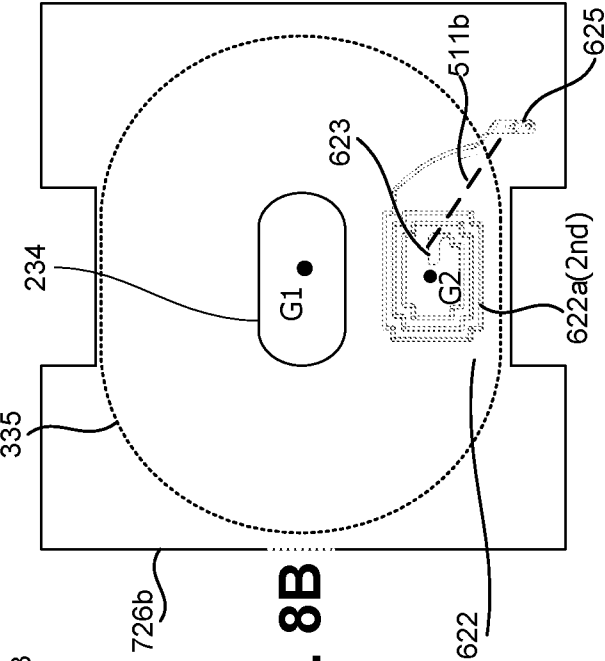


FIG. 8B

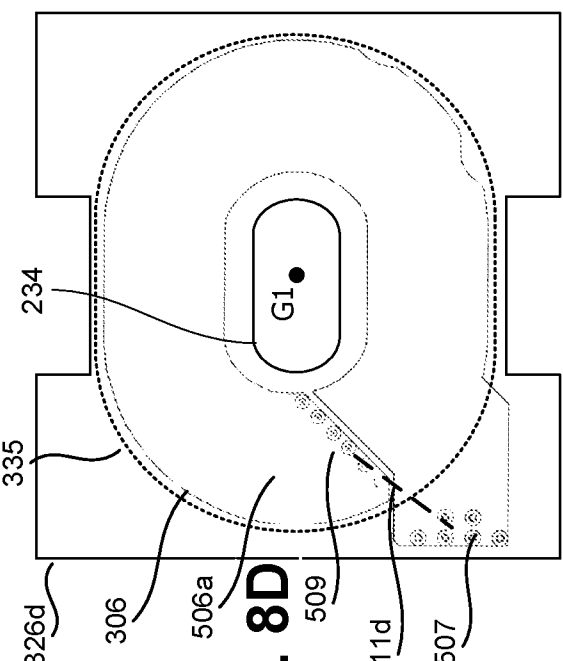


FIG. 8C

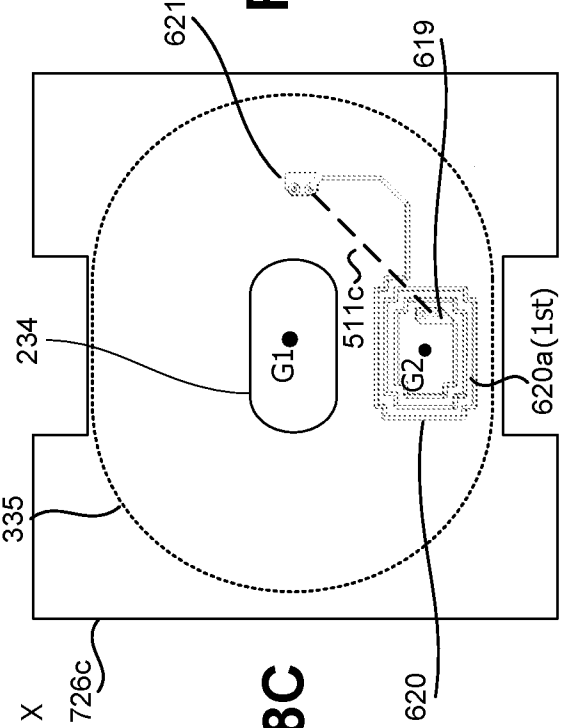


FIG. 8D

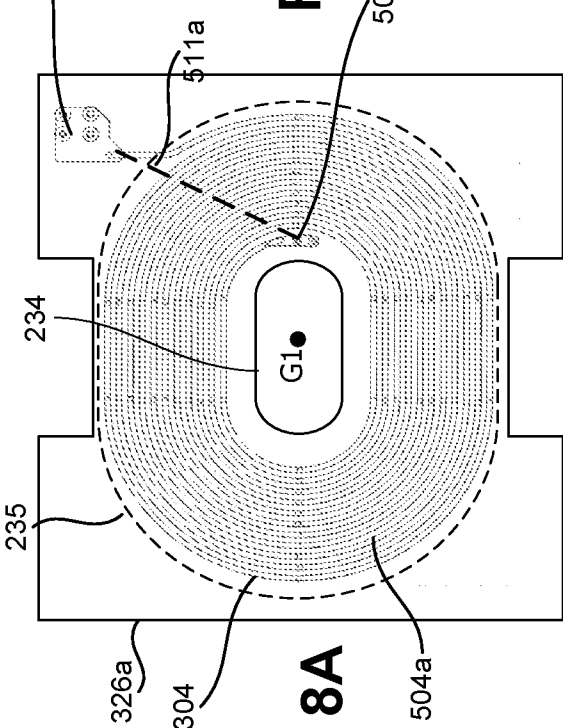
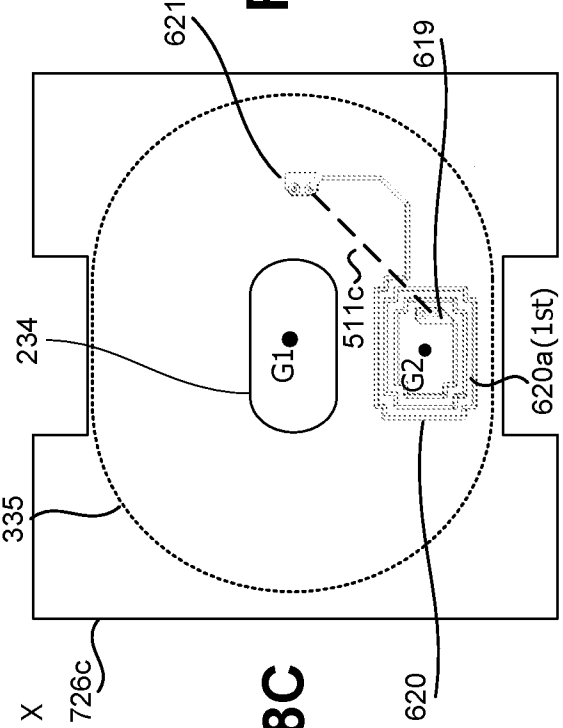


FIG. 8E



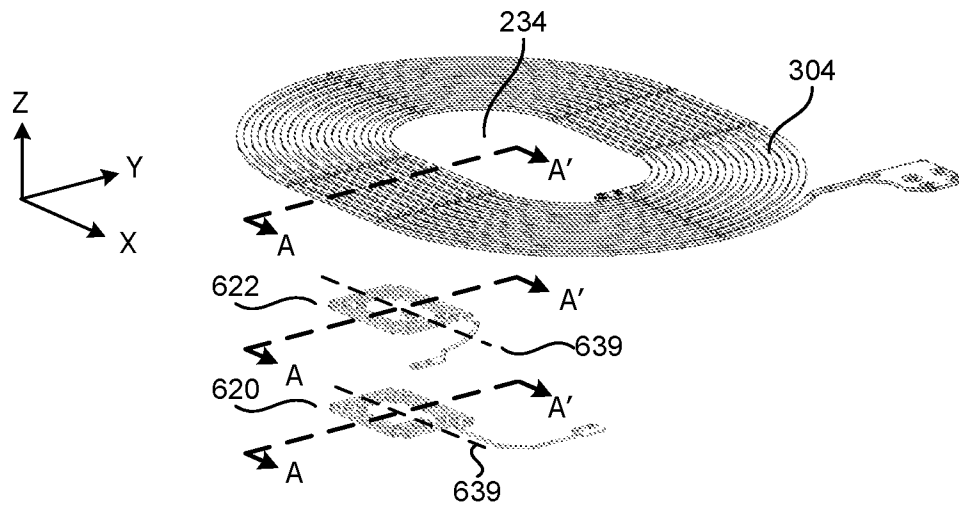


FIG. 9A

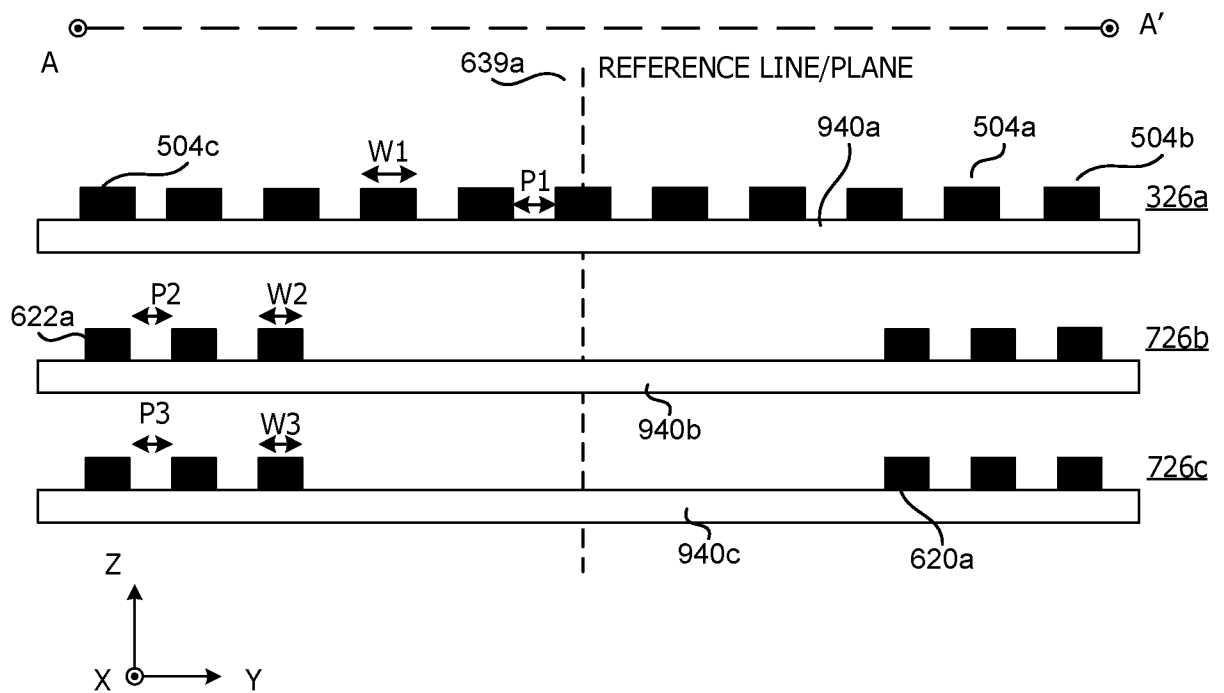
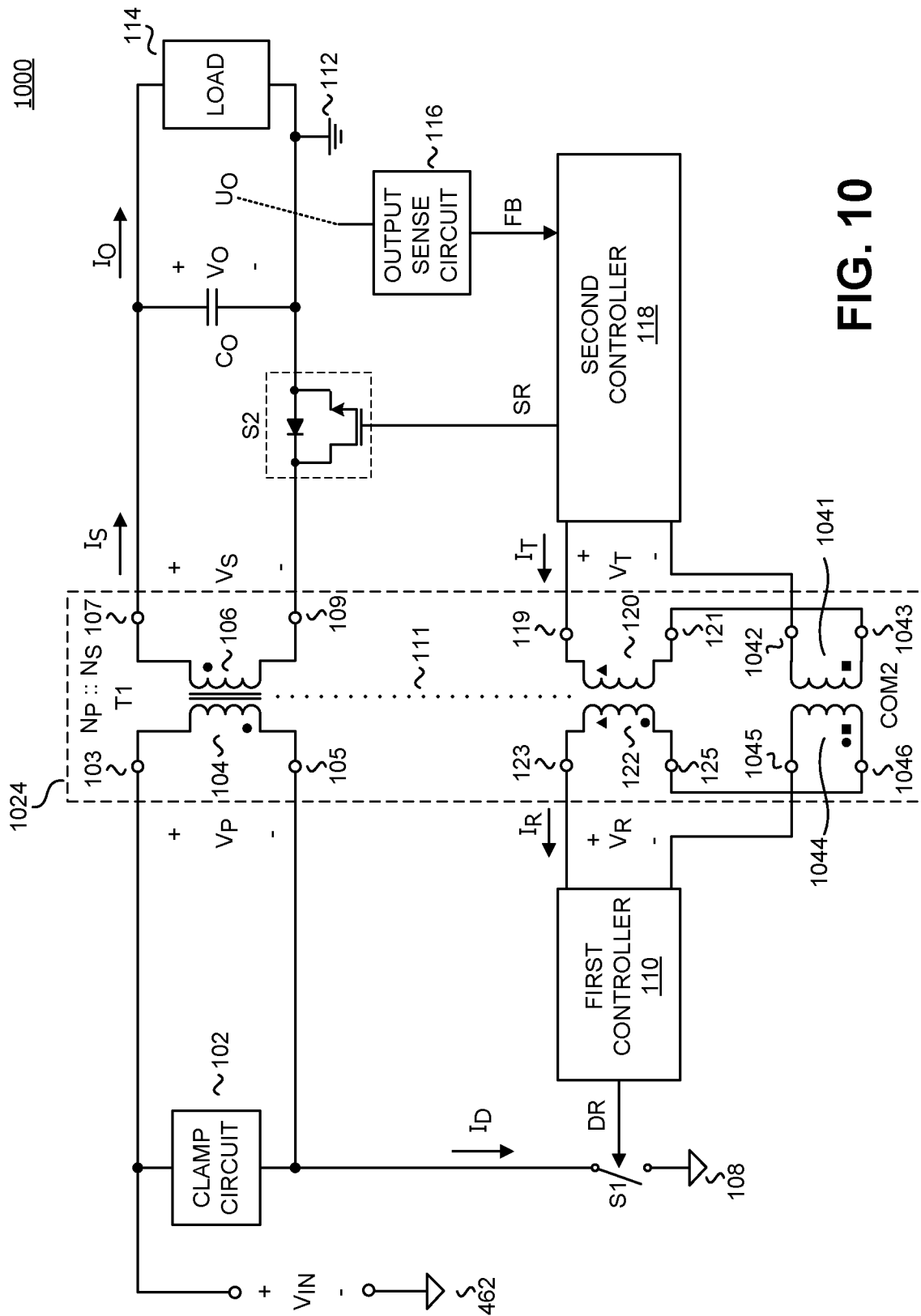


FIG. 9B



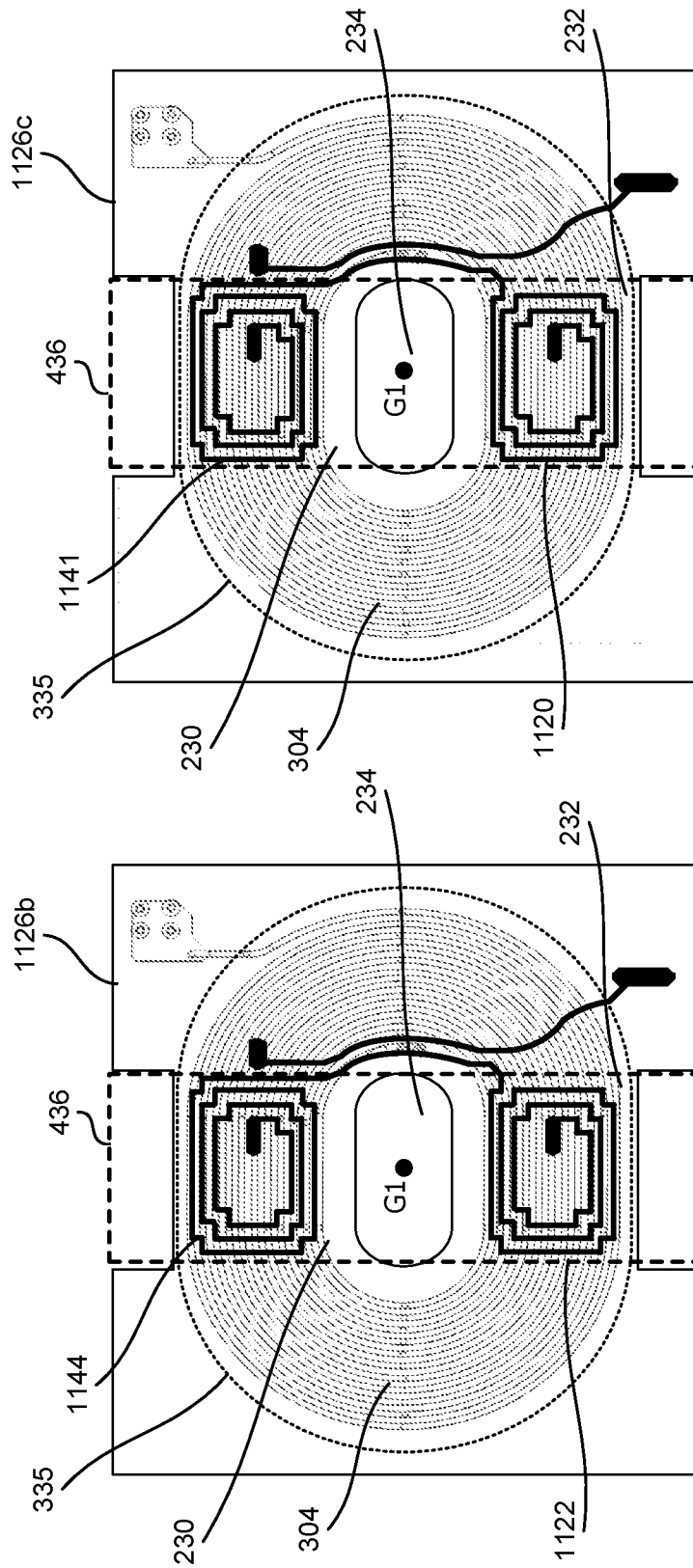


FIG. 11A

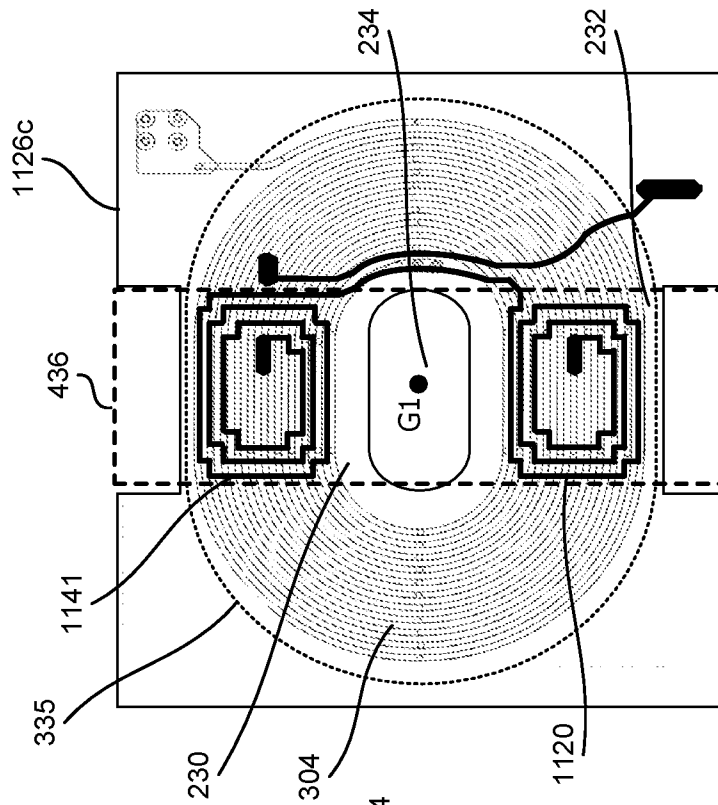
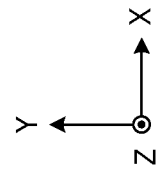
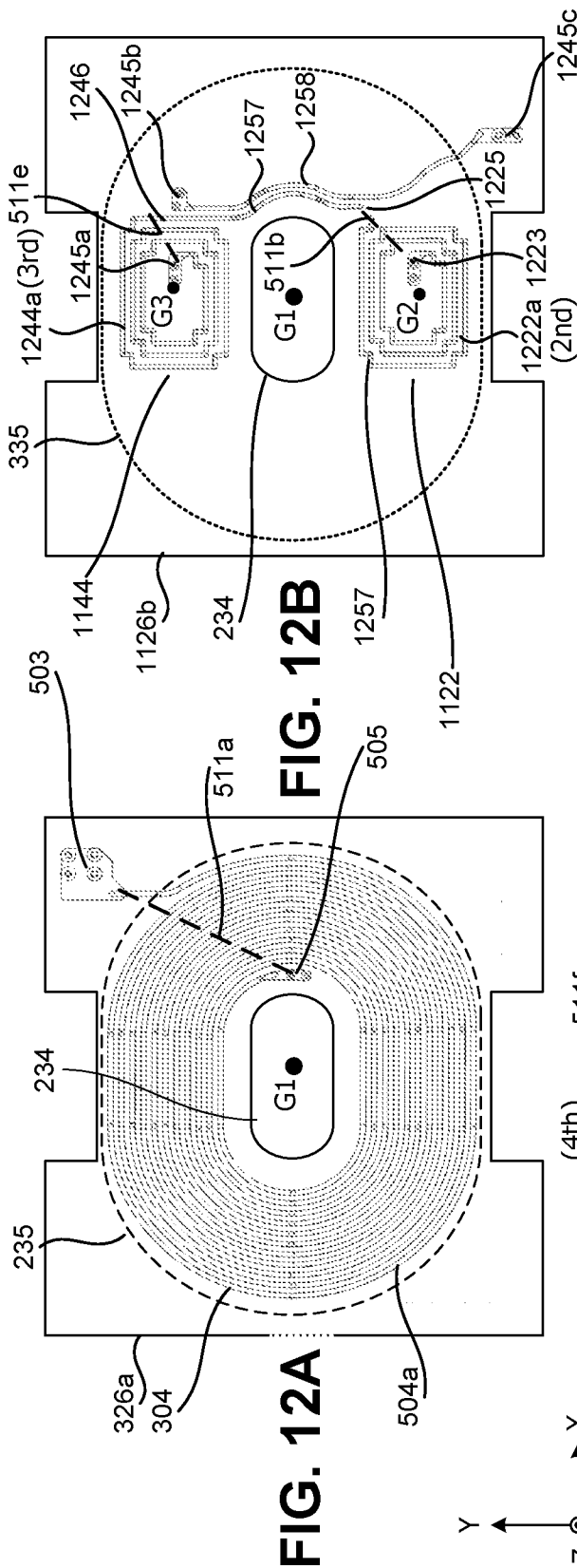


FIG. 11B





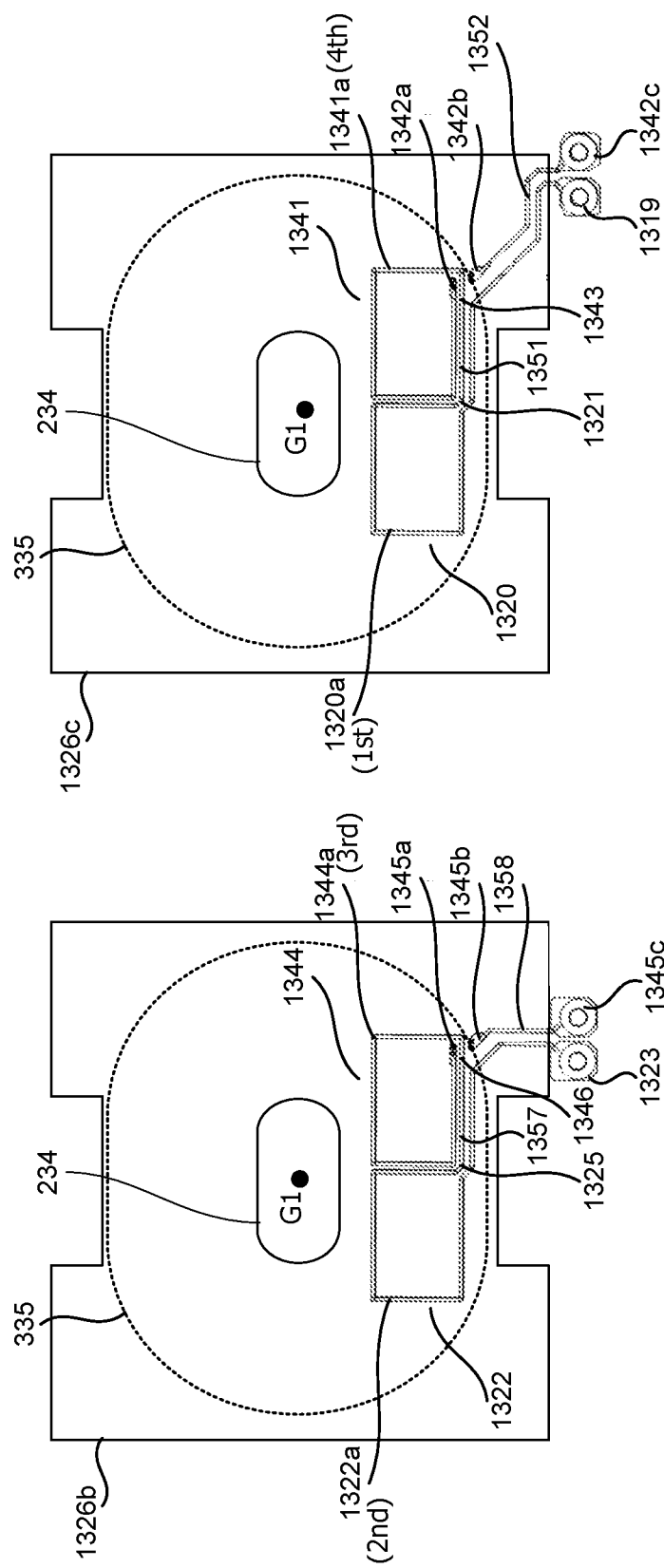
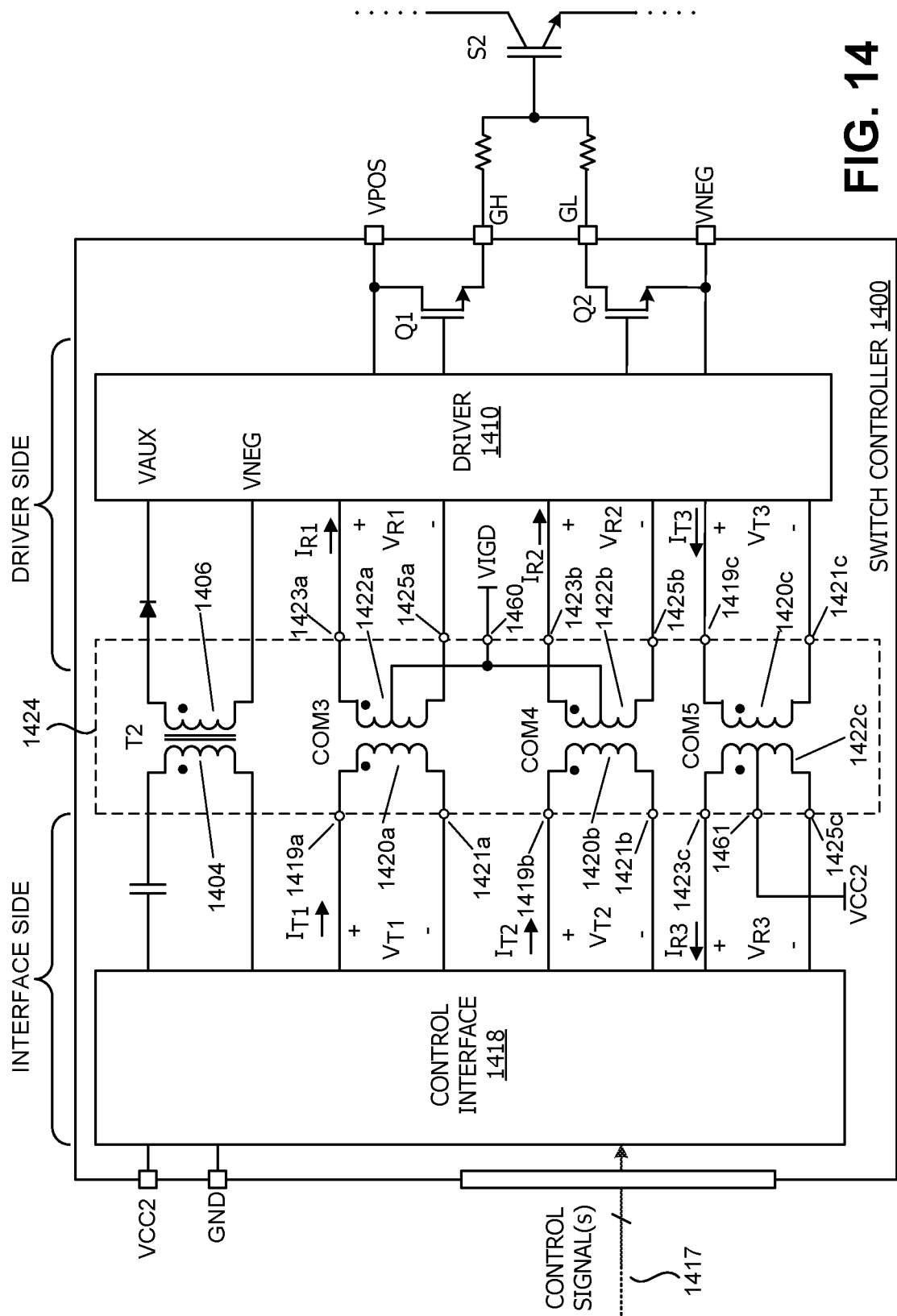
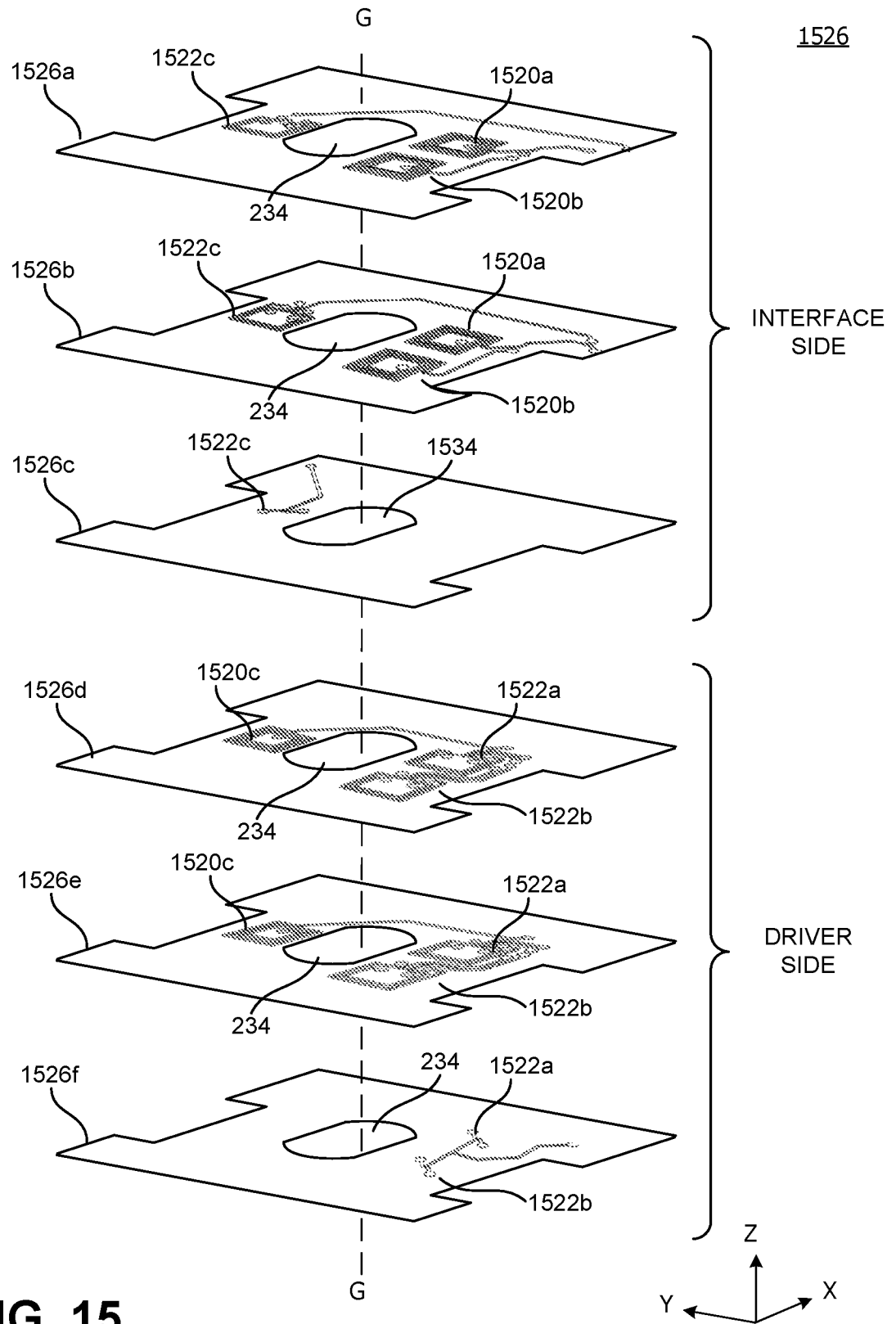


FIG. 13A

FIG. 13B





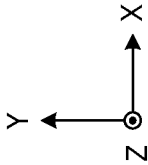
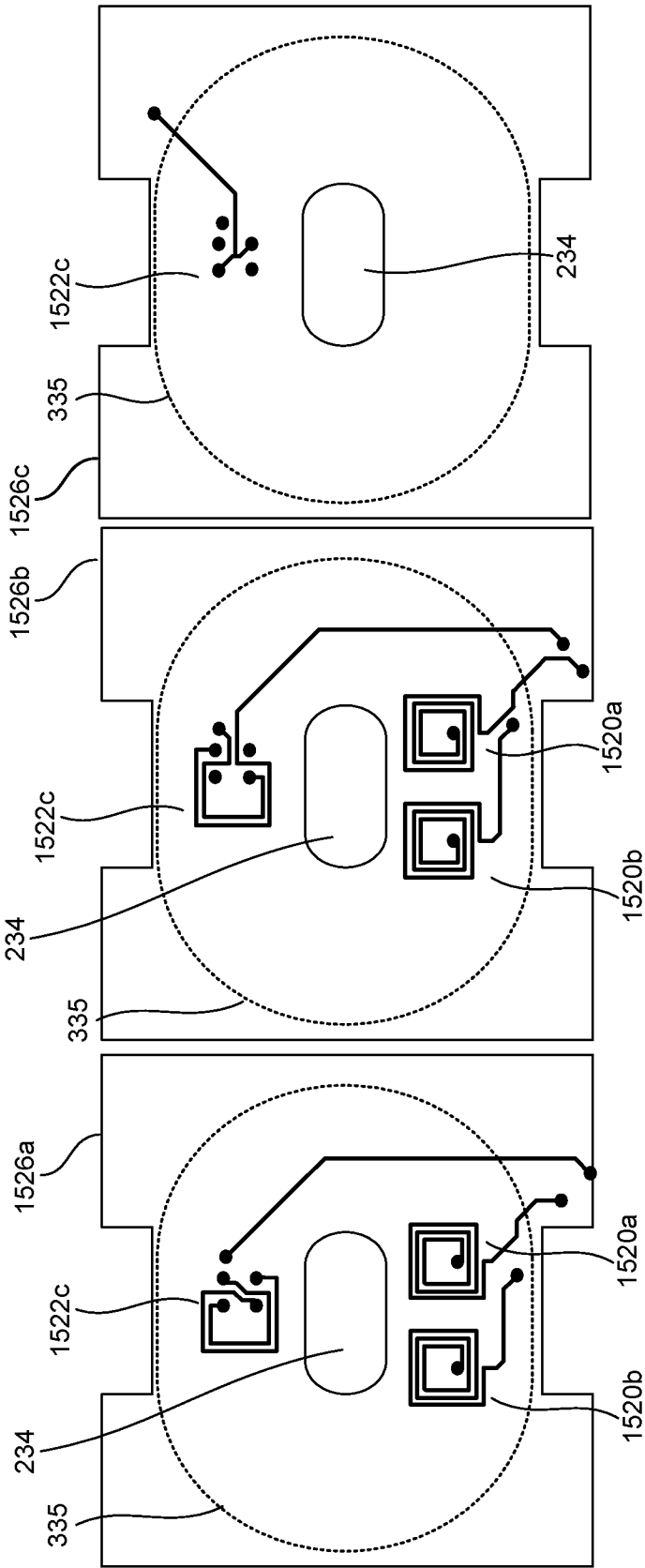


FIG. 16

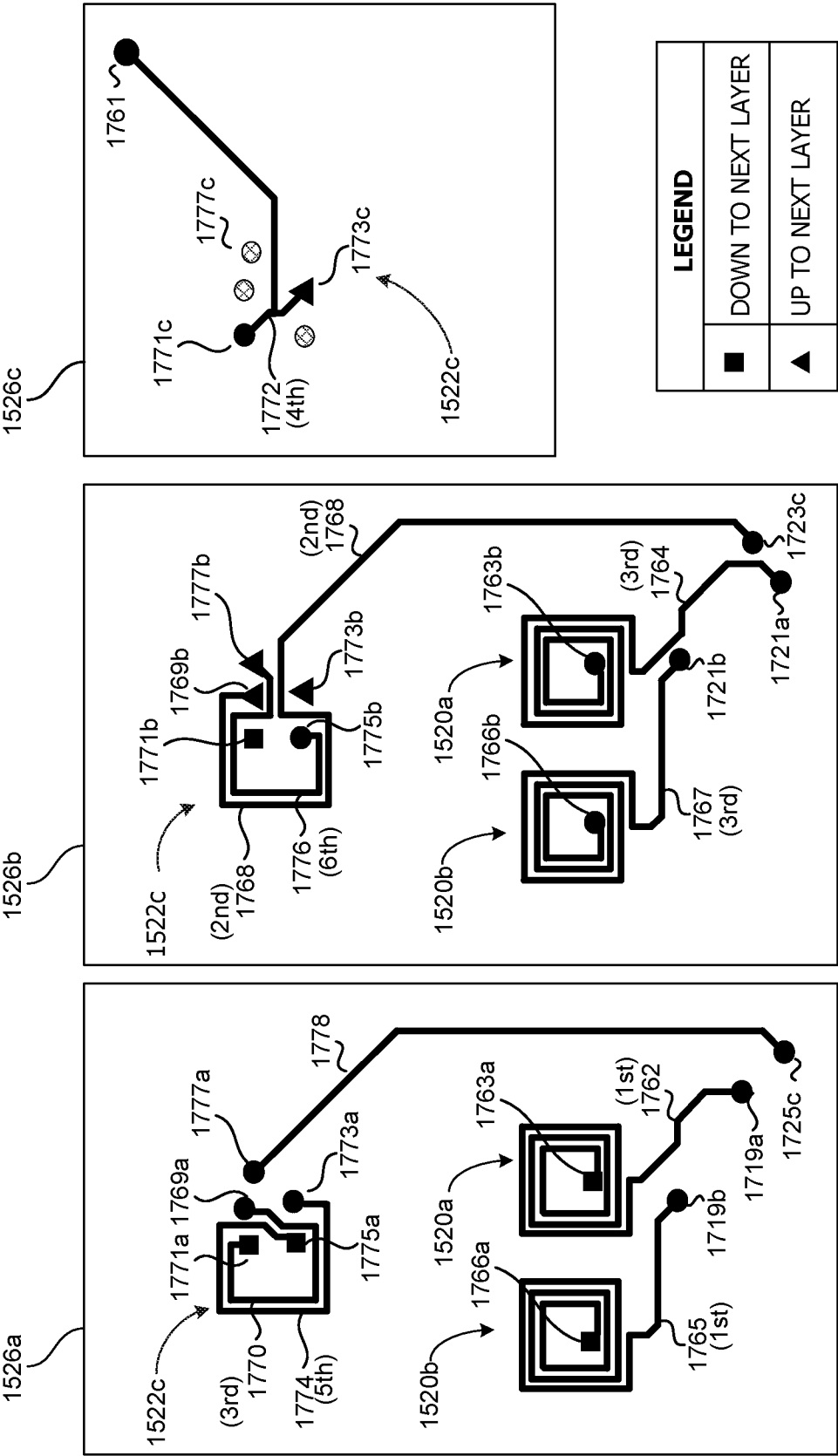
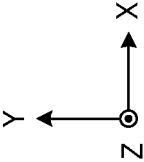


FIG. 17



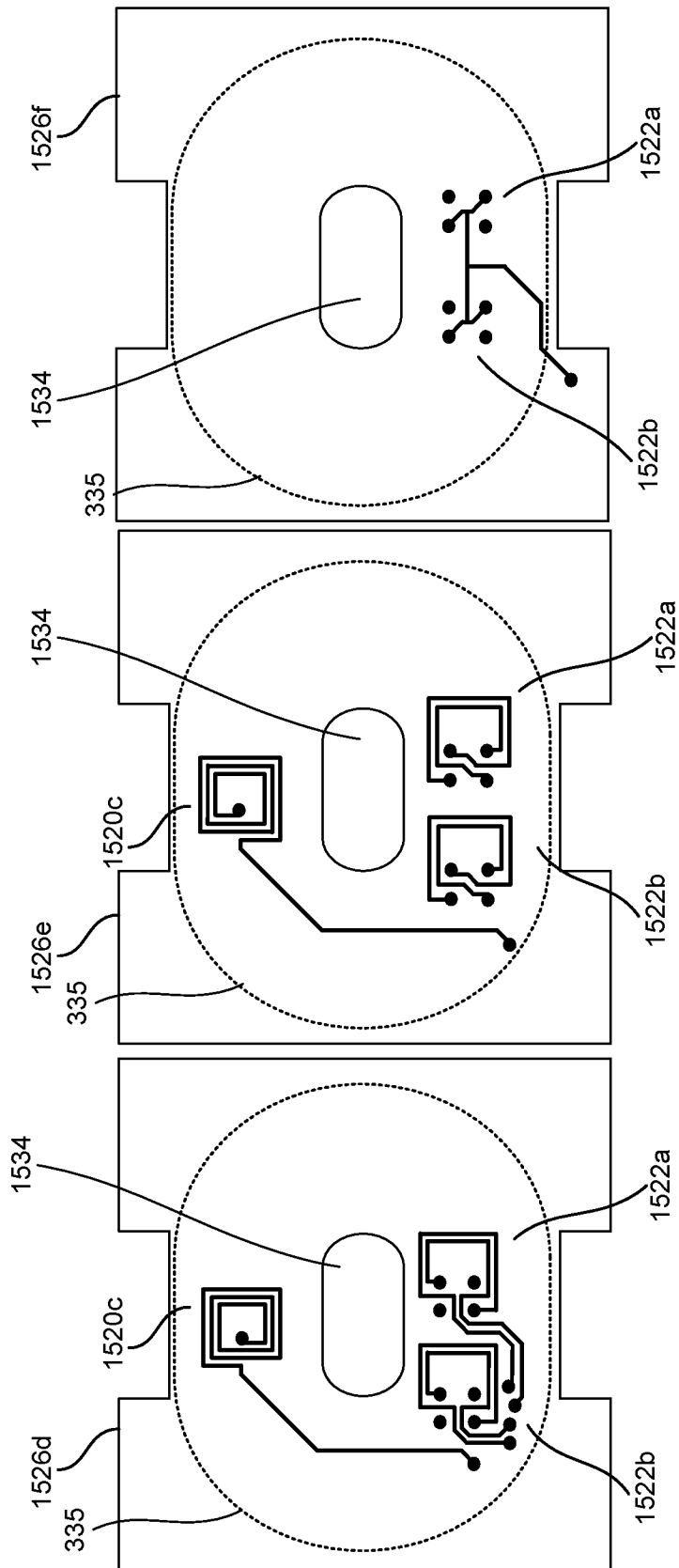
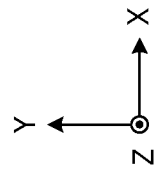


FIG. 18



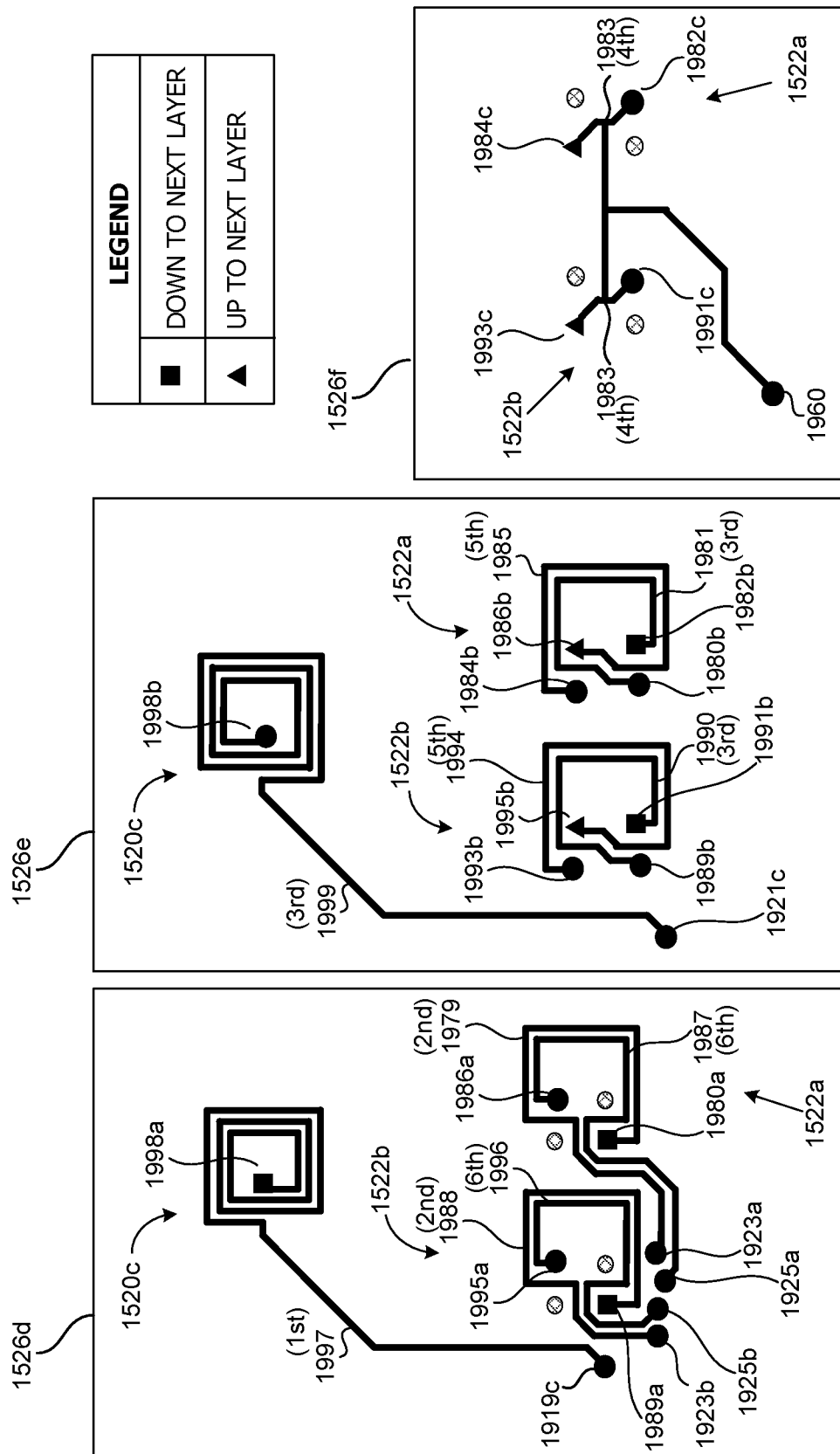
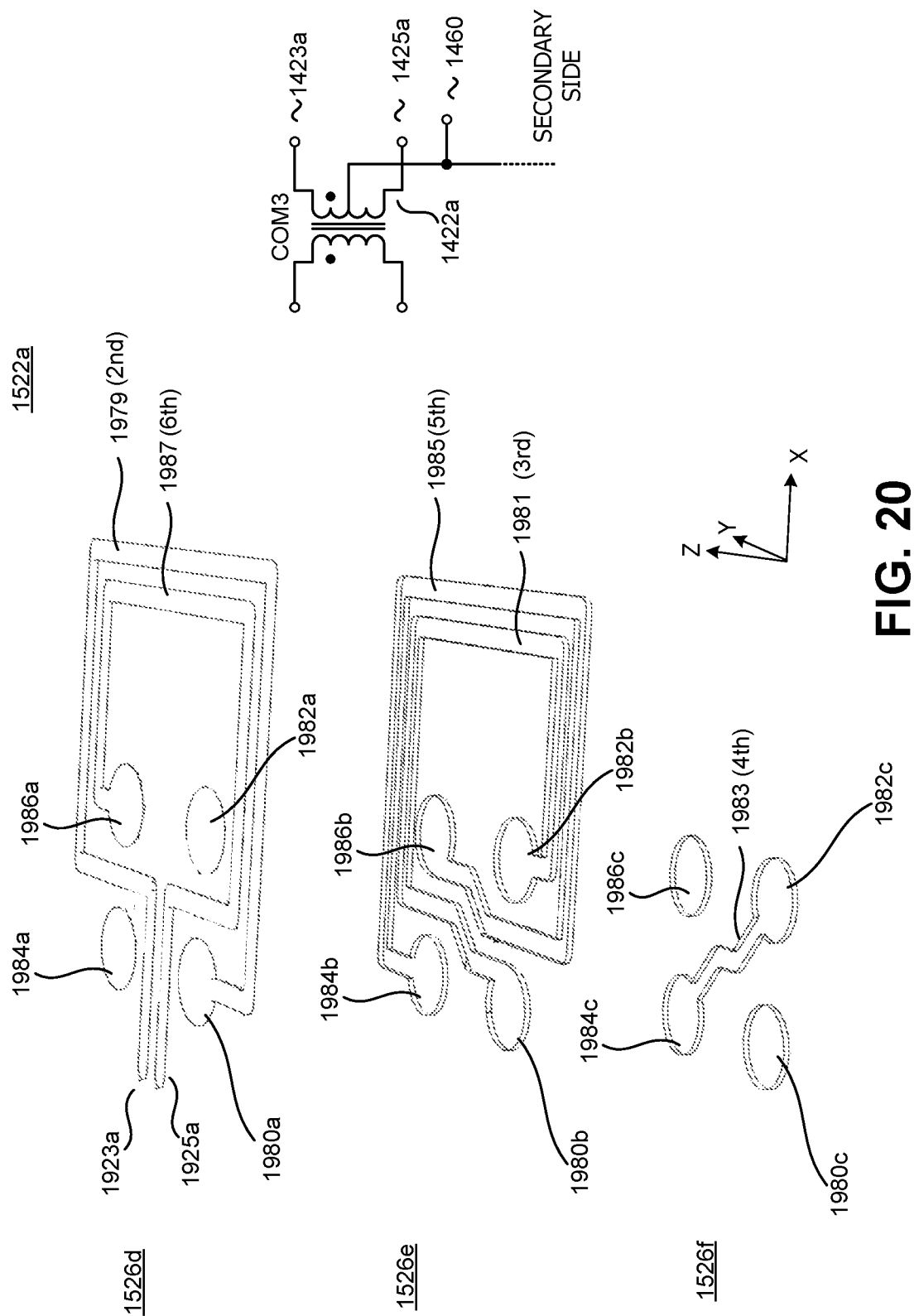


FIG. 19



INTERNATIONAL SEARCH REPORT

International application No
PCT/US2023/084810

A. CLASSIFICATION OF SUBJECT MATTER

INV. H01F27/28 H01F38/14 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

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, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2022/256700 A1 (ZOU YANBO [CN] ET AL) 11 August 2022 (2022-08-11) paragraphs [0096], [0145] - [0150]; figures 1b,14 -----	1 - 49
A	US 2018/351462 A1 (LI YONG [US] ET AL) 6 December 2018 (2018-12-06) abstract; figure 1 -----	1 - 49
A	US 10 128 766 B1 (STRIJKER JOAN WICHARD [NL] ET AL) 13 November 2018 (2018-11-13) abstract; figure 1 -----	1 - 49
A	US 2016/358705 A1 (LIN TIEN-CHI [TW] ET AL) 8 December 2016 (2016-12-08) abstract; figure 4 -----	1 - 49



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

12 July 2024

Date of mailing of the international search report

25/07/2024

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Authorized officer

Rouzier, Brice

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2023/084810

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