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(54) **POWER-OVER-ETHERNET (POE) CONTROL SYSTEM**

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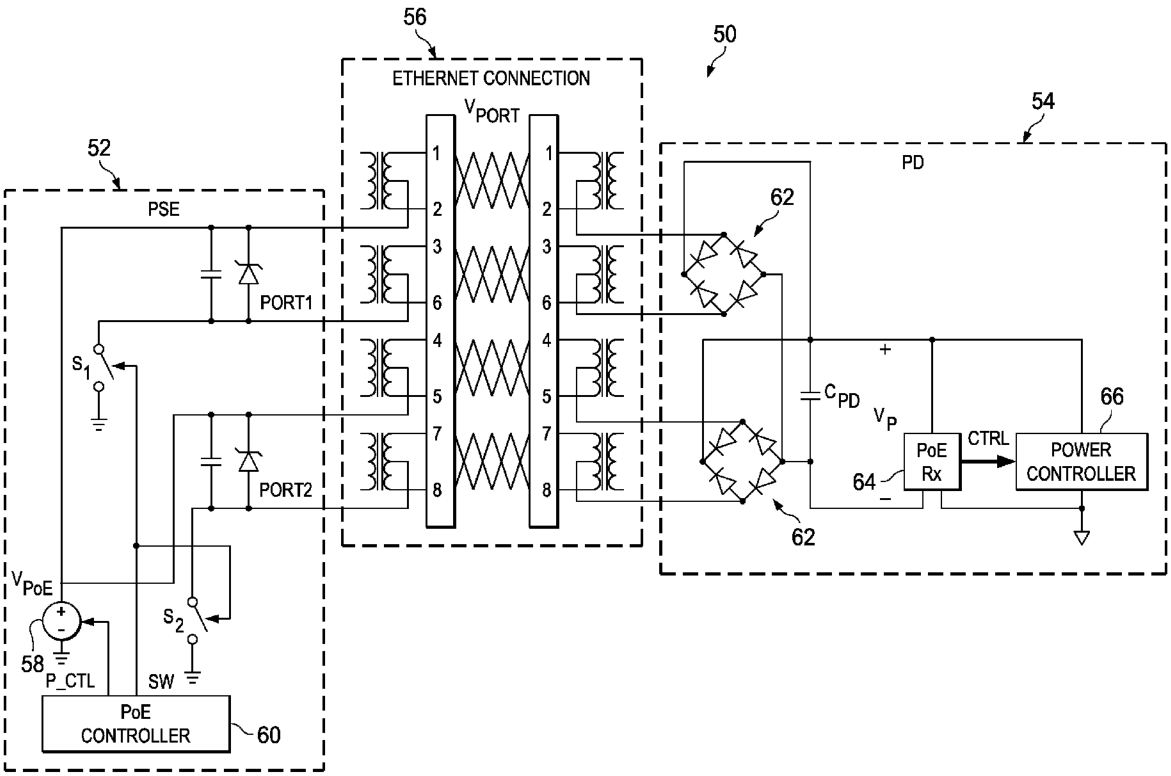
USPC **315/307**; 307/131

(57) **ABSTRACT**

One example includes a power-over-Ethernet (PoE) control system. The system includes a powered device (PD) that is configured to receive a voltage signal via an Ethernet connection and which comprises a PoE signal receiver configured to indicate a nominal power level via the received voltage signal. The system also includes a power sourcing equipment (PSE) device configured to generate the voltage signal and to measure a class current of the voltage signal to determine the nominal power level. The PSE device includes a PoE controller configured to provide a power setting command as a function of the nominal power level to the PoE signal receiver via the voltage signal, such that the PD can operate at a power level that is based on the power setting command.



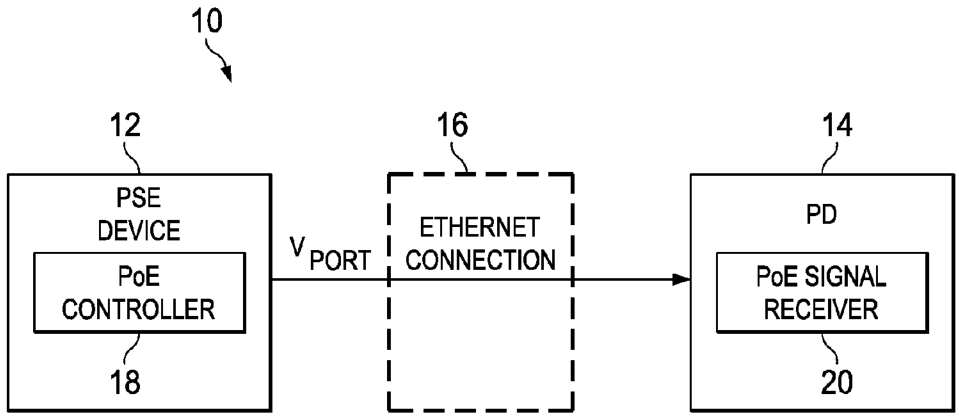

10
12
16
14
PSE
DEVICE
PoE
CONTROLLER
18
V PORT
ETHERNET
CONNECTION
PD
PoE SIGNAL
RECEIVER
20

FIG. 1

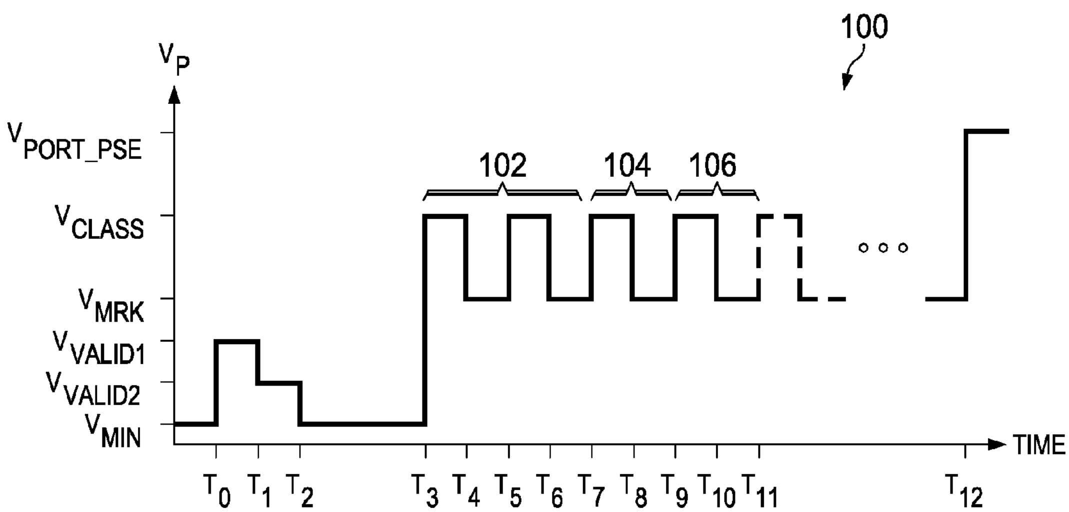

100
V P
V PORT_PSE
V CLASS
V MRK
V VALID1
V VALID2
V MIN
102
104
106
TIME
T 0 T 1 T 2 T 3 T 4 T 5 T 6 T 7 T 8 T 9 T 10 T 11 T 12

FIG. 3

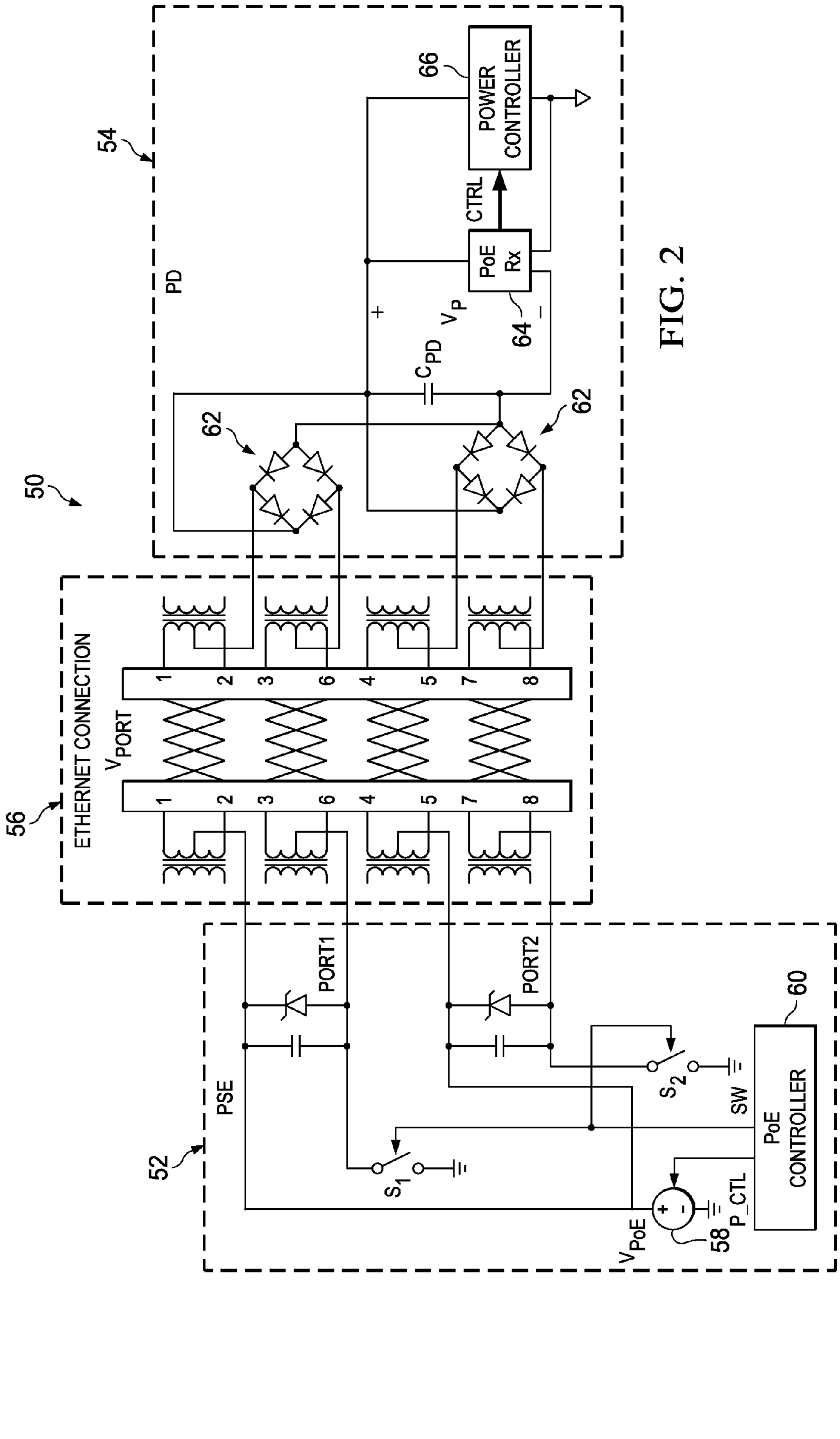

54
PD
66
POWER CONTROLLER
CTRL
PoE Rx
64
V_P
+
–
C_{PD}
62
62
50
56
ETHERNET CONNECTION
V_{PORT}
1 2 3 6 4 5 7 8
1 2 3 6 4 5 7 8
PORT1
PORT2
PSE
52
S_1
S_2
SW
PoE CONTROLLER
60
P_CTL
58
V_{PoE}

FIG. 2

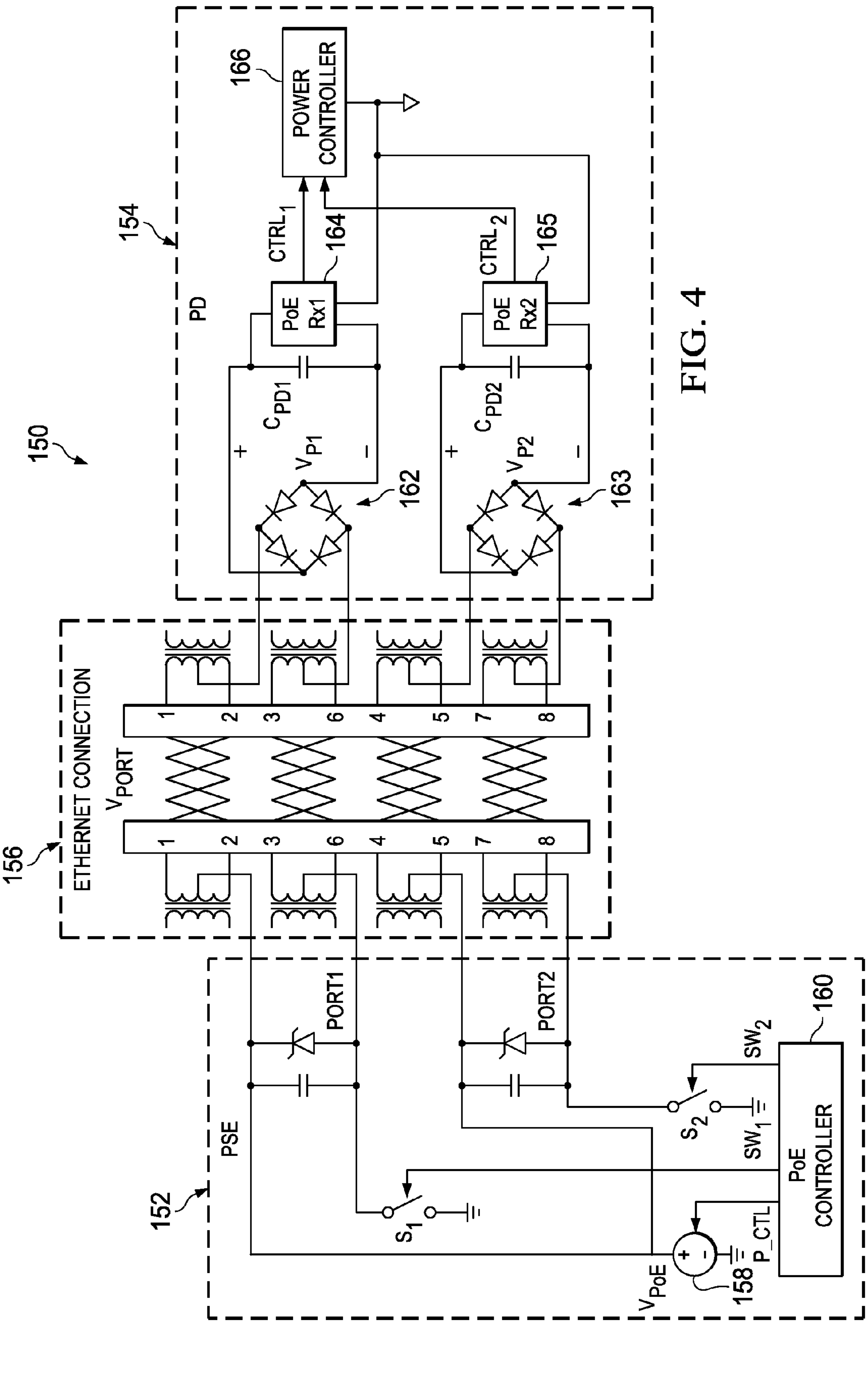

150
154
PD
166
POWER CONTROLLER
CTRL1
164
PoE Rx1
CTRL2
165
PoE Rx2
CPD1
VP1
162
CPD2
VP2
163
156
ETHERNET CONNECTION
VPORT
1 2 3 6 4 5 7 8
152
PSE
PORT1
PORT2
S1
S2
SW1
SW2
P_CTL
PoE CONTROLLER
160
158
VPoE

FIG. 4

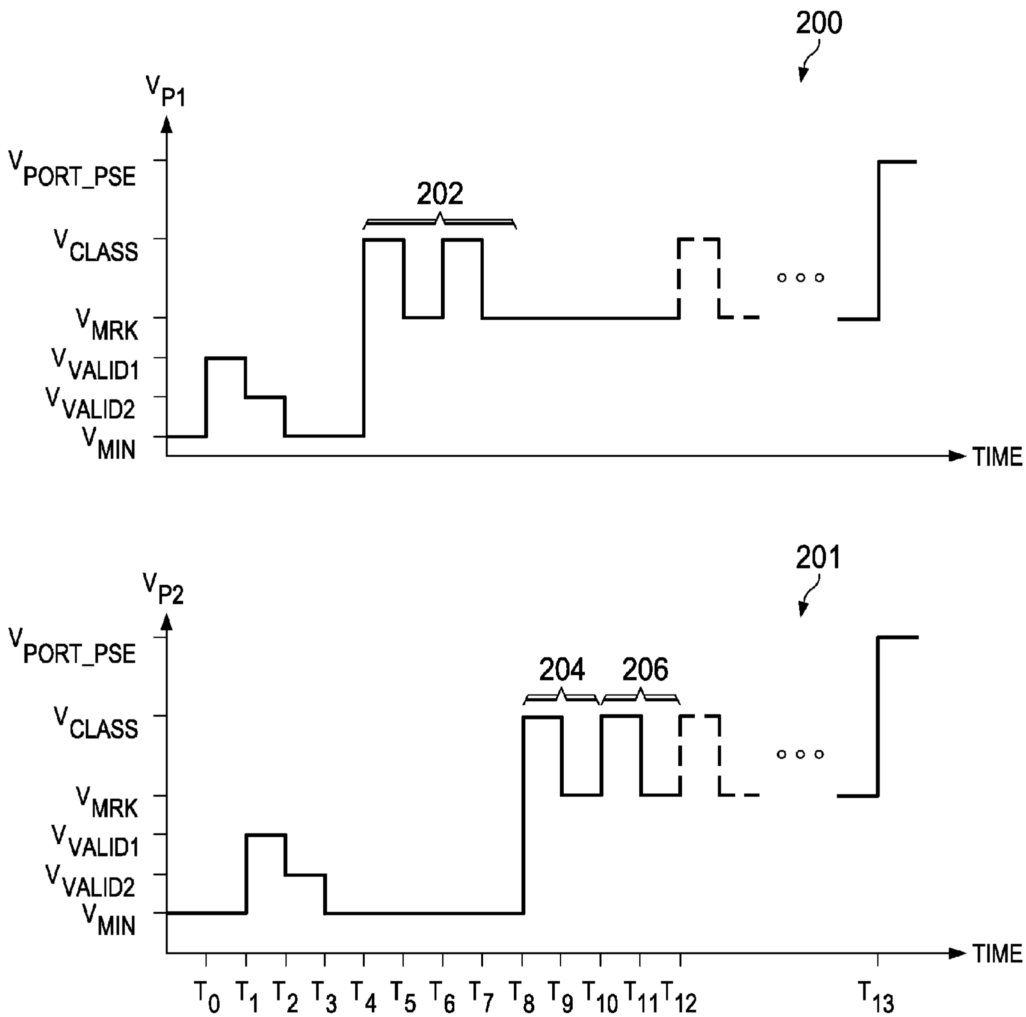

200
V_{P1}
V_{PORT_PSE}
V_{CLASS}
V_{MRK}
V_{VALID1}
V_{VALID2}
V_{MIN}
202
TIME
201
V_{P2}
V_{PORT_PSE}
V_{CLASS}
V_{MRK}
V_{VALID1}
V_{VALID2}
V_{MIN}
204
206
TIME
T_0 T_1 T_2 T_3 T_4 T_5 T_6 T_7 T_8 T_9 T_{10} T_{11} T_{12} T_{13}

FIG. 5

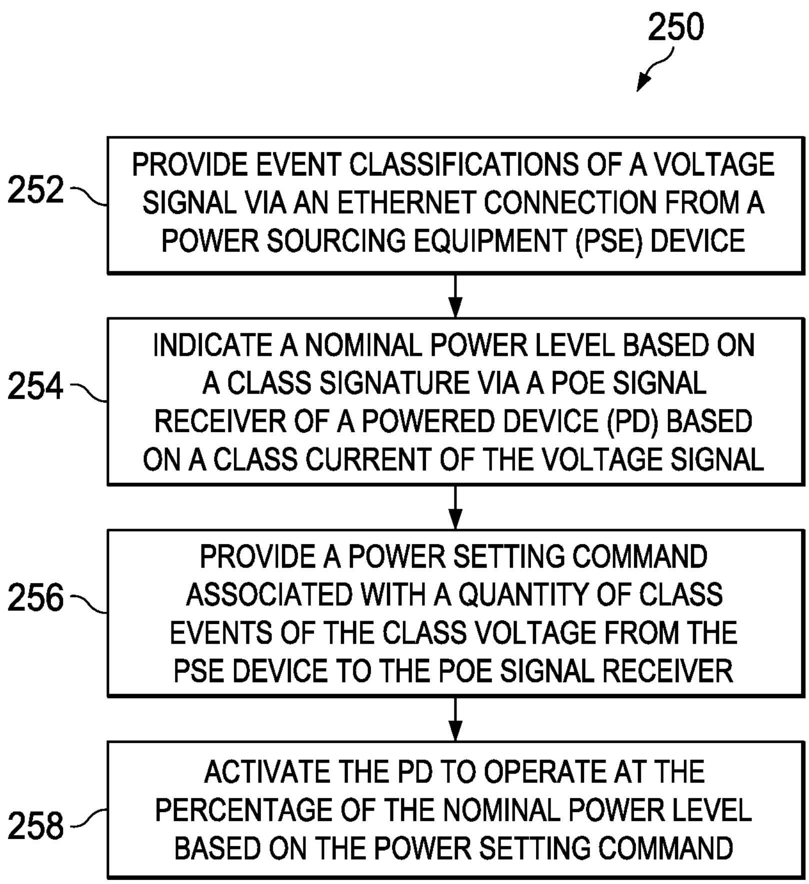

250
252
PROVIDE EVENT CLASSIFICATIONS OF A VOLTAGE SIGNAL VIA AN ETHERNET CONNECTION FROM A POWER SOURCING EQUIPMENT (PSE) DEVICE
254
INDICATE A NOMINAL POWER LEVEL BASED ON A CLASS SIGNATURE VIA A POE SIGNAL RECEIVER OF A POWERED DEVICE (PD) BASED ON A CLASS CURRENT OF THE VOLTAGE SIGNAL
256
PROVIDE A POWER SETTING COMMAND ASSOCIATED WITH A QUANTITY OF CLASS EVENTS OF THE CLASS VOLTAGE FROM THE PSE DEVICE TO THE POE SIGNAL RECEIVER
258
ACTIVATE THE PD TO OPERATE AT THE PERCENTAGE OF THE NOMINAL POWER LEVEL BASED ON THE POWER SETTING COMMAND

FIG. 6

POWER-OVER-ETHERNET (POE) CONTROL SYSTEM

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of U.S. Provisional Patent Application No. 61/864179, filed Aug. 9, 2013, and entitled PoE LIGHTING CLASSIFICATION AND CONTROL METHOD, FOUR PAIRS HIGH POWER, which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

[0002] This disclosure relates generally to electronic systems, and more specifically to a power-over-Ethernet (PoE) control system.

BACKGROUND

[0003] A variety of control systems can be implemented to provide power and control to power consuming equipment, such as lighting devices or other types of devices that consume power. One such control system is Power-over-Ethernet (PoE), such as defined by the IEEE 802.3at standard, is a manner of safely providing power to a powered device (PD) over a cable via power sourcing equipment (PSE), and of removing power if a PD is disconnected. As an example, the process proceeds through an idle state and three operational states of detection, classification, and operation. During detection, the PSE can leave the cable unpowered in the idle state while it periodically looks to see if a PD has been plugged-in. The low-power levels that can be used during detection are unlikely to damage devices not designed for PoE. If a valid PD signature is present, during classification, the PSE may inquire as to how much power the PD requires. The PSE may then provide the required power to the PD if it has sufficient power providing capacity.

SUMMARY

[0004] One example includes a power-over-Ethernet (PoE) control system. The system includes a powered device (PD) that is configured to receive a voltage signal via an Ethernet connection and which comprises a PoE signal receiver configured to indicate a nominal power level via the received voltage signal. The system also includes a power sourcing equipment (PSE) device configured to generate the voltage signal and to measure a class current of the voltage signal to determine the nominal power level. The PSE device includes a PoE controller configured to provide a power setting command as a function of the nominal power level to the PoE signal receiver via the voltage signal, such that the PD can operate at a power level that is based on the power setting command.

[0005] Another example includes a method for providing power control in a PoE control system. The method includes providing event classifications of a voltage signal via an Ethernet connection from a PSE device. The method also includes indicating a nominal power level based on a class signature via a PoE signal receiver of a powered device (PD) based on a class current of the voltage signal. The method also includes providing a power setting command associated with a quantity of class events of the voltage signal from the PSE device to the PoE signal receiver. The power setting command can correspond to a percentage of the nominal power level. The method further includes activating the PD to operate at the percentage of the nominal power level based on the power setting command.

[0006] Another example includes a PoE control system. The system includes a powered device (PD) that is configured to receive a voltage signal via an Ethernet connection and which comprises a PoE signal receiver configured to provide a first class signature in response to a first event classification via a class current of the received voltage signal and a second class signature via the class current, the second class signature having a different class value from the first class signature, and a third class signature that has a class value that is less than the second class signature to indicate that the PD has a capacity for PoE control. The third class signature can indicate a nominal power level of the PD. The system further includes a PSE device configured to generate the voltage signal and to measure the class current of the voltage signal to determine the capacity for PoE control and the nominal power level. The PSE device includes a PoE controller configured to provide a power setting command as a function of the nominal power level to the PoE signal receiver via the voltage signal, such that the PD can operate at a power level that is based on the power setting command.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] FIG. **1** illustrates an example of a power-over-Ethernet (PoE) control system.

[0008] FIG. **2** illustrates another example of a PoE control system.

[0009] FIG. **3** illustrates an example of a timing diagram.

[0010] FIG. **4** illustrates yet another example of a PoE control system.

[0011] FIG. **5** illustrates another example of a timing diagram.

[0012] FIG. **6** illustrates an example of a method for providing power control in a PoE control system.

DETAILED DESCRIPTION

[0013] This disclosure relates generally to electronic systems, and more specifically to a power-over-Ethernet (PoE) control system. A PoE control system can include a power sourcing equipment (PSE) device and a powered device (PD) that are electrically coupled via an Ethernet connection, such as an RJ-45 cable. As an example, the PD can correspond to a lighting system or any of a variety of other electronic devices that consume a varying amount of power. The PSE device includes a PoE controller and is configured to provide a voltage signal that can vary in amplitude depending on the phase of PoE control. The PD can include a PoE signal receiver that is configured as a current source in response to the voltage signal provided by the PSE device. The PoE controller can monitor the class current of the voltage signal to determine class signatures. In this manner, the PD can include a PoE signal receiver to indicate to the PSE device that the PD has a capacity for PoE control, and can indicate a nominal power level of the PD to the PSE device via the class current of the voltage signal. Therefore, the PSE device can provide pulses via the voltage signal as a power setting command to the PD, such that the PD can operate at a power level that is based on the power setting command.

[0014] For example, subsequent to a detection phase during which the PSE device determines if the PD is connected, the PSE device can operate in a classification phase. During the classification phase, the PSE device can provide the voltage signal at a classification amplitude to provide event classifications that include one or more class events and corresponding mark events (e.g., in a 1-Event or 2-Event classification scheme) via the voltage signal to the PD, such that the PD can control the class current of the voltage signal to provide respective class signatures to the PSE device. As an example, the PD can provide a first class signature and a second class signature, with the first and second class signatures being different. Subsequent to the second class signature, the PD can provide a third class signature to the PSE device that is less than the second class signature to indicate the capacity for PoE control by the PSE device. As another example, the third class signature can indicate a nominal power level of the PD to the PSE device. For example, the third class signature can have a value corresponding to one of a plurality of predetermined nominal power levels, such that the PSE device can identify the nominal power level based on the value of the third class signature.

[0015] Subsequent to the indication of the nominal power level, the PSE device can provide a number of class events that can correspond to a code corresponding to the power setting command, with the quantity of pulses corresponding a predetermined percentage of the nominal power level. As a result, the PSE device can provide the voltage signal in the activation phase at a maximum amplitude, such that the PD can operate at the percentage of the nominal power level based on the power command setting. Accordingly, the PoE control system described herein can operate to provide physical (PHY) layer power control of the PD in a simplistic and variable manner.

[0016] FIG. **1** illustrates an example of a power-over-Ethernet (PoE) control system **10**. The PoE control system **10** can be implemented in a variety of power-providing applications, such as illumination. For example, the PoE control system **10** can be implemented to provide power control via existing Ethernet cables (e.g., RJ-45 cables) without Ethernet data communication capability (e.g., utilizing data/link layers, packetization, etc.). Accordingly, as described herein, the PoE control system **10** provides PoE power control in a physical (PHY) layer manner.

[0017] The PoE control system **10** includes a power sourcing equipment (PSE) device **12** and a powered device (PD) **14** that are electrically coupled via an Ethernet connection **16**. As an example, the Ethernet connection **16** can be an RJ-45 cable that implements twisted pair conductors (e.g., four twisted pairs). The PSE device **12** is configured to provide a voltage signal V_{PORT} to the powered device via the Ethernet connection **16** to implement bilateral communication between the PSE device **12** and the PD **14**. For example, the voltage V_{PORT} can correspond to a fixed voltage V_{POE} that is generated in the PSE device **12** and which is modulated in amplitude. As an example, the PD **14** can be configured as a Type 2 PD according to the IEEE 802.3 standard.

[0018] As described herein, the voltage signal V_{PORT} can correspond to a voltage signal that varies to provide event classifications from the PSE device **12** to the PD **14** in an event classification scheme, such that the PD **14** can respond to the class events by varying the current of the voltage signal V_{PORT} to provide a class signature to the PSE device **12**, such as based on the IEEE 802.3 standard. As also described herein, the term "event classification" describes the PSE device **12** providing one or more class events and corresponding mark events to the PD **14** to provide communication to and/or to elicit a communication response from the PD **14** in the form of a class signature. As also described herein, the term "class event" describes a pulse of the voltage signal V_{PORT} at a predetermined amplitude, and which is followed by a mark event (e.g., decreased voltage subsequent to the pulse) that signifies an end of the class event. As further described herein, the term "class signature" refers to a response by the PD **14** of an event classification that includes the one or more class events in the form of a magnitude of class current that corresponds to a class level, described herein as Class 0 through Class 5, with the class values corresponding to increasing amplitudes of the class current in ascending order of class value.

[0019] In the example of FIG. **1**, the PSE device **12** includes a PoE controller **18**, and the PD **14** includes a PoE signal receiver **20**. The PoE controller **18** can be configured to control an activation time and an amplitude of the voltage signal V_{PORT}, such as based on a given operating phase of the PoE control system **10**, to provide communication to the PD **14**. The PoE controller **18** can also be configured to measure the class current associated with the voltage signal V_{PORT}, and thus to determine the class level of a class signature. The PoE signal receiver **20** can be configured to receive the voltage signal V_{PORT} and to act as a class current source with respect to the voltage signal V_{PORT}, such that the PoE signal receiver **20** can adjust the class current of the voltage signal V_{PORT} to provide communication to the PSE device **12** in response to the voltage signal V_{PORT}. As an example, the PoE controller **18** can implement the communication with the PoE signal receiver **20** via a standard, such as IEEE 802.3. For example, the PoE controller **18** can be configured to provide event classifications as a 1-Event Physical Layer classification to provide a single class event, or as a 2-Event Physical Layer classification to provide a series (e.g., two) of class events followed by respective mark events. In response, the PD **14** can provide a corresponding class signature. As described herein, the term

[0020] As an example, the PSE device **12** can initially operate in a detection phase, such that the PSE device **12** can provide the voltage signal V_{PORT} at a valid test voltage amplitude (e.g., between approximately 2.8 volts and approximately 10 volts) at periodic intervals. If the PD **14** is electrically coupled to the PSE device **12** via the Ethernet connection **16**, the PoE signal receiver **20** can respond by providing a sufficient resistance with respect to the voltage signal V_{PORT} to indicate to the PSE device **12** that the PD **14** is coupled via the Ethernet connection **16**. Subsequent to the detection phase, the PSE device **12** switches to a classification phase.

[0021] During the classification phase, the PSE device **12** can provide the voltage signal V_{PORT} at a classification amplitude (e.g., between approximately 15.5 volts and approximately 20.5 volts) to provide class events (e.g., 1-Event classifications and/or 2-Event classifications) via the voltage signal V_{PORT} to the PD **14**, as controlled by the PoE controller **18**. In response to the class events, the PoE signal receiver **20** can control the class current of the voltage signal V_{PORT} to provide respective class signature to the PSE device **12**, such that each class signature has a range of class current amplitudes that corresponds to a predetermined Class (e.g., as dictated by IEEE 802.3at). As described previously, the PoE controller **18** can measure the class current of the voltage signal V_{PORT} in each class event, such that the PoE controller **18** can determine the class signature provided by the PoE signal receiver **20**. Accordingly, as described herein, the PSE device **12** and the PD **14** can communicate with each other.

[0022] As an example, in the classification phase, the PoE signal receiver **20** can provide a first class signature in response to a first event classification, followed by a second class signature in response to a second event classification, and a third class signature in response to a third event classification. The PoE signal receiver **20** can provide the second class signature at a different class (e.g., at a greater current) than the first class signature, and can provide the third class signature at a class less than the second class signature to indicate the capacity for PoE control of the PD **14** by the PSE device **12**. For example, the first class signature can be provided at Class 4 (e.g., in response to each of two class events of the first event classification), the second class signature can be provided at Class 5, and the third class signature can be provided at a range of classes less than Class 5 (e.g., Class 0-4). As described herein, the term "Class 5" with respect to a class signature is defined as a class signature having a higher class current than a Class 4 class signature, such as implemented in the IEEE 802.3 standard. Therefore, in response to the values in the sequence of the classes provided by the PoE signal receiver **20**, the PoE controller **18** can identify that the PD **14** has a capacity for PoE control by the PSE device **12**.

[0023] In response to a determination of the capacity for PoE control of the PD **14** by the PSE device **12**, the PD **14** can provide an indication of a nominal power level of the PD **14** to the PSE device **12**. As described herein, the nominal power level of the PD **14** corresponds to a maximum power consumption of the PD **14** at full and normal operating conditions (e.g., full light level for a PoE lighting system). For example, the third class signature that is less than the second class signature can have a class value (e.g., one of Class 0-4) corresponding to one of a plurality of predetermined nominal power levels, such that the PoE controller **18** can identify the nominal power level based on the value of the third class signature. In response to identifying the nominal power level of the PD **14**, the PoE controller **18** can be configured to control the power level of the PD **14** as a function of the nominal power level, such that the power output of the PD **14** can be variably controlled by the PoE controller **18**.

[0024] For example, subsequent to the indication of the nominal power level, the PoE controller **18** can provide a number of class events via the voltage signal V_{PORT} associated with a code corresponding to the power setting command. As an example, the power setting command can be encoded based on a quantity of pulses of the class events corresponding to a predetermined percentage of the nominal power level. In response to the code, the PoE signal receiver **20** can identify the portion (e.g., percentage) of the nominal power level that is desired to be output from the PD **14** by the PoE controller **18**. As a result, the PSE device **12** can provide the voltage signal V_{PORT} in the activation phase at a maximum power on amplitude (e.g., between approximately 44 volts and approximately 57 volts, as dictated by a maximum voltage of an associated power supply). Therefore, the PD **14** can operate at the percentage of the nominal power level based on the power command setting. Accordingly, the PoE control system **10** described herein can operate to provide PHY layer power control of the PD **14** in a simplistic and variable manner.

[0025] FIG. **2** illustrates another example of a PoE control system **50**. The PoE control system **50** can correspond to the PoE control system **10** in the example of FIG. **1**, such as in a PoE lighting application. For example, the PoE control system **50** can be implemented to provide power control via existing Ethernet cables (e.g., RJ-45 cables) without Ethernet data communication capability (e.g., utilizing data/link layers, packetization, etc.).

[0026] The PoE control system **50** includes a PSE device **52** and a PD **54** that are electrically coupled via an Ethernet connection **56**. In the example of FIG. **2**, the Ethernet connection **56** is demonstrated as an RJ-45 cable that implements four twisted pair conductors. Therefore, the Ethernet connection **56** is demonstrated in the example of FIG. **2** as including two communication ports, demonstrated as PORT **1** and PORT **2**. The PSE device **52** includes a voltage source **58** that is configured to generate a voltage signal V_{POE}. In the example of FIG. **2**, the PSE device **52** includes a PoE controller **60** that provides a voltage control signal P_CTL to the voltage source **58** to control the amplitude of the voltage signal V_{POE} (e.g., depending on the operating phase), and to measure the class current of the voltage signal V_{POE}. The PoE controller **60** is also configured to generate a switching signal SW to control a set of switches S_1 and S_2 to provide the voltage signal V_{POE} and a low-voltage (e.g., ground) connection, respectively, to the PD **54** via the Ethernet connection **56** as the voltage V_{PORT} in the example of FIG. **1**. Therefore, in response to the switching signal SW, the voltage signal V_{PORT} is provided to the PD **54** based on the voltage V_{POE} via each of PORT **1** and PORT **2**. Accordingly, the PoE controller **60** can be configured to control an activation time and an amplitude of the voltage signal V_{PORT}, such as based on a given operating phase of the PoE control system **50**, to provide communication to the PD **54**. As one example, the voltage signal V_{POE} can be provided via the voltage source **58** as the variable voltage V_{PORT}. As another example, the voltage signal V_{POE} can be constant (e.g., between approximately 44 volts and approximately 57 volts), and the PSE device **52** can be configured to modulate the impedance of the switch S_1 to provide the variable voltage V_{PORT} provided to the PD **54**.

[0027] In the example of FIG. **2**, the PD **54** includes a pair of rectifiers **62** that are each coupled to the Ethernet connection **56** at the respective ports PORT **1** and PORT **2**. The rectifiers **62** are configured to provide the voltage signal V_{PORT} across a capacitor C_{PD}. In the example of FIG. **2**, the PD **54** includes a PoE signal receiver **64** ("PoE RX") that receives a voltage V_P corresponding to the voltage signal V_{PORT} across the capacitor C_{PD}. The PoE signal receiver **64** thus receives the voltage V_P and acts as a current source with respect to the voltage V_P, and thus the voltage signal V_{PORT}, such that the PoE signal receiver **64** can adjust the class current of the voltage signal V_{PORT} to provide communication to the PSE device **52** in response to the voltage signal V_{PORT} In addition, the PD **54** includes a power controller **66** to which the PoE signal receiver **64** can provide a control signal CTRL. Therefore, in response to a power setting command provided to the PoE signal receiver **64** by the PoE controller **60**, the PoE signal receiver **64** can indicate a desired output power level, such as being a function (e.g., percentage) of the nominal power level of the PD **54**, to the power controller **66** via the control signal CTRL. Accordingly, during the activation phase described in greater detail herein, the power controller **66** can provide the desired output power dictated by the power setting command in response to the full amplitude of the voltage signal V_{PORT} provided by the PSE device **52**.

[0028] FIG. **3** illustrates an example of a timing diagram **100**. The timing diagram **100** demonstrates an amplitude of the voltage signal V_P as a function of time. The timing diagram **100** can correspond to operation of the PoE control system **50**. Therefore, reference is to be made to the example of FIG. **2** in the following description of the example of FIG. **3**.

[0029] Prior to a time T_0, the voltage signal V_P can have an amplitude V_{MIN}, corresponding to a substantially minimum voltage (e.g., zero volts). As an example, the amplitude V_{MIN} could correspond to an actual voltage amplitude of the voltage signal V_P, or could correspond to the switches S_1 and S_2 being open. At the time T_0, the PSE device **52** can begin operating in a detection phase, such that the voltage signal V_P increases to a low amplitude V_{VALID1} (e.g., between approximately 2.8 volts and approximately 10 volts). Since the PD **54** is electrically coupled to the PSE device **52** via the Ethernet connection **56**, the PoE signal receiver **64** can respond by providing a sufficient resistance with respect to the voltage signal V_P to indicate to the PSE device **52** that the PD **54** is coupled via the Ethernet connection **56**. At a time T_1, the voltage signal V_P decreases to an amplitude V_{VALID2} (e.g., also between approximately 2.8 volts and approximately 10 volts, but different (e.g., less) than the amplitude V_{VALID1}). Therefore, the PSE device **52** can determine the resistance value of the PoE signal receiver **64** based on a $\Delta I/\Delta V$ of the separate amplitudes V_{VALID1} and V_{VALID2}. At a time T_2, the amplitude V_{MIN}, thus concluding the detection phase. While the detection phase is demonstrated in the example of FIG. **3** as including only a single differential measurement of the voltage signal V_P at the amplitudes V_{VALID1} and V_{VALID2}, it is to be understood that the detection phase could include differential measurements and/or additional amplitudes in the detection phase voltage amplitude range, such as dictated by the IEEE 802.3at standard.

[0030] At the time T_3, the PSE device **52** switches to a classification phase, during which the PoE controller **60** can determine whether the PD **54** has a capacity for PoE control, can determine a nominal power level of the PD **54**, and can provide a power setting command to the PoE signal receiver **64**. Beginning at the time T_3, the PSE device **52** provides a first event classification, demonstrated at **102** as a 2-Event classification. At the time T_3, the voltage signal V_P is provided at an amplitude V_{CLASS} in a first class event. The amplitude V_{CLASS} can correspond to a voltage amplitude in a classification amplitude range amplitude (e.g., between approximately 15.5 volts and approximately 20.5 volts). In response to receiving the voltage signal V_P of the first class event at the time T_3 (e.g., via the voltage V_P), the PoE signal receiver **64** can indicate a first class value (e.g., Class 4). At a time T_4, the voltage signal V_P can decrease to an amplitude V_{MRK}, corresponding to a mark event. As an example, the mark event can signify to the PoE signal receiver **64** the end of the first class event. Similarly, at a time T_5, the PSE device **52** provides the voltage signal V_P at the amplitude V_{CLASS} in a second class event of the first event classification (e.g., of the 2 Event classification), in response to which the PoE signal receiver **64** can provide a second class value (e.g., Class 4), followed by another mark event at a time T_6. As an example, the first and second class values can be equal (e.g., Class 4). Thus, the PD **14** can respond to the first event classification with a class signature that comprises two Class 4 current responses to the respective two class events of the first event classification **102**. The example of FIG. **3** demonstrates that the first event classification **102** comprises two class events in a 2-Event classification scheme, such as to ensure a linear response to a substantially constant amplitude of the voltage signal V_P at the classification amplitude range. However, it is to be understood that the PoE controller **60** can be configured to provide the first event classification as a 1-Event classification by providing a single class event, or based on providing more than two class events.

[0031] At a time T_7, the PSE device **52** again provides the voltage signal V_P at an amplitude V_{CLASS} in a second event classification (e.g., a 1-Event classification), demonstrated at **104**. In response to receiving the voltage signal V_P in a class event of the second event classification **104** (e.g., via the voltage V_P), the PoE signal receiver **64** can provide a second class signature (e.g., Class 5). At a time T_8, the voltage signal V_P can decrease to the amplitude V_{MRK}, corresponding to a mark event of the second event classification **104**, thus signifying to the PoE signal receiver **64** the end of the class event of the second event classification **104**. The second class signature can be provided by the PoE signal receiver **64** at a value that is different from (e.g., greater than) the first class signature, thus potentially signifying to the PoE controller **60** that the PD **54** may have a capacity for PoE control.

[0032] At a time T_9, the PSE device **52** again provides the voltage signal V_P at an amplitude V_{CLASS} in a third event classification, demonstrated at **106**. In response to receiving the voltage signal V_P in the third event classification **106** (e.g., via the voltage V_P), the PoE signal receiver **64** can provide a third class signature at a value that is less than the second class signature (e.g., Class 0-4). At a time T_{10}, the voltage signal V_P can decrease to the amplitude V_{MRK}, corresponding to a mark event, thus signifying to the PoE signal receiver **64** the end of the third event classification **106**. The third class signature can be provided by the PoE signal receiver **64** at a value that is less than the second class signature to indicate to the PoE controller **60** that the PD **54** has a capacity for PoE control. In addition, the specific class value of the third class signature **106** can indicate to the PoE controller **60** the nominal power level of the PD **54**. For example, the class value of the third class signature can correspond to one of a plurality of predetermined nominal power levels, such that the PoE controller **60** can identify the nominal power level based on the value of the third class signature, such as provided in Table 1 below:

TABLE 1

Third Class Signature Value	Nominal Power Level of the PD 54
0	15 W
1	30 W
2	45 W
3	60 W
4	90 W

The predetermined nominal power levels demonstrated in the example of Table 1 are provided only by example, in that any of a variety of other predetermined nominal power levels can be provided in the communication from the PoE signal receiver **64** to the PoE controller **60** via the third class signature.

[0033] As described previously, in response to identifying the nominal power level of the PD **54**, the PoE controller **60** can be configured to control the power level of the PD **54** as a function of the nominal power level, such that the power output of the PD **54** can be variably controlled by the PoE controller **60**. At a time T_{11}, the PoE controller **60** can begin to provide a number of event classifications (e.g., 1-Event classifications) via the voltage signal V_P associated with a code corresponding to the power setting command. As an example, the power setting command can be encoded based on a quantity of class events corresponding to a predetermined percentage of the nominal power level, such as provided in Table 2 below:

Quantity of Class Events	Percentage of Nominal Power Level
0	100%
1	80%
2	55%
3	30%

[0034] The predetermined percentage values of the nominal power level demonstrated in the example of Table 2 are provided only by example, in that the PoE controller **60** can be configured to provide any of a variety of predetermined quantities corresponding to associated percentages of nominal power level. The example of FIG. **3** demonstrates a single class event with associated mark event subsequently at the time T_{11}. However, it is to be understood that the PoE controller **60** can be configured to provide zero class events to signify a desired power level of the PD **54**.

[0035] In response to the code, the PoE signal receiver **64** can identify the percentage of the nominal power level that is desired to be output from the PD **54** by the PoE controller **60**. As a result, at a time T_{12}, the PSE device **52** begins operating in the activation phase, and thus provides the voltage signal V_P at a maximum amplitude V_{PORT_PSE} (e.g., between approximately 44 volts and approximately 57 volts, as dictated by a maximum voltage of an associated power supply). Therefore, the PD **54** can operate at the percentage of the nominal power level based on the power command setting. Accordingly, the PoE control system **50** described herein can operate to provide PHY layer power control of the PD **54** in a simplistic and variable manner.

[0036] FIG. **4** illustrates yet another example of a PoE control system **150**. The PoE control system **150** can correspond to the PoE control system **10** in the example of FIG. **1**, such as in a PoE lighting application. For example, the PoE control system **150** can be implemented to provide power control via existing Ethernet cables (e.g., RJ-45 cables) without Ethernet data communication capability (e.g., utilizing data/link layers, packetization, etc.).

[0037] The PoE control system **150** includes a PSE device **152** and a PD **154** that are electrically coupled via an Ethernet connection **156**. In the example of FIG. **4**, the Ethernet connection **156** is demonstrated as an RJ-45 cable that implements four twisted pair conductors. Therefore, the Ethernet connection **156** is demonstrated in the example of FIG. **4** as including two communication ports, demonstrated as PORT **1** and PORT **2**. The PSE device **152** includes a voltage source **158** that is configured to generate a variable voltage signal V_{POE}. Similar to as described previously in the example of FIG. **3**, the PSE device **152** can provide the voltage V_{POE} in a variable manner as the voltage V_{PORT} across the Ethernet connection **156**.

[0038] In the example of FIG. **4**, the PSE device **152** includes a PoE controller **160** that provides a voltage control signal P_CTL to the voltage source **158** to control the amplitude of the voltage signal V_{POE} (e.g., depending on the operating phase), and to measure the class current of the voltage signal V_{PORT}. The PoE controller **160** is also configured to generate a pair of switching signals SW_1 and SW_2 to control a respective set of switches S_1 and S_2 to provide the voltage signal V_{POE} and a low-voltage (e.g., ground) connection, respectively, to the PD **154** via the Ethernet connection **156**. Therefore, in response to the switching signal SW_1, the voltage signal V_{PORT} is provided to the PD **154** via PORT **1**, and in response to the switching signal SW_2, the voltage signal V_{PORT} is provided to the PD **154** via PORT **2**. Accordingly, the PoE controller **160** can be configured to control an activation time and an amplitude of the voltage signal V_{PORT} on each of PORTS **1** and **2** individually, such as based on a given operating phase of the PoE control system **150**, to provide communication to the PD **154**.

[0039] In the example of FIG. **4**, the PD **154** includes a first rectifier **162** that is coupled to the Ethernet connection **156** at PORT **1** and a second rectifier **163** that is coupled to the Ethernet connection **156** at PORT **2**. The first rectifier **162** is configured to provide the voltage signal V_{PORT} across a first capacitor C_{PD1} and the second rectifier **163** is configured to provide the voltage signal V_{PORT} across a second capacitor C_{PD2}. In the example of FIG. **4**, the PD **154** includes a first PoE signal receiver **164** ("PoE RX**1**") that receives a voltage V_{P1} corresponding to the voltage signal V_{PORT} across the first capacitor C_{PD1} and a second PoE signal receiver **165** ("PoE RX**2**") that receives a voltage V_{P2} corresponding to the voltage signal V_{PORT} across the second capacitor C_{PD2}.

[0040] The first PoE signal receiver **164** thus receives the voltage VPD**1** and acts as a current source with respect to the voltage VPD**1**, and thus the voltage signal V_{PORT}, such that the first PoE signal receiver **164** can adjust the class current of the voltage signal V_{PORT} to provide communication to the PSE device **152** in response to the voltage signal V_{PORT}Similarly, the second PoE signal receiver **165** thus receives the voltage VPD**2** and acts as a current source with respect to the voltage VPD**2**, and thus the voltage signal V_{PORT}, such that the second PoE signal receiver **164** can adjust the class current of the voltage signal V_{PORT} to provide communication to the PSE device **152** in response to the voltage signal V_{PORT}In addition, the PD **154** includes a power controller **166** to which the first and second PoE signal receivers **164** and **165** can provide respective control signals CTRL**1** and CTRL**2**. Therefore, in response to a power setting command provided to at least one of the PoE signal receivers **164** and **165** by the PoE controller **160**, the PoE signal receiver(s) **164** and **165** can indicate a desired output power level, such as being a function (e.g., percentage) of the nominal power level of the PD **154**, to the power controller **166** via the control signal(s) CTRL**1** and CTRL**2**. Accordingly, during the activation phase described in greater detail herein, the power controller **166** can provide the desired output power dictated by the power setting command in response to the full amplitude of the voltage signal V_{PORT} provided by the PSE device **152**.

[0041] FIG. **5** illustrates an example of timing diagrams **200** and **201**. The timing diagram **200** demonstrates an amplitude of the voltage V_{P1} as a function of time, and the timing diagram **201** demonstrates an amplitude of the voltage V_{P2} as a function of time. The timing diagrams **200** and **201** can correspond to operation of the PoE control system **150**. Therefore, reference is to be made to the example of FIG. **4** in the following description of the example of FIG. **5**. Thus, the voltage V_{P1} corresponds to the voltage V_{PORT} in response to activation of the switch S_1 via the switching signal SW_1, and voltage V_{P2} corresponds to the voltage V_{PORT} in response to activation of the switch S_2 via the switching signal SW_2.

[0042] Prior to a time T_0, the voltages V_{P1} and V_{P2} can each have an amplitude V_{MIN}, corresponding to a substantially minimum voltage (e.g., zero volts). As an example, the amplitude V_{MIN} could correspond to an actual voltage amplitude of the voltages V_{P1} and V_{P2}, or could correspond to the switches S_1 and S_2 being open. At the time T_0, the PSE device **152** can begin operating in a detection phase, such that the voltage V_{P1} increases to the amplitude V_{VALID1}. Since the PD **154** is electrically coupled to the PSE device **152** via the Ethernet connection **156**, the first PoE signal receiver **164** can respond by providing a sufficient resistance with respect to the voltage V_{P1} to indicate to the PSE device **152** that the PD **154** is coupled via the Ethernet connection **156**. At a time T_1, the voltage V_{P1} decreases to an amplitude V_{VALID1}, while the voltage V_{P2} increases to the amplitude V_{VALID1}. At a time T_2, the voltage V_{P1} decreases back to the amplitude V_{MIN}. Similarly, at a time T_2, the voltage V_{P2} decreases to the amplitude V_{VALID2}. Since the PD **154** is electrically coupled to the PSE device **152** via the Ethernet connection **156**, the second PoE signal receiver **165** can respond by providing a sufficient resistance with respect to the voltage V_{P2} to indicate to the PSE device **152** that the PD **154** is coupled via the Ethernet connection **156**. Therefore, the PSE device **152** can determine the resistance value of the PoE signal receivers **164** and **165** based on a $\Delta I/\Delta V$ of the separate amplitudes V_{VALID1} and V_{VALID2}. At a time T_3, the voltage V_{P2} decreases back to the amplitude V_{MIN}, thus concluding the detection phase, based on which the PoE controller **160** identifies that both PORT **1** and PORT **2** are coupled to the respective first and second PoE signal receivers **164** and **165**. While the detection phase is demonstrated in the example of FIG. **5** as including only a single pulse of the voltages V_{P1} and V_{P2} at the single amplitude V_{VALID}, it is to be understood that the detection phase could include additional pulses and/or additional amplitudes in the detection phase voltage amplitude range, such as dictated by the IEEE 802.3at standard, for each of the voltages V_{P1} and V_{P2}.

[0043] At the time T_4, the PSE device **152** switches to a classification phase, during which the PoE controller **160** can determine whether the PD **154** has a capacity for PoE control, can determine a nominal power level of the PD **154**, and can provide a power setting command to the PoE signal receiver (s) **164** and **165**. Beginning at the time T_4, the PSE device **152** provides a first event classification to the first PoE signal receiver **164**, demonstrated at **102** as a 2-Event classification. Thus, at the time T_4, the voltage V_{P1} increases to an amplitude V_{CLASS} in a first class event. The amplitude V_{CLASS} can correspond to a voltage amplitude in a classification amplitude range amplitude (e.g., between approximately 15.5 volts and approximately 20.5 volts). In response to the increase of the voltage V_{P1} of the first class event in the first event classification **202**, the PoE signal receiver **164** can provide a first class value (e.g., Class 4). At a time T_5, the voltage V_{P1} can decrease to an amplitude V_{MRK}, corresponding to a mark event. As an example, the mark event can signify to the first PoE signal receiver **164** the end of the first class event of the event classification **202**. Similarly, at a time T_6, the voltage V_{P1} increases to the amplitude V_{CLASS} in a second class event of the event classification **202**, in response to which the PoE signal receiver **64** can provide a second class value (e.g., Class 4), followed by another mark event at a time T_7. As an example, the first and second initial class values can be equal (e.g., Class 4). Thus, the first PoE receiver **164** can respond to the first event classification with a class signature that comprises two Class 4 current responses to the respective two class events of the first event classification **202**. The example of FIG. **5** demonstrates that the first event classification **202** comprises two class events in a 2-Event classification scheme, such as to ensure a linear response to a substantially constant amplitude of the voltage signal V_{PORT} at the classification amplitude range. However, it is to be understood that the PSE device **152** can be configured to provide the first event classification as a 1-Event classification by providing a single class event, or based on providing more than two class events.

[0044] At a time T_8, the PSE device **152** provides a second event classification via PORT **2**, demonstrated at **204**, at which the voltage V_{P2} increases to an amplitude V_{CLASS} in a class event at the time T_8. In response to the class event of the second event classification **204**, the second PoE signal receiver **165** can provide a second class signature (e.g., Class 5). At a time T_9, the voltage V_{P2} can decrease to the amplitude V_{MRK}, corresponding to a mark event, thus signifying to the second PoE signal receiver **165** the end of the class event of the event classification **204**. The second class signature can be provided by the second PoE signal receiver **165** at a value that is different from the first class signature, thus potentially signifying to the PoE controller **160** that the PD **154** may have a capacity for PoE control.

[0045] At a time T_{10}, the PSE device **152** provides a third event classification via PORT **2**, demonstrated at **206**, at which the voltage V_{P2} increases to the amplitude V_{CLASS} in a class event at the time T_{10}. In response to the class event of the third event classification **206**, the second PoE signal receiver **166** can provide a third class signature that is less than the second class signature (e.g., Class 0-4). At a time T_{11}, the voltage V_{P2} can decrease to the amplitude V_{MRK}, corresponding to a mark event, thus signifying to the second PoE signal receiver **165** the end of the class event of the third event classification **206**. The third class signature can be provided by the second PoE signal receiver **166** at a value that is less than the second class signature to indicate to the PoE controller **160** that the PD **154** has a capacity for PoE control. In addition, the specific class value of the third class signature **206** can indicate to the PoE controller **160** the nominal power level of the PD **154**, such as demonstrated previously in Table 1.

[0046] As described previously, in response to identifying the nominal power level of the PD **154**, the PoE controller **160** can be configured to control the power level of the PD **154** as a function of the nominal power level, such that the power output of the PD **154** can be variably controlled by the PoE controller **160**. At a time T_{11}, the PoE controller **160** can begin to provide a number of class events via one or both of the voltages V_{P1} and V_{P2} associated with a code corresponding to the power setting command. As an example, the power setting command can be encoded based on a quantity of pulses of the class events corresponding to a predetermined percentage of the nominal power level, such as provided previously in Table 2. As an example, the additional class events that indicate the percentage of nominal power level can be provided solely via the voltage V_{P1}, solely via the voltage V_{P2}, or based on a combination of the voltages V_{P1} and V_{P2}. For example, the code can be based on a sum of the quantity of class events provided via the voltages V_{P1} and V_{P2}, or the code can be based on a binary and/or time-based encoding of the class events provided via the voltages V_{P1} and V_{P2}. Thus, the additional class events that indicate the percentage of nominal power level can be provided in any of a variety of ways.

[0047] In response to the code, the first and/or second PoE signal receivers **164** and **165** can identify the percentage of the nominal power level that is desired to be output from the PD **154** by the PoE controller **160**. As a result, at a time T_{13}, the PSE device **152** begins operating in the activation phase, and thus provides the voltage signal V_{PORT} at a maximum amplitude to provide the voltages V_{P1} and/or V_{P2} at the amplitude V_{PORT_PSE}. Therefore, the PD **154** can operate at the percentage of the nominal power level based on the power command setting. Accordingly, the PoE control system **150** described herein can operate to provide PHY layer power control of the PD **154** in a simplistic and variable manner over multiple ports via the Ethernet connection **156**.

[0048] In view of the foregoing structural and functional features described above, a method in accordance with various aspects of the present invention will be better appreciated with reference to FIG. **6**. While, for purposes of simplicity of explanation, the method of FIG. **6** is shown and described as executing serially, it is to be understood and appreciated that the present invention is not limited by the illustrated order, as some aspects could, in accordance with the present invention, occur in different orders and/or concurrently with other aspects from that shown and described herein. Moreover, not all illustrated features may be required to implement a method in accordance with an aspect of the present invention.

[0049] FIG. **6** illustrates an example of a method **250** for providing power control in a PoE control system. At **252**, event classifications (e.g., event classifications **102**, **104**, and **106**) of a voltage signal (e.g., the voltage signal V_{PORT}) are provided via an Ethernet connection (e.g., the Ethernet connection **16**) from a PSE device (e.g., the PSE device **12**). At **254**, a nominal power level is indicated based on a class signature (e.g., the class signature **106**) via a PoE signal receiver (e.g., the PoE signal receiver **20**) of a powered device (e.g., the PD **14**) based on a class current of the voltage signal. At **256**, a power setting command associated with a quantity of class events of the voltage signal (e.g., at the time T_{11} in the example of FIG. **3**) is provided from the PSE device to the PoE signal receiver. The power setting command can correspond to a percentage of the nominal power level (e.g., Table 1). At **258**, the PD is activated to operate at the percentage of the nominal power level based on the power setting command.

[0050] What have been described above are examples of the invention. It is, of course, not possible to describe every conceivable combination of components or method for purposes of describing the invention, but one of ordinary skill in the art will recognize that many further combinations and permutations of the invention are possible. Accordingly, the invention is intended to embrace all such alterations, modifications, and variations that fall within the scope of this application, including the appended claims.

What is claimed is:

1. A power-over-Ethernet (PoE) control system comprising:

a powered device (PD) that is configured to receive a voltage signal via an Ethernet connection and which comprises a PoE signal receiver configured to indicate a nominal power level via the received voltage signal; and

a power sourcing equipment (PSE) device configured to generate the voltage signal and to measure a class current of the voltage signal to determine the nominal power level, the PSE device comprising a PoE controller configured to provide a power setting command as a function of the nominal power level to the PoE signal receiver via the voltage signal, such that the PD can operate at a power level that is based on the power setting command.

2. The system of claim **1**, wherein the PSE device is configured to provide the power setting command as a function of the nominal power level based on providing the voltage signal as a quantity of class events associated with a code corresponding to a desired percentage of the nominal power level.

3. The system of claim **1**, wherein the PoE signal receiver is configured to indicate the nominal power level via a class signature corresponding to a magnitude of the class current associated with the voltage signal, wherein the PSE device is configured to provide the power setting command subsequent to the PoE signal receiver indicating the nominal power level.

4. The system of claim **3**, wherein the class signature has a class value corresponding to one of a plurality of predetermined nominal power levels.

5. The system of claim **1**, wherein the PoE signal receiver is configured to provide a first class signature of the class current in response to a first event classification associated with the voltage signal, and a second class signature in response to a second event classification, the second class signature having a different class value from the first class signature, and a third class signature in response to a third event classification, with the third class signature being different from the second class signature to indicate that the PD has a capacity for PoE control by the PSE device.

6. The system of claim **5**, wherein the third class signature has a class value that corresponds to one of a plurality of nominal power levels, such that the third class signature indicates the nominal power level of the PD to the PSE device.

7. The system of claim **5**, wherein the first class signature is provided from the PD at Class 4, wherein the second class signature is provided from the PD at Class 5, and wherein the third class signature is provided from the PD at a class level corresponding to the nominal power level.

8. The system of claim **1**, wherein the PD comprises a first PoE signal receiver and a second PoE signal receiver, and wherein the PSE device is configured to provide a first voltage signal to the first PoE signal receiver and a second voltage signal to the second PoE signal receiver, wherein the first PoE signal receiver is configured to provide a first class signature of the class current in response to a first event classification of the first voltage signal and wherein the second PoE signal receiver is configured to provide a second class signature in response to a second event classification associated with the second voltage signal, wherein the second class signature has a greater class value from the first class signature to indicate that the PD has a capacity for PoE control by the PSE device.

9. The system of claim **8**, wherein the second PoE signal receiver is configured to provide a third class signature in response to a third event classification associated with the second voltage signal, wherein the third class signature has a different class value from the second class signature and wherein the third class signature is less than the second class signature to indicate that the PD has a capacity for PoE control by the PSE device, wherein the third class signature corresponds to the nominal power level to the PSE device.

10. The system of claim **9**, wherein the PSE device is configured to provide the power setting command as a function of the nominal power level based on providing at least one of the first and second voltage signals as a quantity of class events corresponding to a desired percentage of the nominal power level subsequent to the indication of the nominal power level via the third class signature.

11. A PoE lighting system comprising the PoE control system of claim **1**.

12. A method for providing power control in a power-over-Ethernet (PoE) control system, the method comprising:

providing event classifications of a voltage signal via an Ethernet connection from a power sourcing equipment (PSE) device;

indicating a nominal power level based on a class signature via a PoE signal receiver of a powered device (PD) based on a class current of the voltage signal;

providing a power setting command associated with a quantity of class events of the voltage signal from the PSE device to the PoE signal receiver, the power setting command corresponding to a percentage of the nominal power level; and

activating the PD to operate at the percentage of the nominal power level based on the power setting command.

13. The method of claim **12**, further comprising indicating a capacity for PoE control by the PSE device based on a plurality of class signatures, wherein indicating the nominal power level comprises indicating the nominal power level based on a last of the plurality of class signatures.

14. The method of claim **13**, wherein providing the event classifications comprises providing a first event classification, a second event classification, and a third event classification, wherein indicating the capacity for PoE control comprises indicating the capacity for PoE control by the PSE device based on a first of the plurality of class signatures provided in response to the first event classification and a second of the plurality of class signatures provided in response to the second event classification, wherein the first and second of the plurality of class signatures have different class values, and based on a third of the plurality of class signatures that has a class value that is less than the second of the plurality of class signatures.

15. The method of claim **12**, wherein indicating the nominal power level comprises indicating the nominal power level based on a value of the last of the plurality of class signatures corresponding to one of a plurality of predetermined nominal power levels, wherein providing the power setting command comprises providing the power setting command corresponding to a percentage of the one of the plurality of predetermined nominal power levels.

16. The method of claim **12**, wherein providing the event classifications comprises providing a first event classification via a first port of the Ethernet connection and providing a second event classification via a second port of the Ethernet connection, wherein indicating the nominal power level comprises indicating the nominal power level based on a first class signature via a first PoE signal receiver of the PD based on a class current of a first voltage signal and a second class signature via a second PoE signal receiver of the PD based on a class current of a second voltage signal, and wherein providing the power setting command comprises providing the power setting command associated with a quantity of class events of at least one of the first voltage signal and the second voltage signal to a respective at least one of the first PoE signal receiver and a second PoE signal receiver.

17. A power-over-Ethernet (PoE) control system comprising:

a powered device (PD) that is configured to receive a voltage signal via an Ethernet connection and which comprises a PoE signal receiver configured to provide a first class signature in response to a first event classification via a class current of the received voltage signal and a second class signature via the class current, the second class signature having a different class value from the first class signature, and a third class signature that has a class value that is less than the second class signature to indicate that the PD has a capacity for PoE control, the third class signature indicating a nominal power level of the PD; and

a power sourcing equipment (PSE) device configured to generate the voltage signal and to measure the class current of the voltage signal to determine the capacity for PoE control and the nominal power level, the PSE device comprising a PoE controller configured to provide a power setting command as a function of the nominal power level to the PoE signal receiver via the voltage signal, such that the PD can operate at a power level that is based on the power setting command.

18. The system of claim **17**, wherein the PSE device is configured to provide the power setting command as a function of the nominal power level based on providing the voltage signal as a quantity of class events associated with a code corresponding to a desired percentage of the nominal power level.

19. The system of claim **17**, wherein the PD comprises a first PoE signal receiver and a second PoE signal receiver, and wherein the PSE device is configured to provide a first voltage signal to the first PoE signal receiver and a second voltage signal to the second PoE signal receiver, wherein the first PoE signal receiver is configured to provide a first class signature of the class current in response to a first event classification of the first voltage signal and wherein the second PoE signal receiver is configured to provide a second class signature in response to a second event classification associated with the second voltage signal, wherein the second class signature is configured to indicate that the PD has a capacity for PoE control by the PSE device based on being greater than the first class signature.

20. The system of claim **18**, wherein the second PoE signal receiver is configured to indicate the nominal power level via the third class signature corresponding to the nominal power level to the PSE device, and wherein the PSE device is configured to provide the power setting command as a function of the nominal power level based on providing at least one of the first and second voltage signals as a quantity of class events associated with class signatures corresponding to a desired percentage of the nominal power level.

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