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(57) Abstract: An active clamp device electrically couples first and second nodes in respective first and second supply domains referenced to ground potentials that can be different. The active clamp device comprises first and second active devices controlled by signals respectively referenced to the first and second supply domains that create a short-circuit or low impedance connection between the first and second nodes in normal operation and drive impedance between the first and second nodes high in response to a transient event.
ACTIVE Clamp PROTECTION DEVICE

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BACKGROUND

[0001] Many electronic systems for usage in various applications such as network communications, telecommunications, data transmission, and many others are susceptible to damage resulting from transient energy. Lightning and other surge energy events can create rapid electrical energy transients. Such transient events can damage electronic circuits or equipment.

[0002] Some circuit arrangements include two or more circuits that are connected but operate with reference to ground potentials that may be different. In response to various conditions, electrical current may flow between different ground domains so that the ground potentials can bounce relative to one another, which may be a source of common-mode noise. In a communication application, the generated noise can interfere with communication between ground domains.

[0003] A conventional clamping circuit can be used to prevent another circuit from exceeding a predetermined voltage level and functions by sensing the output voltage of the monitored circuit and, if the output voltage approaches or exceeds the limit, applying a load. The applied load draws current in a regulated manner to prevent the output voltage from exceeding the limit. The clamp circuit generally operates with lower output impedance than the monitored circuit so that the circuit is overpowered.

SUMMARY

[0004] According to an embodiment of a network device, an active clamp device electrically couples first and second nodes in respective first and second supply domains referenced to ground potentials that can be different. The active clamp device comprises first and second active devices controlled by signals respectively referenced to the first and second supply domains that create a short-circuit or low impedance connection between the first and second nodes in normal operation and drive impedance between the first and second nodes high in response to a transient event.
BRIEF DESCRIPTION OF THE DRAWINGS

[0005] Embodiments of the invention relating to both structure and method of operation may best be understood by referring to the following description and accompanying drawings:

5  FIGURE 1A is a schematic block diagram illustrating an embodiment of a network interface that is configured to provide transient event suppression according to the various disclosed embodiments;

FIGURE 1B is a schematic block diagram illustrating an embodiment of electrical paths through the network interface of FIG. 1A during normal operation and during a transient event;

FIGURE 1C is a schematic diagram of a generalized stressing circuit that can be used to explain the cause of stress from a transient event in a system, such as network interface apparatus FIG. 1A;

FIGURES 1D and 1E show an embodiment of system including a T-connect element connected to earth ground to limit energy through a PHY device during a transient energy event;

FIGURE 2 is a schematic block diagram illustrating an embodiments of other devices that can be used for the transient event suppression module of FIG. 1A;

FIGURES 3A and 3B are schematic block diagrams depicting embodiments of an electronic apparatus that can be used to protect electronic equipment from potentially harmful transient events and reduce or eliminate noise resulting from current flow between different supply domains while allowing current flow to reduce common-mode emissions;

FIGURE 4A is a block diagram which illustrates a functional view of a circuit enabling creation of an isolated supply for a protection apparatus, indicating the high impedance to the isolated portion of the circuit;

FIGURE 4B is a schematic circuit diagram showing a switched-capacitor approach to generating a surge isolated supply which allowing a draw of high current from the isolated domain within the protection apparatus;

30 FIGURE 4C is a pictorial diagram depicting a pin-out structure of a differential PHY protection apparatus;
FIGURES 5A, 5B, and 5C are schematic flow charts illustrating an embodiment of a transient protection method for protecting an electronic system against transient energy and suppressing noise;

FIGURES 6A, 6B, 6C, 6D, and 6E are schematic block diagrams illustrating embodiments of a transient event protection apparatus;

FIGURE 7 is a schematic flow chart depicting an embodiment of a method electronic devices and components against transient energy;

FIGURE 8 is a schematic block diagram illustrating an embodiment of a Power-over-Ethernet (PoE) system that can include a transient protection apparatus according to the various disclosed embodiments;

FIGURES 9A, 9B, and 9C are schematic flow charts illustrating an embodiment of a transient protection method for protecting an electronic system against transient energy and suppressing noise; and

FIGURE 10 is a schematic flow chart depicting an embodiment of a method electronic devices and components against transient energy.

DETAILED DESCRIPTION

[0006] In some embodiments, a network interface apparatus is disclosed that includes a connector coupled to a plurality of communication lines. A Physical Layer (PHY) device coupled to the communication lines and to a first ground level. A transient event suppression module coupled between the communication lines and a low impedance path to earth ground. During a transient event the transient event suppression module provides a low impedance path to the earth ground to protect the PHY device from the transient event. A power circuit that delivers power from a second ground level to the PHY device that is coupled to first ground level. The first ground level and the second ground level are coupled to provide a low impedance path during normal operation and high impedance during transient events.

[0007] In other embodiments, a transient protection apparatus is disclosed that includes a transient event suppression device coupled between a plurality of communication lines and an ac/dc power block. The ac/dc power block is referenced to earth ground level. A power supply transformer including a secondary winding and a primary winding is coupled to the transient event suppression device. The primary winding is referenced to a power ground level and the secondary winding is coupled to a PHY ground level. A common mode suppression circuit coupled between the communication lines and the power supply transformer. A PHY device coupled between
the communication lines and the common mode suppression circuit. The PHY device is referenced to the PHY ground level. A transient protection apparatus coupled between the power ground level and the PHY ground level. The transient protection apparatus is configured to create a short-circuit or low impedance connection between the power ground level and the PHY ground level in normal operation and an open circuit during a transient event. The transient event suppression device creates a low impedance connection sufficient to draw destructive transient energy to earth ground in response to a transient event.

[0008] In still further embodiments, a transient event suppression method includes directing energy on a plurality of communication lines through a PHY device coupled to a PHY ground level during normal operation. Transient energy on the plurality of communication lines is directed to earth ground through a transient protection device that is isolated from the PHY device and the PHY ground level during a transient energy event.

[0009] A network interface apparatus is disclosed that includes a transient protection apparatus for adaptive impedance control for multiple ground planes according to various disclosed embodiments. The ground levels of a physical layer (PHY) device and a power section are separated via a power transformer in order to create a surge block path through the power plane. The network interface apparatus can be used to protect electronic equipment from potentially harmful transient events and reduce or eliminate common-mode noise that is a result of switching transients in DC/DC converters that flow from the primary side to the secondary side of a power transformer.

[0010] Referring to FIG. 1A, network interface apparatus 100 includes a network connector 104 coupled to Physical Layer (PHY) device 106 via a plurality of signal lines. PHY device 106 is also coupled to a first ground level 107, which may also be referred to as chassis ground level. A power controller device 108 is coupled to the network connector 104 can include a transient suppression device 110, a powered device (PD) controller 112, and a DC-DC converter 114.

[0011] Common mode suppression (CMS) circuit 116 can be an active device that is coupled in parallel to transmit and receive differential signal lines connecting PHY device 106 and network connector 104. The CMS circuit 116 may be described functionally as a shunt choke or choke. CMS circuit 116 is connected in parallel to the same signal lines as the Ethernet PHY 106 whereby the shunt choke terminology is descriptive of the parallel connection. The CMS circuit 116 operates as a functional block, coupled in parallel to the signal lines to supply a very low common mode impedance termination.
Accordingly, substantially all common mode noise in the network interface apparatus 100 is absorbed by the common mode suppression circuit 116.

[0012] A DC isolation barrier 117 can be coupled to the communication lines between the connector 104 and the PHY device 106. The isolation barrier 117 is shown including a plurality of capacitors, but in other embodiments, other suitable devices such as transformers can be used.

[0013] FIG. 1B shows an embodiment of network interface apparatus 100A, with a greater level of detail of some of the components in network interface apparatus 100. Transient event suppression module 110 is shown as a T-connect element 110A coupled between the connector 104 and ac/dc power brick 122. The ac/dc power brick 122 is coupled to earth ground 118, thereby providing a low impedance path to earth ground 118 via T-connect element 110A, as indicated by the dashed line through the T-connect element 110A. The low impedance path to the earth ground 118 protects the PHY device 106 from transient events.

[0014] The embodiment of T-connect element 110A shown includes two differential transistor pairs denoted by m1 and m2. Each transistor of the differential transistor pairs is operable to pass an Ethernet power signal. T-connect element 110A further includes a pair of inductors L1, L2, wherein each of the inductors is coupled to a single transistor of the differential transistor pairs. A pair of impedance sense resistors (r) are coupled between the drains of the differential transistors. The impedance sense resistors are operable to pass Ethernet power signals received from the drain of the coupled transistor. An output node L1, L2 associated with each transistor of the differential transistor pair m1, m2 is configured to provide power to the PHY device 106.

[0015] Any suitable type of device or interface can be protected, for example including Universal Serial Bus (USB) interfaces and/or devices, a RETMA standard (RS)-232 interfaces and/or devices, Transmission level 1 (T1) interfaces and/or devices, and others. Accordingly, the network interface apparatus 100 can be used for a variety of physical layer (PHY) devices in a variety of applications.

[0016] The PHY device 106 is coupled between the communication lines and the common mode suppression (CMS) circuit 116A. A power circuit 126 includes a power supply transformer with a primary winding and a secondary winding. The primary winding is coupled to the transient event suppression device 110A and referenced to a power ground level 128. The secondary winding is coupled to a PHY ground level 107. The power circuit 126 delivers power from the PHY ground level 107 to the PHY device.
The PHY device 106 is also referenced to the power ground level 128. Note that in some embodiments, a magnetic transformer of conventional systems may be eliminated while transformer functionality is maintained. Techniques enabling replacement of the transformer may be implemented in the form of integrated circuits (ICs) or discrete components. Examples of such devices, including an autoformer device, that can be used in addition to or instead of a magnetic transformer are further described in U.S. Patent Application No. 11/279,322 entitled "Network Devices for Separating Power and Data Signals", filed April 11, 2006, and incorporated herein by reference.

The power ground level 128 and the PHY ground level 107 are coupled to provide a low impedance path during normal operation and high impedance during transient events. Transient protection apparatus 124 is coupled between the power ground level 128 and the PHY ground level 107 and operates to create an open circuit up to a voltage sufficient to fully turn on the T-connect element 110A. Transient protection apparatus 124 subsequently operates to become a short-circuit to enable passing strikes from the T-connect element 110A to form a discharge path, directing the strikes away from an undesired path through PHY device 106. The transient protection apparatus 124 is thus configured to create a low impedance connection between the power ground level 128 and the PHY ground level 107 in normal operation and a high impedance connection between the power ground level 128 and the PHY ground level 107 during a transient event.

FIG. 1C shows a generalized stressing circuit 150 that can be used to explain the cause of stress from a transient event in a system, such as network interface apparatus 100A. All stressing circuits use capacitive storage devices, represented by capacitor 152, to set the energy level of the stress from a transient energy event. The higher the voltage of the event and the capacitance of the system, generally the higher the stress from the event. Series resistance, represented by resistor 154, limits the peak current of the stress. Note that the thermal stress created is generally proportional to the peak current. Additional components 156 in the system 150 can be used to shape the pulse. The level of stress is typically proportional to the rate of increase of the current in the system 150. Additionally, transient events can occur in negative and positive directions relative to the components of system 150.

A pathway through the T-connect element 110A forms a DC path for current that limits energy through the PHY device 106. The T-connect element 110A and the PHY 106 are referenced to different ground levels. Referring to FIGS. 1D and 1E, an embodiment of system 160 is shown including a T-connect element 162 connected to
earth ground 164 to limit energy through PHY device 106 during a transient energy event. The T-connect element 162 is sized to handle both surge current and Power-over-Ethernet current feed. During a surge event, the T-connect element 162 will start to turn on, typically in less than 1 nanosecond. Transient protection apparatus 124 operates to limit energy through the PHY device 106 to approximately 1 percent of the energy of the stress event. FIG. 1E shows a time history of current through components in system 160 over time during a transient energy event. When the strike initially occurs, as indicated by graph 170, current flows to PHY device 106, as indicated by graph 172. Once the current across capacitor 152 rises to a specified level during the stress event, T-connect element 162 begins conducting, as indicated by graph 174, providing a low impedance path to earth ground 164. For even a relatively high level of cross-ground capacitance, for example 50OpF, the T-connect element 110A turns on rapidly, for in example in about 2 nanoseconds or less. The energy from the transient event is thus directed away from the PHY device 106 while the current remains at the specified level.

[0020] Other devices that can be used for transient event suppression module 110 are shown in FIG. 2. One embodiment depicts a zener diode 110B coupled to local ground. In some embodiments, a zener diode can have a forward-biased diode. Another example that can be used in place of zener diode protection is an active device 110C such as an N-channel MOS (NMOS) device with a gate tied to ground. In another example of an active shunt device, a parasitic bipolar device can enable a snap back operation to enable protection. A further example is a stack of diodes coupled in series 110D coupled in parallel with another diode.

[0021] Referring again to FIG. 1A, in absence of a clamping capability of the transient protection apparatus 124, current flows through the PHY 106. Current initially flows into the PHY 106 and then switches to the transient event suppression module 110, thereby moving the ground levels apart. In a typical configuration, the amount of current for a positive strike is larger than for a negative strike. A clamping circuit in the transient protection apparatus 124 can be used to internally limits current, thereby limiting current through the PHY 106 and the T-connect element 110A. The clamping circuit functions to saturate and limit current. Current through the PHY 106 predominantly results from capacitance between the grounds.

[0022] Referring to FIG. 3A, a schematic block diagram depicts an embodiment of an electronic apparatus 124A that can be used as the transient protection apparatus 124 in FIG. 1. Apparatus 124A incorporates a clamping circuit that operates to protect electronic equipment from potentially harmful transient events and reduce or eliminate
common-mode noise that is a result of switching transients in DC/DC converters that flow from the primary side to the secondary side of the power transformer. The electronic apparatus 124A can comprise first 302A and second 302B Metal Oxide Semiconductor Field Effect Transistor (MOSFET) enhancement mode devices that are coupled respectively in series between first 304A and second 304B supply domains and coupled to respective first 306A and second 306B nodes. First 308A and second 308B active circuits are coupled to gates of the respective first 302A and second 302A MOSFET enhancement mode devices and operate to close the respective device in low current/voltage conditions while opening the respective device for large currents.

[0023] The MOSFETs 302A and 302B operate as switches that are closed for low currents and/or voltages and open for large DC and/or transient currents under control of the active circuits 308A, 308B. The active circuits 308A, 308B are connected to control the switches 302A and 302B and reference to ground domains that can be different. In the illustrative embodiment, the grounds can be described as a control ground (GND_CRTL) which corresponds to an output node or pin and a physical layer (PHY) ground (GND_PHY) which corresponds to an input node or pin.

[0024] In a different implementation, instead of a direct ground level a high-voltage capacitor can be used to connect either ground side potential to allow isolation while maintaining low impedance to reduce common-mode noise. Various circuits disclosed herein can be used to provide an isolated supply potential.

[0025] The illustrative electronic apparatus 124A includes active devices and accordingly is a powered circuit, as distinguished from circuits using depletion-mode devices that can be non-powered. The use of active devices enables integration into a much wider range of process technologies where depletion mode devices are not generally available. For clarification of definitions herein, note that native MOSFET transistors in some processes under certain conditions are called depletion mode devices but would still require active gate control to provide good performance. Such devices are defined as "enhancement mode" devices since threshold voltages are not sufficiently negative to be used without power. The illustrative embodiment of the electronic apparatus 124A can be configured for high voltage application. Voltages between the grounds 318A and 318B can move a relatively large voltage apart. In a particular embodiment, the grounds can move 60-70 volts apart, although other configurations can operate at different levels. The shunting circuit that sets the voltage movement of the grounds can be the TlessConnect™ circuit described hereinafter.
First 310A and second 310B circuits can be coupled across the respective first 302A and second 302A MOSFET enhancement mode devices in a configuration such that removal of a transient condition returns the short-circuit or low impedance connection between the first 306A and second 306B nodes, thereby returning to normal operation. Circuits 310A and 310B ensure that once a condition is removed, ground level for the two references returns concurrently. The circuit can be designed, for example by selection of resistors 336A and 336B, for fast opening and slow closing of the switches 302A, 302B, for example using the resistors 336A and 336B rather than directly driving switches. In the illustrative embodiment, the circuits 310A and 310B are depicted as resistors 310A and 310B that return the circuit to low impedance operation. Use of resistors enables control of impedance in a relatively simple implementation. Other embodiments, the control circuits can be arranged to detect removal of the transient condition and returns the short-circuit or low impedance connection between the first and second nodes and normal operation. A protection circuit can be constructed to return to the short-circuit or low impedance condition by monitoring output and input nodes for detection of a condition that either the current or voltage transient has diminished. An active circuit can be controlled that returns the switches 302A, 302B to normal operation.

The electronic apparatus 124A can be configured to rapidly drive impedance between the first 306A and second 306B nodes high in response to the transient event while returning to a short-circuit or low impedance connection between the first 306A and second 306B nodes when the transient event has ceased. Thus, the illustrative electronic apparatus 124A is configured to handle large current transients. Inherent in a MOSFET transistor is a transient limiting capability that arises because once current in the transistor is sufficiently large, the drain-to-source voltage rises to the point that the transistor will saturate, enabling a first level of surge protection that is inherently extremely fast-acting. The transient limiting capability protects against electrostatic discharge (ESD) events such as those defined in International Electrotechnical Commission (IEC) standard 61000-4-2, which have very high current, for example as much as 30A, and short durations. Active shutting off of devices is more pertinent for slow acting but longer duration events such as events defined in IEC 61000-4-5.

The first 316A and second 316B power supplies are independent and DC isolated from one another with power to operate the circuit continuous even during the surge event.
[0029] The active devices 308A, 308B are depicted as comparators. In normal operation, as long as the voltage at the center-point 307 is lower than a predetermined reference voltage which is set by the comparators 308A, 308B, the electronic apparatus 124A remains in normal operation. Under conditions of a strong surge or stress event, then the voltage at point 307 is elevated and one of the two comparators 308A, 308B is activated and shuts off the relatively large MOSFET device 302A or 302B that is controlled by the activated comparator. The comparators 308A, 308B control the large MOSFETs 302A, 302B through low or medium size transistors 332A, 332B to facilitate switching and overcoming the parasitic diodes that can be inherent in the back-to-back MOSFETs 302A, 302B which are coupled in series.

[0030] In some embodiments, the electronic apparatus 124A can be configured as a generic protection device rather for a particular application. In a specific example embodiment, the high voltage MOSFETs 302A, 302B can be 80 volt devices and the low or middle voltage transistors 332A and 332B can be 5 volt devices.

[0031] In some embodiments, the electronic apparatus 124A can be formed using a silicon-on-insulator (SOI) process. In other embodiments, the electronic apparatus 124A can be formed using a junction-isolated process. Various other processes may also be suitable. The electronic devices 124A and 124B are typically a highly suitable application for the silicon-on-insulator (SOI) process. The silicon-on-insulator (SOI) process reduces the amount of electrical charge that a transistor moves during a switching operation, thereby increasing switching speed and reducing switching energy over other processes such as CMOS. SOI differs from generic CMOS in that a silicon junction is located above an electrical insulator so that the insulator reduces capacitance. Thus, a transistor can switch after a smaller amount of charging, thereby reducing switching time, elevating resistance to latch-up, and reducing leakage. The SOI process also allows higher voltages between the input and output nodes, due to parasitic devices breakdown voltages, than would be allowed on a standard junction isolated process. In some configurations, a deep nwell CMOS process can potentially provide isolation that would be sufficient for a lower voltage application, such as applications in embodiments shown hereinafter.

[0032] FIGs. 3A and 3B depict embodiments wherein multiple independent supplies 316A, 316B are available to the circuit, and illustrate example techniques for coupling the independent supplies 316A, 316B. Referring to FIG. 3B, a schematic block diagram shows another embodiment of an electronic apparatus 124B that can be used for transient protection, node suppression, and the like. The electronic apparatus 124B can
comprise one or more shunt devices 312A coupled from the first node 306A to a point that has low impedance to an earth ground reference 318 for shunting transient event energy to the earth ground reference 318A. The shunt devices 312A, 312B, 314A, 314B can be coupled around the MOSFETs 302A, 302B in compliance with Joint Electron Device Engineering Council (JEDEC) specifications, for example JEDEC 2000V ESD chip level specifications, while still limiting system level surge events. Such JEDEC compliance ensures that the devices can handle transient events before assembly into a system.

[0033] Some embodiments may further comprise one or more shunt devices 312B
coupled between the second active circuit 308A and the second MOSFET enhancement mode device 302B and can be controlled by the second active circuit 308B for shunting transient event energy to a ground reference 318B. FIG. 3B depicts the shunt devices 312A, 312B, 314A, and 314B as single zener diodes. Other embodiments may implement any suitable configuration, such as multiple diodes in series or parallel, which can be selected on the basis of various considerations such as process technology.

[0034] In various embodiments and arrangements, the shunt devices can be
selected from among zener diodes, avalanche diodes, diode stacks, snapback metal oxide semiconductor field effect transistor (MOSFET)s, a Silicon-Controlled Rectifier (SCR) thyristors, other transient suppressor circuits, or the like.

[0035] Referring again to FIGs. 3A and 3B, further embodiments of an apparatus
124A,B for transient protection are illustrated. An apparatus electrically couples first and second nodes in respective first 304A and second 304B supply domains, which are referenced to ground levels 318A and 318B that can be different. The apparatus 124A comprises first 302A and second 302B high voltage devices coupled in parallel to first
332A and second 332B low and/or medium voltage devices, respectively. The first 302A
and second 302B high voltage devices are controlled by signals respectively referenced
to the first 304A and second 304B supply domains.

[0036] The apparatus 124A,B can further comprise a controller 334 coupled to the
first 302A and second 302B high voltage devices and the first 332A and second 332B
low and/or medium voltage devices. The controller 334 can be controlled by the signals
that are respectively referenced to the first 304A and second 304B supply domains to
create a short-circuit or low impedance connection between the first 306A and second
306B nodes in normal operation and increase impedance between the first 306A and
second 306B nodes sufficiently to isolate against destructive transient energy in
response to a transient event.
For example, the apparatus 124A,B can include a controller 334 that comprises first 308A and second 308B comparators coupled respectively to the first 302A and second 302B high voltage devices and the first 332A and second 332B low and/or medium voltage devices. The first 308A and second 308B comparators are controlled by the signals respectively referenced to the first 304A and second 304B supply domains to create a short-circuit or low impedance connection between the first and second nodes in normal operation and increase impedance between the first and second nodes sufficiently to isolate against destructive transient energy in response to a transient event.

The apparatus 124A,B can further comprise first 310A and second 310B resistors respectively coupled across the first 302A and second 302B high voltage devices so that removal of a transient condition returns the short-circuit or low impedance connection to node 307 in normal operation.

One or more shunt devices 312 can be coupled to at least one of the first 302A and second 302B high voltage devices for shunting transient event energy to an earth ground reference 318. In various embodiments and arrangements, the shunt devices 312 can be selected from among zener diodes, avalanche diodes, diode stacks, snapback metal oxide semiconductor field effect transistor (MOSFET)s, a Silicon-Controlled Rectifier (SCR) thyristors, other transient suppressor circuits, or the like.

The apparatus 124A can be constructed using any suitable process, for example a silicon-on-insulator process, a junction isolated process, or another process.

The apparatus 124A can operate to rapidly drive impedance between the first 306A and second 306B nodes high in response to the transient event and return to the short-circuit or low impedance connection between the first 306A and second 306B nodes when the transient event has ceased.

The first 306A and second 306B nodes can be respectively powered by first 316A and second 316B power supplies that are held in substantially independent isolation by the apparatus 124A whereby circuits referenced to the respective first 304A and second 304B supply domains are supplied with power constantly including during the transient event.

In accordance with a specific embodiment of an electronic apparatus 124A shown in FIG. 3A, first 302A and second 302B Metal Oxide Semiconductor Field Effect Transistor (MOSFET) depletion mode devices can coupled respectively in series between first 304A and second 304B supply domains and coupled to first 306A and
second nodes 306B. The electronic apparatus 124A can further comprise first 308A and second 308B active circuits coupled to gates of the respective first 302A and second 302B MOSFET depletion mode devices, thereby operating to close the appropriate device for a low current/voltage condition and open the device for large currents.

[0044] In accordance with another specific embodiment of an electronic apparatus 124A shown in FIG. 3A, first 302A and second 302B Junction Field Effect Transistor (JFET) devices coupled respectively in series between first 304A and second 304B supply domains and coupled to respective first 306A and second 306B nodes. First 308A and second 308B active circuits can be coupled to gates of the first 302A and second 302B JFET devices, thereby functioning to close the appropriate device for a low current/voltage condition and open the device for large currents.

[0045] Referring again to FIG. 3A, a further embodiment of an apparatus 124A for transient protection is shown. An apparatus 124A electrically couples first 306A and second 306B nodes in respective first 304A and second 304B supply domains coupled through low impedance to separate ground levels. The apparatus 124A comprises first 302A and second 302B active devices controlled by signals respectively referenced to the first 304A and second 304B supply domains and create a short-circuit or low impedance connection between the first 306A and second 306B nodes in normal operation and increase impedance between the first 306A and second 306B nodes sufficiently to isolate against destructive transient energy in response to a transient event.

[0046] A clamping device enables two electrically-connected nodes to become a short circuit or low resistance in normal conditions but to form an open circuit under strong surge or transient events. In various embodiments, the clamping device can function as a cross-clamp combined with surge protection. In some illustrative embodiments, protection is implemented when independent supplies are available in a system. In other embodiments, protection is attained in a circuit that generates a pseudo-isolated or surge-isolated supply using a switched capacitor or other circuit. In further embodiments, protection is implemented in a circuit that generates a surge-isolated supply through usage of resistors alone.

[0047] In a particular application, an active clamping circuit can be used in an appropriate configuration to directly protect transceivers of physical layer (PHY) devices in a transmission signal path to prevent surge events from damaging the PHY device.
The various embodiments of active clamping devices can be used generally in any application that has low impedance for normal operation and high impedance during transient current/voltage events. Accordingly, the disclosed clamping devices have potential application outside of surge protection, for instance circuits and systems with common-mode immunity capability and non-linear signal separation.

Another application of various embodiments of the active clamping circuit disclosed herein is a series current limiting element that can protect a PHY transmitter or receiver device wherein the active clamping circuit is combined in series with a sensitive transmission signal path, often differential. The active clamping device ensures that over-voltage and over-current events do not discharge through the either the transmitter or receiver element but instead are harmlessly passed to earth ground via a shunting surge element.

Referring to FIGURE 3A, a schematic block diagram depicts an embodiment of an electronic apparatus 300A that can be used to protect electronic equipment from potentially harmful transient events and reduce or eliminate common-mode noise that is a result of switching transients in DC/DC converters that flow from the primary side to the secondary side of the power transformer. The electronic apparatus 300A can comprise first 302A and second 302B Metal Oxide Semiconductor Field Effect Transistor (MOSFET) enhancement mode devices that are coupled respectively in series between first 304A and second 304B supply domains and coupled to respective first 306A and second 306B nodes. First 308A and second 308B active circuits are coupled to gates of the respective first 302A and second 302A MOSFET enhancement mode devices and operate to close the respective device in low current/voltage conditions while opening the respective device for large currents.

The MOSFETs 302A and 302B operate as switches that are closed for low currents and/or voltages and open for large DC and/or transient currents under control of the active circuits 308A, 308B. The active circuits 308A, 308B are connected to control the switches 302A and 302B and reference to ground domains that can be different. In the illustrative embodiment, the grounds can be described as a control ground (GND_CTRL) which corresponds to an output node or pin and a physical layer (PHY) ground (GND_PHY) which corresponds to an input node or pin.

In a different implementation, instead of a direct ground potential a high-voltage capacitor can be used to connect either ground side potential to allow isolation while maintaining low impedance to reduce common-mode noise. Various circuits disclosed herein can be used to provide an isolated supply potential.
The illustrative electronic apparatus 300A includes active devices and accordingly is a powered circuit, as distinguished from circuits using depletion-mode devices that can be non-powered. The use of active devices enables integration into a much wider range of process technologies where depletion mode devices are not generally available. For clarification of definitions herein, note that native MOSFET transistors in some processes under certain conditions are called depletion mode devices but would still require active gate control to provide good performance. Such devices are defined as "enhancement mode" devices since threshold voltages are not sufficiently negative to be used without power. The illustrative embodiment of the electronic apparatus 300A can be configured for high voltage application. Voltages between the grounds 318A and 318B can move a relatively large voltage apart. In a particular embodiment, the grounds can move 60-70 volts apart, although other configurations can operate at different levels. The shunting circuit that sets the voltage movement of the grounds can be the TlessConnect™ circuit described hereinafter.

First 310A and second 310B circuits can be coupled across the respective first 302A and second 302A MOSFET enhancement mode devices in a configuration such that removal of a transient condition returns the short-circuit or low impedance connection between the first 306A and second 306B nodes, thereby returning to normal operation. Circuits 310A and 310B ensure that once a condition is removed, ground potential for the two references returns concurrently. The circuit can be designed, for example by selection of resistors 336A and 336B, for fast opening and slow closing of the switches 302A, 302B, for example using the resistors 336A and 336B rather than directly driving switches. In the illustrative embodiment, the circuits 310A and 310B are depicted as resistors 310A and 310B that return the circuit to low impedance operation. Use of resistors enables control of impedance in a relatively simple implementation. Other embodiments, the control circuits can be arranged to detect removal of the transient condition and returns the short-circuit or low impedance connection between the first and second nodes and normal operation. A protection circuit can be constructed to return to the short-circuit or low impedance condition by monitoring output and input nodes for detection of a condition that either the current or voltage transient has diminished. An active circuit can be controlled that returns the switches 302A, 302B to normal operation.

The electronic apparatus 300A can be configured to rapidly drive impedance between the first 306A and second 306B nodes high in response to the transient event while returning to a short-circuit or low impedance connection between the first 306A and
second 306B nodes when the transient event has ceased. Thus, the illustrative electronic apparatus 300A is configured to handle large current transients. Inherent in a MOSFET transistor is a transient limiting capability that arises because once current in the transistor is sufficiently large, the drain-to-source voltage rises to the point that the transistor will saturate, enabling a first level of surge protection that is inherently extremely fast-acting. The transient limiting capability protects against electrostatic discharge (ESD) events such as those defined in International Electrotechnical Commission (IEC) standard 61000-4-2, which have very high current, for example as much as 30A, and short durations. Active shutting off of devices is more pertinent for slow acting but longer duration events such as events defined in IEC 61000-4-5.

[0056] The first 316A and second 316B power supplies are independent and DC isolated from one another with power to operate the circuit continuous even during the surge event.

[0057] The active devices 308A, 308B are depicted as comparators. In normal operation, as long as the voltage at the center-point 307 is lower than a predetermined reference voltage which is set by the comparators 308A, 308B, then the clamping apparatus 300A remains in normal operation. Under conditions of a strong surge or stress event, then the voltage at point 307 is elevated and one of the two comparators 308A, 308B is activated and shuts off the relatively large MOSFET device 302A or 302B that is controlled by the activated comparator. The comparators 308A, 308B control the large MOSFETs 302A, 302B through low or medium size transistors 332A, 332B to facilitate switching and overcoming the parasitic diodes that can be inherent in the back-to-back MOSFETs 302A, 302B which are coupled in series.

[0058] In some embodiments, the electronic apparatus 300A can be configured as a generic protection device rather for a particular application. In a specific example embodiment, the high voltage MOSFETs 302A, 302B can be 80 volt devices and the low or middle voltage transistors 332A and 332B can be 5 volt devices.

[0059] The illustrative electronic apparatus 300A depicts a singled-ended structure. In other embodiments, a differential configuration may be implemented. For example, the first and second nodes can be powered by respective first and second transient-isolated power supplies that are held mutually independent in transient isolation by a differential active clamp device that transfers power from the transient-isolated power supplies using a switched-capacitor circuit such as is shown in FIGURES 4A, 4B, and 4C.
In some embodiments, the electronic apparatus 300A can be formed using a silicon-on-insulator (SOI) process. In other embodiments, the electronic apparatus 300A can be formed using a junction-isolated process. Various other processes may also be suitable. The electronic devices 300A and 300B are typically a highly suitable application for the silicon-on-insulator (SOI) process. The silicon-on-insulator (SOI) process reduces the amount of electrical charge that a transistor moves during a switching operation, thereby increasing switching speed and reducing switching energy over other processes such as CMOS. SOI differs from generic CMOS in that a silicon junction is located above an electrical insulator so that the insulator reduces capacitance. Thus, a transistor can switch after a smaller amount of charging, thereby reducing switching time, elevating resistance to latch-up, and reducing leakage. The SOI process also allows higher voltages between the input and output nodes, due to parasitic devices breakdown voltages, than would be allowed on a standard junction isolated process. In some configurations, a deep nwell CMOS process can potentially provide isolation that would be sufficient for a lower voltage application, such as applications in embodiments shown hereinafter.

FIGURES 3A and 3B depict embodiments wherein multiple independent supplies 316A, 316B are available to the circuit, and illustrate example techniques for coupling the independent supplies 316A, 316B. Referring to FIGURE 3B, a schematic block diagram shows another embodiment of an electronic apparatus 300B that can be used for transient protection, node suppression, and the like. The electronic apparatus 300B can comprise one or more shunt devices 312A coupled from the first node 306A to a point that has low impedance to an earth ground reference 318 for shunting transient event energy to the earth ground reference 318. The shunt devices 312A, 312B, 314A, 314B can be coupled around the MOSFETs 302A, 302B in compliance with Joint Electron Device Engineering Council (JEDEC) specifications, for example JEDEC 2000V ESD chip level specifications, while still limiting system level surge events. Such JEDEC compliance ensures that the devices can handle transient events before assembly into a system.

Some embodiments may further comprise one or more shunt devices 312B coupled between the second active circuit 308A and the second MOSFET enhancement mode device 302B and can be controlled by the second active circuit 308B for shunting transient event energy to a ground reference 318. FIGURE 3B depicts the shunt devices 312A, 312B, 314A, and 314B as single zener diodes. Other embodiments may
implement any suitable configuration, such as multiple diodes in series or parallel, which can be selected on the basis of various considerations such as process technology.

[0063] In various embodiments and arrangements, the shunt devices can be selected from among zener diodes, avalanche diodes, diode stacks, snapback metal oxide semiconductor field effect transistor (MOSFET)s, a Silicon-Controlled Rectifier (SCR) thyristors, other transient suppressor circuits, or the like.

[0064] Referring again to FIGURES 3A and 3B, further embodiments of an apparatus 300A, B for transient protection are illustrated. An active clamp device 300A, B electrically couples first and second nodes in respective first 304A and second 304B supply domains which are referenced to ground potentials 318A and 318B that can be different. The active clamp device 300A comprises first 302A and second 302B high voltage devices coupled in parallel to first 332A and second 332B low and/or medium voltage devices, respectively. The first 302A and second 302B high voltage devices are controlled by signals respectively referenced to the first 304A and second 304B supply domains.

[0065] The active clamp device 300A, B can further comprise a controller 334 coupled to the first 302A and second 302B high voltage devices and the first 332A and second 332B low and/or medium voltage devices. The controller 334 can be controlled by the signals that are respectively referenced to the first 304A and second 304B supply domains to create a short-circuit or low impedance connection between the first 306A and second 306B nodes in normal operation and increase impedance between the first 306A and second 306B nodes sufficiently to isolate against destructive transient energy in response to a transient event.

[0066] For example, the active clamp device 300A, B can include a controller 334 that comprises first 308A and second 308B comparators coupled respectively to the first 302A and second 302B high voltage devices and the first 332A and second 332B low and/or medium voltage devices. The first 308A and second 308B comparators are controlled by the signals respectively referenced to the first 304A and second 304B supply domains to create a short-circuit or low impedance connection between the first and second nodes in normal operation and increase impedance between the first and second nodes sufficiently to isolate against destructive transient energy in response to a transient event.

[0067] The active clamp device 300A, B can further comprise first 310A and second 310B resistors respectively coupled across the first 302A and second 302B high voltage
devices so that removal of a transient condition returns the short-circuit or low impedance connection to node 307 in normal operation.

[0068] One or more shunt devices 312 can be coupled to at least one of the first 302A and second 302B high voltage devices for shunting transient event energy to an earth ground reference 318. In various embodiments and arrangements, the shunt devices 312 can be selected from among zener diodes, avalanche diodes, diode stacks, snapback metal oxide semiconductor field effect transistor (MOSFET)s, a Silicon-Controlled Rectifier (SCR) thyristors, other transient suppressor circuits, or the like.

[0069] The active clamp device 300A can be constructed using any suitable process, for example a silicon-on-insulator process, a junction isolated process, or another process.

[0070] The active clamp device 300A can operate to rapidly drive impedance between the first 306A and second 306B nodes high in response to the transient event and return to the short-circuit or low impedance connection between the first 306A and second 306B nodes when the transient event has ceased.

[0071] The first 306A and second 306B nodes can be respectively powered by first 316A and second 316B power supplies that are held in substantially independent isolation by the active clamp device 300A whereby circuits referenced to the respective first 304A and second 304B supply domains are supplied with power constantly including during the transient event.

[0072] In accordance with a specific embodiment of an electronic apparatus 300A shown in FIGURE 3A, first 302A and second 302B Metal Oxide Semiconductor Field Effect Transistor (MOSFET) depletion mode devices can coupled respectively in series between first 304A and second 304B supply domains and coupled to first 306A and second nodes 306B. The electronic apparatus 300A can further comprise first 308A and second 308B active circuits coupled to gates of the respective first 302A and second 302B MOSFET depletion mode devices, thereby operating to close the appropriate device for a low current/voltage condition and open the device for large currents.

[0073] In accordance with another specific embodiment of an electronic apparatus 300A shown in FIGURE 3A, first 302A and second 302B Junction Field Effect Transistor (JFET) devices coupled respectively in series between first 304A and second 304B supply domains and coupled to respective first 306A and second 306B nodes. First 308A and second 308B active circuits can be coupled to gates of the first 302A and
second 302B JFET devices, thereby functioning to close the appropriate device for a low current/voltage condition and open the device for large currents.

[0074] Referring again to FIGURE 3A, a further embodiment of an apparatus 300A for transient protection is shown. An active clamp device 300A electrically couples first 306A and second 306B nodes in respective first 304A and second 304B supply domains coupled through low impedance to separate ground potentials. The active clamp device 300A comprises first 302A and second 302B active devices controlled by signals respectively referenced to the first 304A and second 304B supply domains and create a short-circuit or low impedance connection between the first 306A and second 306B nodes in normal operation and increase impedance between the first 306A and second 306B nodes sufficiently to isolate against destructive transient energy in response to a transient event.

[0075] Referring to FIGURES 4A, 4B, and 4C, schematic block diagrams show an embodiment of a protection apparatus 400 that can be used for transient protection and noise reduction and illustrate an example implementation of a differential circuit. FIGURE 4A is a block diagram which illustrates isolated supply generation for the protection apparatus 400 and indicates the high surge impedance of the circuit. FIGURE 4B is a schematic circuit diagram showing a switched-capacitor approach to generating a surge-isolated supply which allows high current to be drawn from the isolated domain within the protection apparatus 400. FIGURE 4C depicts a pin-out structure of the protection apparatus 400.

[0076] The illustrative protection apparatus 400 can comprise one or more protection circuits 402 that couple a plurality of input 404I and output 404O nodes and one or more ground references 416. The protection apparatus 400 comprises a plurality of active devices 408 and at least one shunt device 410. The active devices 408 are controlled by signals at the input nodes 404I and the output nodes 404O that function as switches and create a short circuit or low impedance connection between the input and output nodes in normal operation and increase impedance between the input and output nodes to isolate against destructive transient energy in response to a transient event. The one or more shunt devices 410 are shunting means that are configured to conduct transient currents associated with destructive transient energy to a ground reference 416.

[0077] The protection apparatus 400 is a differential circuit and enables formation of an independent supply from the local supply 414L. The differential circuit 400 includes a differential input terminal 404I, a differential output terminal 404O, local powering \( V_{\text{LOCAL}} \), 414L, and ground GND \(_{\text{LOCAL}}\) 416L and GND\(_{\text{ISO}}\) 416L.
FIGURE 4A shows a local supply $V_{LCA414L}$ that is input to the protection apparatus 400 and the isolated supply $V_{LCO4141}$ which is created by the circuit 400. The $V_{LCA414L}$ is not truly DC isolated from the local supply $V_{LCO414L}$ but is effectively surge-protected, isolated, or surge-isolated due to the large resistance $R_{L1}R_{L2}$. The isolated impedance between the supplies and the switched-capacitor circuit 418. Most pertinently, the protection apparatus 400 enables the portion of the circuit labeled isolated to operate independently during a surge or transient event.

The switched-capacitor circuit 418 facilitates transient protection and transfers charge from the local supply $V_{LCA414L}$ to the isolated supply $V_{LCO4141}$ using, for example, a non-overlapping clock driver 430. The protection apparatus 400 includes surge protection circuitry that functions during a surge or transient event by opening the circuit between the two supplies so that the transient or surge event does not activate the isolated portion of the system. When the transient energy is no longer present, the protection apparatus 400 restores the high impedance connection between the supplies to restart the isolated portion of the circuit using a much smaller amount of power than the power to drive the main switch 408. Very large resistances and high impedances drive the circuit that powers the isolated portion of the circuit. The differential protection circuit 400 can operate with low power expenditure and can be formed through usage of large resistors $R_{L1}R_{L2}$. The switched-capacitor circuit 418 is illustratively clocked through a series of inverters 432 and large resistances $R_{L1}R_{L2}$. During a transient event, the protection apparatus 400 powers the isolated portion so that the reference potential GND is followed the surge energy up and down so that the energy does not couple directly through low impedance to the local supply $V_{LCA414L}$.

In the illustrative embodiment, components of the protection apparatus 400 include zener diodes 410, inverters 432, NOR gates 436, and large resistors $R_{L1}R_{L2}$. and MOSFETs 408.

The zener diodes 410 coupled adjacent the NOR gates 436, and inverters 432 operate to supply shunt protection. Other embodiments may increase or reduce the number, or eliminate usage, of the zener diodes for applications and conditions of varying exposure to surge and transient energy.

Referring again to FIGURES 4A, 4B, and 4C, another embodiment of a transient event protection apparatus 400 is illustrated. The transient event protection apparatus 400 comprises two or more differential input terminals 404I and two or more differential output terminals 404O. A first protection circuit 412A is coupled between a first of the differential input terminals 404I and a first of the differential output terminals.
404O. Similarly, a second protection circuit 412B is coupled between a second of the
differential input terminals 404I and a second of the differential output terminals 404O. A
local supply 414L is coupled to power a first portion 420A of the transient event
protection apparatus 400 relative to a local ground reference 416L. A switched-
capacitive circuit 418 is coupled to the first 412A and second 412B protection circuits
and formed to create an independent supply 4141 that powers a second portion 420B of
the transient event protection apparatus 400 relative to an associated independent
ground reference 4161.

[0083] The transient event protection apparatus 400 can further comprise a first
resistance 422A coupled between the local supply 414L and the independent supply
4141 and a second resistance 422B coupled between the local ground reference 416L
and the independent ground reference 4161. The switched capacitive circuit 418
transfers charge from the local supply 414L between the first 412A and second 412B
protection circuits so that the independent supply 4141 is isolated from the local supply
414L.

[0084] The switched capacitive circuit 418 isolates the independent supply 4141 from
the local supply 414L whereby energy in the second portion 420B of the transient event
protection apparatus 400 can move independently in response to a transient event and is
isolated from coupling to the first portion 420A and the local supply 414L.

[0085] In the illustrative embodiment, the first 412A and second 412B protection
circuits can individually comprise first 408A and second 408B active devices coupled in
series in a configuration that conducts current in opposite directions so that the active
devices 408A and 408B operate mutually out-of-phase. The active devices 408A and
408B are controlled, for example via some type of external protection or external active
circuitry to control gates of the active devices 408A and 408B, to create a short-circuit or
low impedance connection between the first 420A and second 420B portions of the
transient event protection apparatus 400 in normal operation and increase impedance
between the first 420A and second 420B portions sufficiently to isolate against
destructive transient energy in response to a transient event.

[0086] A shunt 410 can be coupled to at least one of the protection circuits 412A
and/or 412B and configured to respond during a transient event by forming a pathway for
shunting transient energy to local ground 416L. In various specific implementations, the
shunt 410 can be a parallel surge detection circuitry that is optional and can be included
or excluded from the circuit.
In accordance with another embodiment of a protection apparatus 400 as shown in FIGURES 4A, 4B, and 4C, the protection apparatus 400 can comprise at least one protection circuit 402 that couple a plurality of input 404I and output 404O nodes. The protection apparatus 400 comprises a plurality of active devices 408. The active devices 408 are controlled by signals at the input nodes 404I and the output nodes 404O that create a short circuit or low impedance connection between the input and output nodes in normal operation and increase impedance between the input and output nodes to isolate to isolate either a first node or a second node from either transient or short-circuit events. The impedance increase is sufficient to create a short circuit between the first and second node, preventing damage of a driving device on the isolated node. The protection apparatus 400 can be implemented to enable short-circuit protection whereby a shunt device can be eliminated.

The active devices 408 can be configured so that the impedance increase prevents an interaction of a transient event at the first node with circuits on the second node, a configuration that enables common-mode immunity testing or for conditions that a user desires to prevent a transient event.

In accordance with still another embodiment of a protection apparatus 400 as shown in FIGURES 4A, 4B, and 4C, the protection apparatus 400 can comprise at least one protection circuit 402 coupling a plurality of input 404I and output 404O nodes. The protection apparatus 400 comprises a plurality of active devices 408. The active devices 408 are controlled by signals at the input nodes 404I and the output nodes 404O that create a short circuit or low impedance connection between the input and output nodes in normal operation and increase impedance between the input and output nodes to isolate to isolate either a first node or a second node from either transient or short-circuit events. The impedance increase is sufficient to create high impedance to high currents whereby effects outside a range of normal current level are prevented. The active devices 408 can be constructed so that the impedance increase prevents an interaction of a transient event at the first node with circuits on the second node.

Referred to FIGURES 5A, 5B, and 5C, schematic flow charts illustrate an embodiment of a transient protection method 500 for protecting an electronic system against transient energy and suppressing noise. As shown in FIGURE 5A, the method 500 comprises electrically coupling 502 first and second nodes in respective first and second supply domains and referencing 504 the first and second supply domains to ground potentials that can be different. Impedance is controlled 506 based on signals referenced to the first and second supply domains. A short-circuit or low impedance
connection is created between the first and second nodes in normal operation. Impedance is increased between the first and second nodes sufficiently to isolate against destructive transient energy in response to a transient event.

[0091] Referring to FIGURE 5B, in some embodiments a method 520 can include rapidly driving 522 impedance between the first and second nodes high in response to the transient event. In contrast, impedance can be returned 524 to the short-circuit or low impedance connection between the first and second nodes when the transient event has ceased.

[0092] Referring to FIGURE 5C, the first and second nodes can be powered 532 by respective first and second power supplies that are held in substantially independent isolation. The method 530 can further comprise supplying 534 the respective first and second supply domains with power constantly, even during the transient event.

[0093] Referring to FIGURES 6A, 6B, 6C, and 6D, schematic block diagrams illustrate embodiments of a transient event protection apparatus 600A, 600B, 600C and 600D including example implementations of techniques for generating an isolated physical layer (PHY). A transient event protection apparatus 600A comprises a plurality of active devices 602A, 602B coupled in series between an input terminal 628I and an output terminal 6280. In various embodiments the illustrative active devices 602A, 602B can be N-channel metal oxide semiconductor (NMOS) transistors as shown in FIGURE 6A, P-channel metal oxide semiconductor (PMOS) transistors as shown in FIGURE 6B, or any other suitable active device. The active devices 602A and 602B are configured to conduct current in opposite directions. First 608A and second 608B control elements are respectively coupled to control the active devices 602A, 602B that conduct current in opposite directions. The first 608A and second 608B control elements are configured to create a short-circuit or low impedance connection between the input terminal 628I and the output terminal 6280 in normal operation and increase impedance between the input terminal 628I and the output terminal 6280 a sufficient amount to isolate against destructive transient energy in response to a transient event.

[0094] In the illustrative embodiment, a shunt 612 is coupled to the input terminal 628I and is arranged to respond during a transient event by forming a pathway that shunts transient energy to a low impedance path to an earth ground 618B. In some embodiments, the transient event protection apparatus 600A-D can have multiple shunts coupled in series to the input terminal 628I that can respond during the transient event by forming a pathway to shunt transient energy to earth ground. FIGURE 6A depicts multiple examples of shunt devices that can be used in various implementations. One
embodiment depicts a zener diode 612 coupled to local ground. In some embodiments, a zener diode can have a forward-biased diode. Another example that can be used in place of zener diode protection is an active device 612A such as an N-channel MOS (NMOS) device with a gate tied to ground. In another example of an active shunt device, a parasitic bipolar device can enable a snap back operation to enable protection. A further example is a stack of diodes coupled in series 612S coupled in parallel with another diode.

[0095] In the illustrative arrangement, the active devices 602A, 602B can be transistors coupled between the input terminal 628I and the output terminal 628O to conduct current in opposite directions. The first 608A and second 608B control elements are shown coupled to control terminals of the respective first 602A and second 602B transistors and are controlled by signals respectively referenced to first 616A and second 616B supply domains.

[0096] In a particular embodiment, the active devices 602A, 602B can be Metal Oxide Semiconductor Field-Effect Transistors (MOSFETs) coupled between the input terminal 628I and the output terminal 628O to conduct current in opposite directions. First 608A and second 608B comparators can be coupled to the control terminals of the first 602A and second 602B MOSFETs, respectively, and configured to compare signals between the input terminal 628I and the output terminal 628O with a voltage that is referenced to first 618A and second 618B references.

[0097] In a particular application, the input terminal 628I can be coupled to an Ethernet Physical Layer (PHY) and the transient event protection apparatus 600A-D configured to protect the Ethernet PHY by isolating against passing the destructive transient energy to the Ethernet PHY in response to the transient event. In other embodiments, the input terminal 628I can be configured for coupling to an interface or device and the transient event protection apparatus protects the interface and devices and systems coupled to the interface by isolating against passing the destructive transient energy to the interface. Any suitable type of device or interface can be protected, for example including Universal Serial Bus (USB) interfaces and/or devices, a RETMA standard (RS)-232 interfaces and/or devices, Transmission level 1 (T1) interfaces and/or devices, and others. Accordingly, the protection apparatus 600A-D can be used for a variety of physical layer (PHY) devices in a variety of applications.

[0098] The illustrative transient event protection apparatus 600A-D can be used as a PHY protection circuit which does not have independent supplies. The MOSFETs 602A, 602B can be connected with either the sources or drains coupled in bulk to the output.
node. In the illustrative embodiment, the drain is tied to the output node and the source
tied to the middle node. The comparators 608A, 608B control the circuit 600A-D. At the
input node 628I, another limiting circuit - the shunt 612 - can be inserted so that, during
a surge event, the voltage increases and the circuit 600A-D shuts down. The shunt 612
forms a path for the surge energy to pass to ground, preventing damaging energy from
passing to the PHY. In a Power-over-Ethernet (PoE) application, the input node 628I
can be connected to a transformer or may connect directly to a network line. In either
case, damaging energy flows away from the PHY and into the transient event protection
apparatus 600A-D. The transient event protection apparatus 600A-D activates and
creates an open circuit, forming a path to ground and shunting the transient or shunt
energy away from the PHY. Accordingly, the transient event protection apparatus 600A-
D combines series protection with surge protection in the form of shunt parallel
protection. In some embodiments and/or applications, the shunt 612 can be omitted.

[0099] Referring again to FIGURES 6A-6D, embodiments of a transient event
protection apparatus 600A-D can comprise first 602A and second 602B active
semiconductor devices coupled in series between an input terminal 628I and an output
terminal 6280 in a configuration so that the semiconductor devices 602A and 602B
conduct current in opposite directions. The semiconductor devices 602A and 602B are
controlled to create a short-circuit or low impedance connection between the input
terminal 628I and the output terminal 6280 in normal operation while increasing
impedance between the input terminal 628I and the output terminal 6280 sufficiently to
isolate against destructive transient energy in response to a transient event. A shunt 612
can be coupled to the input terminal 628I to enable a response during a transient event
which includes formation of a pathway shunting transient energy to an earth ground
618B of the system.

[0100] In the illustrative embodiments, the active control circuits are shown as
comparators. In other embodiments, the control circuits can be implemented in other
ways. For example, as shown in FIGURE 6E, some embodiments may implement an
active control circuit 608 using a sense resistor (R_sE_68E) coupled between MOSFETs and
coupled to an active circuit block, for example that can control a device such as an
amplifier rather than a comparator. The control circuit may implement voltage sensing or
current sensing to activate control operations. For example, a current sense control
circuit can sense current and when the current becomes too high, activate the switches.

[0101] FIGURES 6C and 6D show embodiments of transient event protection
devices 600C and 600D for usage in conditions that an isolated supply is not available.
Cross-coupling of the control elements 608A and 608B enables creation of an isolated supply in the absence of an actual or physical isolated supply. Cross-coupling connects the input terminal through resistors that are sufficiently large to create a deterrent to the surge. The capacitor 622 stores the energy that is used to operate the protection circuit during a surge event. The time constant is set by values of the resistor and capacitor. The illustrative transient event protection devices 600C and 600D enable implementation of protection without usage of a switched-capacitor circuit and are highly suitable for implementation in a standard complementary metal-oxide-semiconductor (CMOS) process. In normal operation the current draw of these active devices 602A, 602B, for example MOSFETs, does not draw much capacitance and the control elements 608A, 608B, for example comparators, have very low power. The amount of current drawn through the circuit that ties to the isolated section of the circuit draws a low enough current that impact on the drive voltages for the active devices 602A, 602B is small or negligible. In contrast, during a surge event and the input surge is high, one active device tracks the surge event and ensures that the opposing active device remains shut off through operation of the cross-coupling. The transient event protection devices 600C and 600D, rather than generating an isolated physical layer (PHY), uses resistive isolation to generate a surge-isolated supply through usage of resistors alone since a relatively small amount of power is driven. Capacitive overcharge on the circuit moves up and down with the surge event.

FIGURES 6A, 6B, and 6C illustrate embodiments of transient event protection devices that include two MOSFET devices, either N-channel or P-channel, coupled in series in a structure that is most useful when the potential is near ground. However, in many applications a signal may be applied to the circuit that raises the potential substantially above ground, for example creating a large Vgs voltage on the MOSFET devices. FIGURE 6D illustrates an embodiment comprising a plurality of MOSFET enhancement mode devices, specifically a circuit that includes both N-channel MOS (NMOS) 612A, 612B and P-channel MOS (PMOS) 614A, 614B transistors. The series-connected NMOS devices 612A, 612B are connected in parallel with series-connected PMOS devices 614A, 614B of the opposite polarity type to enable usage with a broader range of operating voltages. The transient event protection devices 600A-D are typically highly suitable for implementation using a junction-isolated process.

Referring to FIGURE 7, a schematic flow chart depicts an embodiment of a method 700 electronic devices and components against transient energy. The illustrative transient event protection method 700 can comprise coupling 702 first and
second active semiconductor devices in series between an input terminal and an output
terminal and configuring 704 the first and second active semiconductor devices to
conduct current in opposite directions. The first and second active semiconductor
devices are controlled 706 to create a short-circuit or low impedance connection
between the input terminal and the output terminal in normal operation and increase
impedance between the input terminal and the output terminal sufficiently to isolate
against destructive transient energy in response to a transient event.

[0104] In some applications, a shunt can be coupled 708 to the input terminal. The
shunt can be configured 710 to respond during a transient event by forming a pathway
for shunting transient energy to a local ground.

[0105] Referring to FIGURE 8, a schematic block diagram illustrates an embodiment
of a Power-over-Ethernet (PoE) system 800 that can include a transient protection
apparatus 802 according to the various disclosed embodiments. The PoE system 800
includes a network connector 804 coupled to an Ethernet Physical Layer (PHY) 806. A
controller device 808 is coupled to the network connector 804 and to the PHY 806 and
includes a TConnect element 810 such as a TLessConnect™ solid state transformerless
device, a powered device (PD) controller 812, and a DC-DC converter 814. The
transient protection apparatus 802 is low impedance in normal operation. In response to
a transient or surge event, the transient protection apparatus 802 creates an open circuit
up to the voltage sufficient to fully turn on the TConnect element 810, subsequently
becoming a short-circuit again to enable passing strikes from the TConnect element 810
to form a discharge path, directing the strikes away from an undesired path.

[0106] A pathway through the TConnect element 810 forms a DC path for current
that limits energy through the PHY 806. The TConnect element 810 and the PHY 806
are referenced to different ground potentials. For even a relatively high level of cross-
ground capacitance, for example 50OpF, the TConnect 810 turns on rapidly, for in
example in about 2 nanoseconds or less. The transient protection apparatus 802 can
increase current in the TConnect path.

[0107] In absence of the clamping capability of the transient protection apparatus
802, current flows through the PHY 806. Current initially flows into the PHY 806 and
then switches to the TConnect element 810, thereby moving the ground potentials apart.
In a typical configuration, the amount of current for a positive strike is larger than for a
negative strike. The clamping circuit in the transient protection apparatus 802 internally
limits current, thereby limiting current through the PHY 806 and the TConnect element
810. The clamping circuit functions to saturate and limit current. Current through the PHY 806 predominantly results from capacitance between the grounds.

[0108] Referring to FIGURES 9A, 9B, and 9C, schematic flow charts illustrate an embodiment of a transient protection method 900 for protecting an electronic system against transient energy and suppressing noise. As shown in FIGURE 9A, the method 900 comprises electrically coupling 902 first and second nodes in respective first and second supply domains and referencing 904 the first and second supply domains to ground levels that can be different. The transient suppression module is coupled 906 to earth ground. A switch is opened 908 to separate the respective grounds referenced to the supply domains. Once the switch is opened, the transient energy is conducted 910 to earth ground. When the transient event is over, the switch is closed 912 to couple the respective grounds back together during regular operation.

[0109] Referring to FIGURE 9B, in some embodiments a method 920 can include rapidly driving 922 impedance between the first and second nodes high in response to the transient event. In contrast, impedance can be returned 924 to the short-circuit or low impedance connection between the first and second nodes when the transient event has ceased.

[0110] Referring to FIGURE 9C, the first and second nodes can be powered 932 by respective first and second power supplies that are held in substantially independent isolation. The method 930 can further comprise supplying 934 the respective first and second supply domains with power constantly, even during the transient event.

[0111] Referring to FIGURE 10, a schematic flow chart depicts an embodiment of a method 1000 electronic devices and components against transient energy. The illustrative transient event protection method 1000 can comprise coupling 1002 first and second active semiconductor devices in series between an input terminal and an output terminal and configuring 1004 the first and second active semiconductor devices to conduct current in opposite directions. The first and second active semiconductor devices are controlled 1006 to create a short-circuit or low impedance connection between the input terminal and the output terminal in normal operation and increase impedance between the input terminal and the output terminal sufficiently to isolate against destructive transient energy in response to a transient event.

[0112] In some applications, a shunt can be coupled 1008 to the input terminal. The shunt can be configured 1010 to respond during a transient event by forming a pathway for shunting transient energy to a local ground.
Terms "substantially", "essentially", or "approximately", that may be used herein, relate to an industry-accepted tolerance to the corresponding term. Such an industry-accepted tolerance ranges from less than one percent to twenty percent and corresponds to, but is not limited to, component values, integrated circuit process variations, temperature variations, rise and fall times, and/or thermal noise. The term "coupled", as may be used herein, includes direct coupling and indirect coupling via another component, element, circuit, or module where, for indirect coupling, the intervening component, element, circuit, or module does not modify the information of a signal but may adjust its current level, voltage level, and/or power level. Inferred coupling, for example where one element is coupled to another element by inference, includes direct and indirect coupling between two elements in the same manner as "coupled".

While the present disclosure describes various embodiments, these embodiments are to be understood as illustrative and do not limit the claim scope. Many variations, modifications, additions and improvements of the described embodiments are possible. For example, those having ordinary skill in the art will readily implement the steps necessary to provide the structures and methods disclosed herein, and will understand that the process parameters, materials, and dimensions are given by way of example only. The parameters, materials, and dimensions can be varied to achieve the desired structure as well as modifications, which are within the scope of the claims. Variations and modifications of the embodiments disclosed herein may also be made while remaining within the scope of the following claims. For example, various aspects or portions of a network interface are described including several optional implementations for particular portions. Any suitable combination or permutation of the disclosed designs may be implemented.
WHAT IS CLAIMED IS:

1. An electronic apparatus comprising:
   first and second Metal Oxide Semiconductor Field Effect Transistor (MOSFET) enhancement mode devices coupled respectively in series between first and second supply domains and coupled to respective first and second nodes; and
   first and second active circuits coupled to gates of the respective first and second MOSFET enhancement mode devices and operative to close the respective device for a low current/voltage condition and open the respective device for large currents.

2. The apparatus according to Claim 1 further comprising:
   first and second circuits coupled across respective first and second MOSFET enhancement mode devices and configured whereby removal of a transient condition returns the short-circuit or low impedance connection between the first and second nodes and normal operation.

3. The apparatus according to Claim 1 further comprising:
   first and second resistors coupled across respective first and second MOSFET enhancement mode devices and configured whereby removal of a transient condition returns the short-circuit or low impedance connection between the first and second nodes and normal operation.

4. The apparatus according to Claim 1 further comprising:
   first and second control circuits configured to detect removal of a transient condition and return the short-circuit or low impedance connection between the first and second nodes and normal operation.

5. The apparatus according to Claim 1 further comprising:
   at least one shunt device coupled from a control terminal of the first and second MOSFET enhancement mode devices to the respective first and second nodes.
6. The apparatus according to Claim 5 further comprising:
at least one shunt device coupled from a ground reference of the respective first
and second supply domains to a control terminal of the first and second
MOSFET enhancement mode devices to the respective first and second
nodes.

7. The apparatus according to Claim 6 further comprising:
the shunt devices comprising at least one device selected from a group of device
consisting of a zener diode, an avalanche diode, a diode stack, a
snapback metal oxide semiconductor field effect transistor (MOSFET), a
Silicon-Controlled Rectifier (SCR) thyristor, and a transient suppressor
circuit.

8. The apparatus according to Claim 1 further comprising:
the electronic apparatus is formed using a silicon-on-insulator process.

9. The apparatus according to Claim 1 further comprising:
the electronic apparatus is formed using a junction-isolated process.

10. The apparatus according to Claim 1 further comprising:
the electronic apparatus configured to rapidly drive impedance between the first
and second nodes high in response to the transient event and return to
the short-circuit or low impedance connection between the first and
second nodes when the transient event has ceased.

11. The apparatus according to Claim 1 further comprising:
the first and second nodes powered by respective first and second power
supplies that are held in substantially independent isolation by the
electronic apparatus whereby circuits referenced to the respective first
and second supply domains are supplied with power constantly including
during the transient event.

12. The apparatus according to Claim 1 further comprising:
the first and second nodes powered by respective first and second transient-
isolated power supplies that are held mutually independent in transient
isolation by a differential active clamp device that transfers power from the transient-isolated power supplies using a switched-capacitor circuit.

13. An apparatus comprising:
   an active clamp device electrically coupling first and second nodes in respective first and second supply domains referenced to ground potentials that can be different, the active clamp device comprising first and second high voltage devices coupled in parallel to respective first and second low and/or medium voltage devices and controlled by signals respectively referenced to the first and second supply domains.

14. The apparatus according to Claim 13 further comprising:
   a controller coupled to the first and second high voltage devices and the first and second low and/or medium voltage devices and controlled by the signals respectively referenced to the first and second supply domains to create a short-circuit or low impedance connection between the first and second nodes in normal operation and increase impedance between the first and second nodes sufficiently to isolate against destructive transient energy in response to a transient event.

15. The apparatus according to Claim 13 further comprising:
   first and second comparators coupled to the respective first and second high voltage devices and coupled to the respective first and second low and/or medium voltage devices, the first and second comparators controlled by the signals respectively referenced to the first and second supply domains to create a short-circuit or low impedance connection between the first and second nodes in normal operation and increase impedance between the first and second nodes sufficiently to isolate against destructive transient energy in response to a transient event.

16. The apparatus according to Claim 13 further comprising:
   first and second resistors coupled across respective first and second high voltage devices and configured whereby removal of a transient condition returns the short-circuit or low impedance connection between the first and second nodes in normal operation.
17. The apparatus according to Claim 13 further comprising:
at least one shunt device coupled to at least one of the first and second high
voltage devices for shunting transient event energy to an earth ground
reference.

18. The apparatus according to Claim 17 further comprising:
the at least one shunt device comprising at least one device selected from a
group of device consisting of a zener diode, an avalanche diode, a diode
stack, a snapback metal oxide semiconductor field effect transistor
(MOSFET), a Silicon-Controlled Rectifier (SCR) thyristor, and a transient
suppressor circuit.

19. The apparatus according to Claim 13 further comprising:
the active clamp device is formed using a silicon-on-insulator process or a
junction isolated process.

20. The apparatus according to Claim 13 further comprising:
the active clamp device configured to rapidly drive impedance between the first
and second nodes high in response to the transient event and return to
the short-circuit or low impedance connection between the first and
second nodes when the transient event has ceased.

21. The apparatus according to Claim 13 further comprising:
the first and second nodes powered by respective first and second power
supplies that are held in substantially independent isolation by the active
clamp device whereby circuits referenced to the respective first and
second supply domains are supplied with power constantly including
during the transient event.

22. The apparatus according to Claim 13 further comprising:
the first and second nodes powered by respective first and second transient-
isolated power supplies that are held mutually independent in transient
isolation by a differential active clamp device that transfers power from the
transient-isolated power supplies using a switched-capacitor circuit.
23. A transient event protection apparatus comprising:
a plurality of active devices coupled in series between an input terminal and an
output terminal and configured to conduct current in opposite directions;
and
first and second control elements respectively coupled to control the active
devices that conduct current in opposite directions, the first and second
control elements configured to create a short-circuit or low impedance
connection between the input terminal and the output terminal in normal
operation and increase impedance between the input terminal and the
output terminal sufficiently to isolate against destructive transient energy
in response to a transient event.

24. The apparatus according to Claim 23 further comprising:
a shunt coupled to the input terminal configured to respond during a transient
event by forming a pathway for shunting transient energy to a low
impedance path to an earth ground.

25. The apparatus according to Claim 23 further comprising:
a plurality of shunts coupled in series to the input terminal configured to respond
during a transient event by forming a pathway for shunting transient
energy to a low impedance path to an earth ground.

26. The apparatus according to Claim 23 further comprising:
the input terminal configured for coupling to an Ethernet Physical Layer (PHY)
and the transient event protection apparatus is configured to protect the
Ethernet PHY by isolating against passing the destructive transient
energy to the Ethernet PHY in response to the transient event.

27. The apparatus according to Claim 23 further comprising:
the input terminal configured for coupling to an interface and the transient event
protection apparatus is configured to protect the interface and devices
and systems coupled to the interface by isolating against passing the
destructive transient energy to the interface in response to the transient
event.
28. The apparatus according to Claim 27 further comprising:
the interface selected from a group consisting of a Universal Serial Bus (USB) interface, a RETMA standard (RS)-232 interface, a Transmission level 1 (T1) interface, and a communication interface.

29. The apparatus according to Claim 23 further comprising:
the active device plurality comprises first and second transistors coupled between the input terminal and the output terminal to conduct current in opposite directions; and
the first and second control elements coupled to control terminals of the respective first and second transistors and controlled by signals respectively referenced to first and second supply domains.

30. The apparatus according to Claim 23 further comprising:
the active device plurality comprises first and second Metal Oxide Semiconductor Field-Effect Transistors (MOSFETs) coupled between the input terminal and the output terminal in a configuration that conducts current in opposite directions; and
respective first and second comparators coupled to the control terminals of the respective first and second MOSFETs and configured to compare signals between the input terminal and the output terminal with a voltage referenced to respective first and second references.

31. A protection apparatus comprising:
at least one protection circuit coupling a plurality of input and output nodes and at least one ground reference, and comprising a plurality of active devices and at least one shunt device, the active device plurality controlled by signals at the input and output node plurality that create a short-circuit or low impedance connection between the input and output node plurality in normal operation and increase impedance between the input and output node plurality to isolate against destructive transient energy in response to a transient event, the at least one shunt device configured to conduct transient currents associated with destructive transient energy to the at least one ground reference.
32. A transient protection method comprising:
electrically coupling first and second nodes in respective first and second supply domains;
referencing the first and second supply domains to ground potentials that can be different;
controlling impedance based on signals referenced to the first and second supply domains;
creating a short-circuit or low impedance connection between the first and second nodes in normal operation; and
increasing impedance between the first and second nodes sufficiently to isolate against destructive transient energy in response to a transient event.

33. The method according to Claim 32 further comprising:
rapidly driving impedance between the first and second nodes high in response to the transient event; and
returning to the short-circuit or low impedance connection between the first and second nodes when the transient event has ceased.

34. The method according to Claim 32 further comprising:
powering the first and second nodes by respective first and second power supplies that are held in substantially independent isolation;
supplying the respective first and second supply domains with power constantly including during the transient event.

35. A transient event protection apparatus comprising:
at least two differential input terminals;
at least two differential output terminals;
a first protection circuit coupled between a first of the at least two differential input terminals and a first of the at least two differential output terminals;
a second protection circuit coupled between a second of the at least two differential input terminals and a second of the at least two differential output terminals;
a local supply coupled to power a first portion of the transient event protection apparatus relative to a local ground reference; and
a switched-capacitive circuit coupled to the first and second protection circuits and configured to create an independent supply that powers a second
portion of the transient event protection apparatus relative to an associated independent ground reference.

36. The apparatus according to Claim 35 further comprising:
a first resistance coupled between the local supply and the created independent supply;
a second resistance coupled between the local ground reference and the created independent ground reference; and the switched capacitive circuit that transfers charge from the local supply between the first and second protection circuits whereby the independent supply is isolated from the local supply.

37. The apparatus according to Claim 35 further comprising:
the switched capacitive circuit that isolates the independent supply from the local supply whereby energy in the second portion of the transient event protection apparatus oscillates in response to a transient event and is isolated from coupling to the first portion and the local supply.

38. The apparatus according to Claim 35 further comprising:
the first and second protection circuits individually comprising first and second active devices coupled in series in a configuration to conduct current in opposite directions and controlled to create a short-circuit or low impedance connection between the first and second portions of the transient event protection apparatus in normal operation and increase impedance between the first and second portions sufficiently to isolate against destructive transient energy in response to a transient event.

39. The apparatus according to Claim 35 further comprising:
a shunt coupled to at least one of the first and second protection circuits and configured to respond during a transient event by forming a pathway for shunting transient energy to a local ground.

40. A protection apparatus comprising:
at least one protection circuit coupling a plurality of input and output nodes and at least one ground reference, and comprising a plurality of switch means and at least one shunt means, the switch means responsive to signals at
the input and output node plurality for creating a short-circuit or low impedance connection between the input and output node plurality in normal operation and for increasing impedance between the input and output node plurality for isolating against destructive transient energy in response to a transient event, the shunt means for conducting transient currents associated with destructive transient energy to the at least one ground reference.

41. A transient event protection apparatus comprising:
first and second active semiconductor devices coupled in series between an input terminal and an output terminal in a configuration to conduct current in opposite directions and controlled to create a short-circuit or low impedance connection between the input terminal and the output terminal in normal operation and increase impedance between the input terminal and the output terminal sufficiently to isolate against destructive transient energy in response to a transient event.

42. The apparatus according to Claim 41 further comprising:
a shunt coupled to the input terminal configured to respond during a transient event by forming a pathway for shunting transient energy to a local ground.

43. A transient event protection method comprising:
coupling first and second active semiconductor devices coupled in series between an input terminal and an output terminal;
configuring the first and second active semiconductor devices to conduct current in opposite directions; and
controlling the first and second active semiconductor devices to create a short-circuit or low impedance connection between the input terminal and the output terminal in normal operation and increase impedance between the input terminal and the output terminal sufficiently to isolate against destructive transient energy in response to a transient event.
44. The method according to Claim 43 further comprising:
coupling a shunt to the input terminal; and
configuring the shunt to respond during a transient event by forming a pathway
for shunting transient energy to a local ground.

45. An electronic apparatus comprising:
first and second Metal Oxide Semiconductor Field Effect Transistor (MOSFET)
depletion mode devices coupled respectively in series between first and second
supply domains and coupled to respective first and second nodes; and
first and second active circuits coupled to gates of the respective first and second
MOSFET depletion mode devices and operative to close the respective device for a low current/voltage condition and open the respective device for large currents.

46. An electronic apparatus comprising:
first and second Junction Field Effect Transistor (JFET) devices coupled
respectively in series between first and second supply domains and
coupled to respective first and second nodes; and
first and second active circuits coupled to gates of the respective first and second
JFET devices and operative to close the respective device for a low current/voltage condition and open the respective device for large currents.

47. A protection apparatus comprising:
at least one protection circuit coupling a plurality of input and output nodes, and
comprising a plurality of active devices, the active device plurality
controlled by signals at the input and output node plurality that create a
short-circuit or low impedance connection between the input and output node plurality in normal operation and increase impedance between the input and output node plurality to isolate either a first node or a second node from either transient or short-circuit events, the impedance increase
being sufficient to create a short circuit between the first and second node, preventing damage of a driving device on the isolated node.
48. The protection apparatus according to Claim 47 further comprising: the active device plurality configured whereby the impedance increase prevents an interaction of a transient event at the first node with circuits on the second node.

49. A protection apparatus comprising: at least one protection circuit coupling a plurality of input and output nodes, and comprising a plurality of active devices, the active device plurality controlled by signals at the input and output node plurality that create a short-circuit or low impedance connection between the input and output node plurality in normal operation and increase impedance between the input and output node plurality to isolate either a first node or a second node from either transient or short-circuit events, the impedance increase being sufficient to create a high impedance to high currents whereby effects outside a range of normal current level are prevented.

50. The protection apparatus according to Claim 49 further comprising: the active device plurality configured whereby the impedance increase prevents an interaction of a transient event at the first node with circuits on the second node.

51. An electronic apparatus comprising: an active clamp device electrically coupling first and second nodes in respective first and second supply domains coupled through low impedance to separate ground potentials, the active clamp device comprising first and second active devices controlled by signals respectively referenced to the first and second supply domains that create a short-circuit or low impedance connection between the first and second nodes in normal operation and increase impedance between the first and second nodes sufficiently to isolate against destructive transient energy in response to a transient event.

52. A network interface apparatus comprising: a connector coupled to a plurality of communication lines; a Physical Layer (PHY) device coupled to the communication lines and to a first ground level;
a transient event suppression module coupled between the communication lines and a low impedance path to earth ground, wherein during a transient event the transient event suppression module provides a low impedance path to the earth ground to protect the PHY device from the transient event; and

5 a power circuit that delivers power from a second ground level to the PHY device that is coupled to first ground level, wherein the first ground level and the second ground level are coupled to provide a low impedance path during normal operation and high impedance during transient events.

10 53. The apparatus according to Claim 52 further comprising:
a DC isolation barrier coupled between the connector and the PHY device.

54. The apparatus according to Claim 53 wherein the isolation barrier includes a plurality of capacitors.

55. The apparatus according to Claim 53 wherein the isolation barrier includes a plurality of transformers.

56. The apparatus according to Claim 52 wherein the transient event suppression module includes a solid-state inductance boosting autoformer device.

57. The apparatus according to Claim 52 further comprising:
an ac/dc power brick, wherein the first ground level has a low impedance for transient event to the earth ground of the ac/dc power brick.

58. The apparatus according to Claim 52 wherein:
the interface is selected from a group consisting of a Universal Serial Bus (USB) interface, a RETMA standard (RS)-232 interface, a Transmission level 1 (T1) interface, a 10/100/1/10 GB Ethernet communication interface, and a communication interface.
59. The apparatus according to Claim 52 further comprising:
a common mode suppression module coupled between the communication lines
and the transient protection module, and between the PHY device and a
power transformer.

60. The apparatus according to Claim 52 further comprising:
a limit resistor coupled between the first ground level and the power ground level.

61. The apparatus according to Claim 52 wherein:
the transient event suppression module includes a transformer.

62. The apparatus according to Claim 52 wherein:
the second ground level is coupled to the first ground level via a surge limiting
circuit.

63. The apparatus according to Claim 52 wherein:
the surge limiting circuit includes at least one of the group consisting of: a
Positive Temperature Coefficient (PTC) device, a zener diode, a zener
diode including a forward-biased diode, a N-channel MOS (NMOS) device
with a gate tied to the earth ground, a parasitic bipolar device configured
to enable a snap back operation to enable protection; and a stack of
diodes coupled in series and coupled in parallel with another diode.

64. The apparatus according to Claim 52 wherein:
the apparatus is an Ethernet network device operable to receive both a power
signal and a data signal through a coupled Ethernet network,
the transient event suppression module is implemented in an integrated circuit
(IC) coupled to the connector, and
the power circuit is operable to:
pass the received data signal to the PHY device, and
at least partially power the Ethernet network device from the received
power signal.
65. A transient protection apparatus comprising:
a transient event suppression device coupled between a plurality of communication lines and an ac/dc power block, wherein the ac/dc power block is referenced to earth ground level;
a power supply transformer including a secondary winding and a primary winding coupled to the transient event suppression device, wherein the primary winding is referenced to a power ground level and the secondary winding is coupled to a PHY ground level;
a common mode suppression circuit coupled between the communication lines and the power supply transformer;
a PHY device coupled between the communication lines and the common mode suppression circuit, wherein the PHY device is referenced to the PHY ground level;
a transient protection apparatus coupled between the power ground level and the PHY ground level, wherein the transient protection apparatus is configured to create a short-circuit or low impedance connection between the power ground level and the PHY ground level in normal operation and an open circuit during a transient event; and the transient event suppression device creates a low impedance connection sufficient to draw destructive transient energy to earth ground in response to a transient event.

66. The apparatus according to Claim 65 wherein the power circuit includes:
two differential transistor pairs wherein each transistor of the differential transistor pairs is operable to pass an Ethernet power signal;
two pairs of inductors, wherein each of the inductors is coupled to a single transistor of the differential transistor pairs; and
a pair of impedance sense resistors coupled between drains of the differential transistor pair, wherein the impedance sense resistors are operable to pass Ethernet power signals received from a drain of the coupled transistor.

67. The apparatus according to Claim 66 further comprising:
a pair of output nodes, wherein one output node is associated with each of the differential transistor pairs, and wherein the pair of output nodes provide power to an Ethernet network powered device.
68. A transient event suppression method comprising:
   directing energy on a plurality of communication lines through a PHY device
coupled to a PHY ground level during normal operation; and
directing transient energy on the plurality of communication lines to earth ground
   through a transient protection device that is isolated from the PHY device
   and the PHY ground level during a transient energy event.

69. The method of Claim 68 further comprising:
   directing the energy during normal operation through a common mode
   suppression (CMS) module, wherein the CMS module is coupled between
   the PHY device and the PHY ground level.

70. The method of Claim 68 further comprising:
   using a T-connect element as the transient protection device.

71. The method of Claim 68 further comprising:
   coupling the PHY ground level and a power ground level to a current limiting
device.

72. The method of Claim 68 further comprising:
   electrically coupling first and second nodes in respective first and second supply
domains;
   referencing the first and second supply domains to ground potentials that can be
different.

73. The method according to Claim 72 further comprising:
   rapidly driving impedance between the first and second nodes high in response
to the transient event; and
   returning to the short-circuit or low impedance connection between the first and
   second nodes when the transient event has ceased.

74. The method according to Claim 72 further comprising:
   powering the first and second nodes by respective first and second power
   supplies that are held in substantially independent isolation;
   supplying the respective first and second supply domains with power constantly
   including during the transient event.
75. The method of Claim 68 further comprising:
coupling the earth ground level through an AC/DC power block.
500

ELECTRICALLY COUPLE NODES IN RESPECTIVE SUPPLY DOMAINS

502

REFERENCE SUPPLY DOMAINS TO RESPECTIVE GROUNDS

504

CONTROL IMPEDANCE BASED ON SIGNALS REFERENCED TO THE SUPPLY DOMAINS

506

CREATE LOW IMPEDANCE CONNECTION BETWEEN NODES IN NORMAL OPERATION

508

INCREASE IMPEDANCE FOR ISOLATION IN RESPONSE TO TRANSIENT EVENT

510

FIG. 5A
RAPIDLY DRIVE IMPEDANCE BETWEEN NODES HIGH IN RESPONSE TO TRANSIENT EVENT

RETURN IMPEDANCE TO LOW IMPEDANCE CONNECTION WHEN TRANSIENT EVENT CEASES

FIG. 5B

POWER NODES BY RESPECTIVE SUPPLIES HELD IN INDEPENDENT ISOLATION

SUPPLY DOMAINS WITH POWER CONSTANTLY

FIG. 5C
1. Couple active devices in series between input and output terminals.
2. Configure active devices to conduct current in opposite directions.
3. Form low impedance connection between input and output terminals in normal conditions.
4. Couple shunt to input terminal.
5. Configure shunt to respond to transient event by forming path to ground.

FIG. 7
16/18

FIG. 9A

900

ELECTRICALLY COUPLE NODES IN RESPECTIVE SUPPLY DOMAINS

902

REFERENCE SUPPLY DOMAINS TO RESPECTIVE GROUNDS

904

CONTROL IMPEDANCE BASED ON SIGNALS REFERENCED TO THE SUPPLY DOMAINS

906

CREATE LOW IMPEDANCE CONNECTION BETWEEN NODES IN NORMAL OPERATION

908

INCREASE IMPEDANCE FOR ISOLATION IN RESPONSE TO TRANSIENT EVENT

910
RAPIDLY DRIVE IMPEDANCE BETWEEN NODES HIGH IN RESPONSE TO TRANSIENT EVENT

RETURN IMPEDANCE TO LOW IMPEDANCE CONNECTION WHEN TRANSIENT EVENT CEASES

FIG. 9B

POWER NODES BY RESPECTIVE SUPPLIES HELD IN INDEPENDENT ISOLATION

SUPPLY DOMAINS WITH POWER CONSTANTLY

FIG. 9C
1000

COUPLE ACTIVE DEVICES IN SERIES BETWEEN INPUT AND OUTPUT TERMINALS

1002

CONFIGURE ACTIVE DEVICES TO CONDUCT CURRENT IN OPPOSITE DIRECTIONS

1004

FORM LOW IMPEDANCE CONNECTION BETWEEN INPUT AND OUTPUT TERMINALS IN NORMAL CONDITIONS

1006

COUPLE SHUNT TO INPUT TERMINAL

1008

CONFIGURE SHUNT TO RESPOND TO TRANSIENT EVENT BY FORMING PATH TO GROUND

1010

FIG. 10