Application Note

Sourcing Power Over Ethernet

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Revision History

Each instance in the Revision History reflects a change to this document from its previous revision. For more details, refer to the corresponding pages or appropriate links given in the table below.

Date	Revision Level	Section	Description	Page No
September 2006	01	All	Formatted to current publication standards	All

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Abstract

This Reference Design describes ZiLOG's Z8 Encore! XP® based power sourcing equipment (PSE) for Power over Ethernet (PoE) enabled devices connected to local area network (LAN). Power over Ethernet is a cost-effective solution which allows data and power to be sourced over the same Ethernet cable connected to power devices (PD) such as VOIP telephones, WLAN transmitters, and security cameras. Power devices are connected to PSE using standard Ethernet cable with no separate power supply connection. The source code file associated with Z8 Encore! XP® based Power over Ethernet Application is available in the Application Sample Libraries on www.zilog.com.

The reference design consists of the following:

- Motherboard
- Plug-In Board

Motherboard

Motherboard houses circuit for power supply management, battery management, boost converter, LCD display, and slots to plug 6 plug-in boards.

Plug-In Board

Plug-in board controls the power supplied to the PD which is connected to the Ethernet cable. Plug-in board consists of two RJ45 sockets called ports (DATA IN and DATA + POWER OUT). The data cable from an Ethernet Hub is connected to DATA IN port and the PD is connected to DATA + POWER OUT port of PSE.

The power sourcing equipment is compliant to the IEEE802.3af standard and is capable of power sourcing up to six ports. It also includes features like hardware for over current protection, battery backup, fast switching between power source and battery. It uses RS-485 communication standard to transfer measured electrical parameters from plug-in board to Motherboard for LCD. Single low-cost Z8 Encore! XP® 8-pin microcontroller is used for controlling single power device which improves programmability and power control for power management. Motherboard uses single Z8 Encore! XP® 28-pin microcontroller for power management.

Features

PSE supports the following features:

- Conforms to IEEE802.3af publication standards.
- Capable of power sourcing up to six independent ports.
- Detects 25 kΩ signature resistor of the power device.

- Categorizes the class (0, 1, 2, 3, and 4) of the power device connected to LAN.
- Hardware electronic circuit breaker for short circuit protection on LAN cable.
- Load over-current, under-current detection, and fault protection.
- Power device disconnect detection.
- Continuous port current monitoring.
- Battery backup for ½ hour with battery charging circuitry.
- In case of power loss the boost converter generates 12 V to 48 V, 350 mA from battery to provide power to IP device connected to LAN.
- A 4 line, 20 character (4*20) LCD to display parameters related to plug-in board and Motherboard (that is, device ID, class, power, battery status, boost converter voltage, and battery voltage).

Theory of Operation

Power over Ethernet is a cost-effective solution which allows data and power to be sourced over the same Ethernet cable connected to a power device (PD). Examples of power devices include:

- Voice over internet protocol (VOIP) telephones
- Wireless local area network (WLAN) transmitters
- Security cameras

Power sourcing equipment (PSE) is a device that provides power to a PD. Methods of powering a PSE include external power supply or battery. When the PSE is embedded into the Ethernet switch it is called Endspan and when it is connected between Ethernet switch and power devices it is called Midspan.

The IEEE802.3af standard defines the standard for using PoE devices and covers the PSE (Endspan or Midspan), the powered device, and the cabling requirements.

Figure 1 displays how to connect PD to PSE, Ethernet Switch/Hub, and associated power supply. The data input port of PSE is connected to output port of Ethernet Switch/Hub. PDs are connected to the output port of PSE. PSE receives data from the Ethernet Switch/Hub and injects 48 VDC to data and supplies DATA + POWER OUT to PD. 48 VDC is derived from the AC mains or battery.

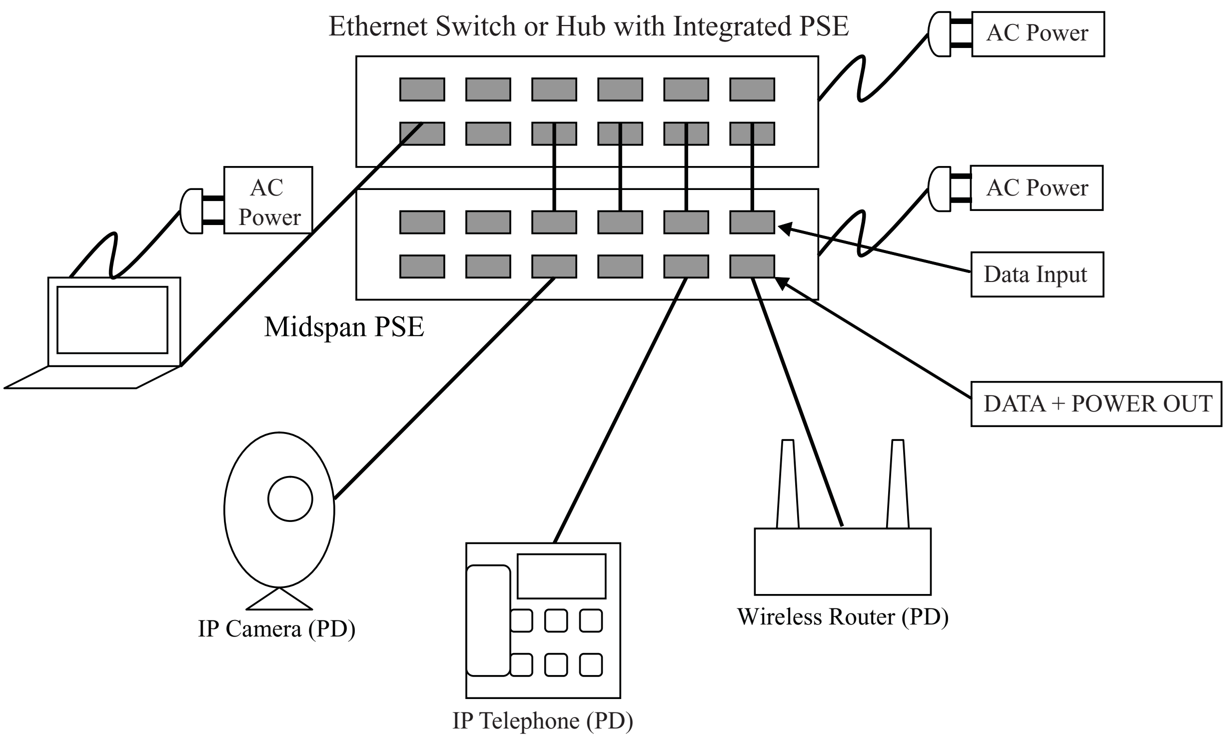


Figure 1. Connection of PD to Midspan PSE

An Ethernet cable consists of four pairs of wires. Two pairs are used as data lines (transmit and receive) and the other two pairs are unused. Power is injected into these unused pairs of wires as displayed in Figure 2 on page 4. Existing category-5 (CAT-5) cable is used for sourcing power to PD.

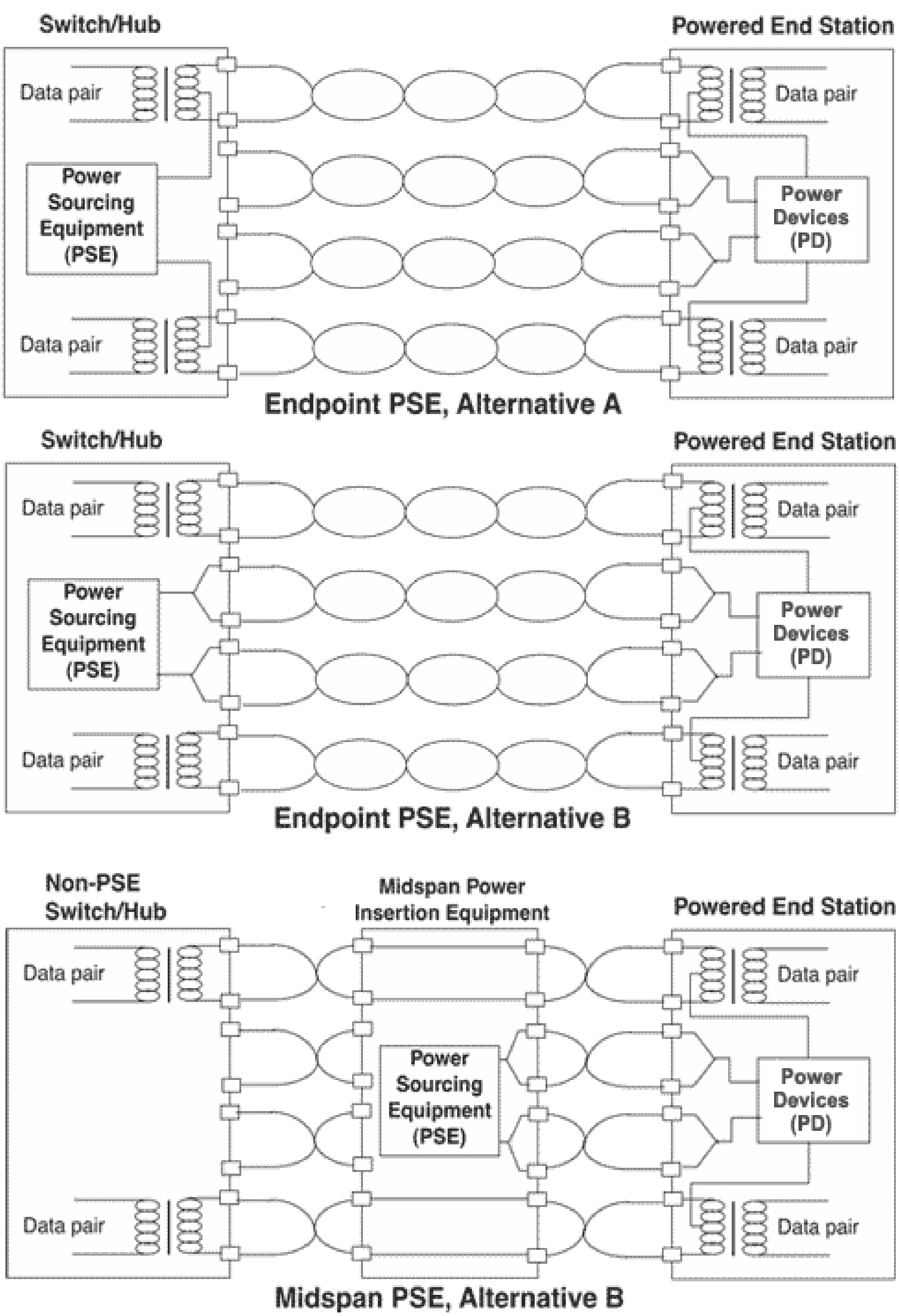


Figure 2. Connections Between Data Hub, PSE, and PD

Developing Power Sourcing Equipment with Z8 Encore! XP® MCU

This section provides an overview of the functional architecture of the PSE using Z8 Encore! XP® MCU.

The reference design consists of the following:

- Motherboard
- Plug-In Board

Motherboard

Motherboard houses circuit for power supply management, battery management, boost converter, LCD display, and slots to plug 6 plug-in boards.

The design requirements for Motherboard are listed below:

- Three analog inputs to measure battery voltage, charging current, and boost converter voltage.
- Four data lines and three control lines for LCD.
- Edge interrupt detect to switch between external power supply and battery.
- One timer in pulse width modulation (PWM) mode and one port pin to switch PWM between charger and boost converter.
- External crystal oscillator to perform all time critical tasks.
- Universal Asynchronous Receiver Transmitter (UART) to communicate with plug-in boards.

Z8 Encore! XP® 28-pin was chosen because it meets the design requirements. This processor provides the following capability:

- A controller with at least three Analog-to-Digital Converter (ADC) channels
- A 9-bit UART
- One Timer
- Nine GPIO lines
- An on-chip debugger (OCD) to enable rapid development
- Flash memory to support software functionalities

Plug-In Board

Plug-in board controls the power supplied to the PD which are connected to the Ethernet cable.

The design requirements for plug-in board are listed below:

- Two analog inputs to read output current and output voltage through the Ethernet cable.
- One PWM output for voltage control on the Ethernet cable.
- One receiver (RX) and transmitter (TX) pin each for serial data communication.
- One GPIO for switching the gain of an external amplifier.

Z8 Encore! XP® 8-pin was chosen because it meets the design requirements. This processor provides the following capability:

- A controller with two ADC input
- One PWM output
- One 9-bit UART with TX and RX pin for data communication
- A GPIO pin required for operation
- Internal precession oscillator (reduced cost and foot print)
- An OCD to enable rapid development
- Flash memory to support software functionalities

Hardware Architecture

Power sourcing equipment consists of a Motherboard (which is the main board) to which all the plug-in boards (maximum 6) and power supplies are connected.

Power sourcing equipment has the following functional blocks:

- Device detection, classification, and powering
- Current limiting circuits
- Battery charging
- Battery current and voltage sensing
- Boost converter and boost voltage sensing
- LCD
- Communication on RS-485

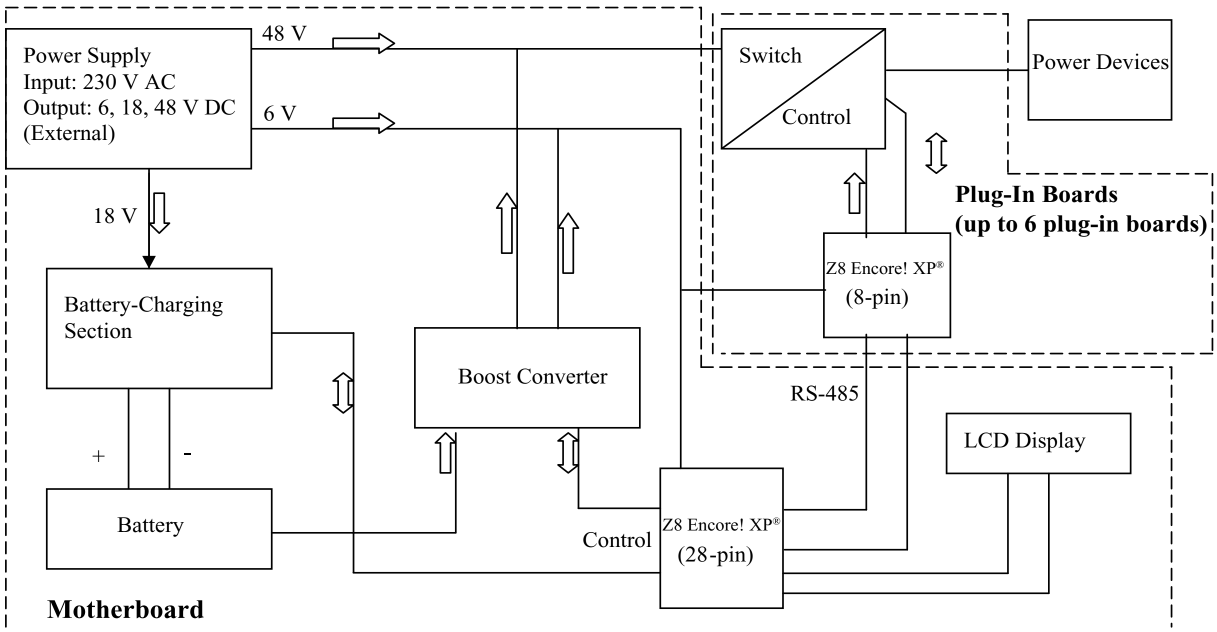


Figure 3. Hardware Block Diagram of Z8 Encore! XP® based Power Over Ethernet PSE Application

Motherboard

The Motherboard consists of the following hardware functional blocks:

- External Power Supply to Motherboard
- Battery Charging
- Boost Converter
- Communication Between Motherboard and Plug-In Board on RS-485 Network
- Power Loss Detection
- LCD Display

External Power Supply to Motherboard

Motherboard requires three external input voltages of 48 V, 18 V, and 6 V. 48 V is required by the power devices connected to plug-in board. 18 V is used to charge the nickel metal hydride (NiMH) 12 V, 1500 mAh battery. 6 V is used to provide power to the system.

Battery Charging

Battery charging circuit is designed to charge a NiMH battery of 12 V,1500 mAh with constant charging current. A constant charging current of 375 mA is used when battery voltage is below nominal voltage (12 V). A constant charging current of 150 mA is used when battery voltage is above the nominal voltage.

A PWM frequency of 50 kHz is used to charge the battery. This is generated using one of the timers present on Z8 Encore! XP®. This frequency is applied to a metal oxide semiconductor field effect transistor (MOSFET) which acts as a switch. Source terminal of MOSFET is connected to 18 V (used for charging the battery) and Drain terminal of MOSFET is connected to positive terminal of the battery. Negative terminal of the battery is connected to a resistor (low-value resistor of 0.1 Ω) which in turn is connected to ground. Therefore, the current flowing through the resistor is same as the current used for battery charging. This voltage drop across resistor is provided to ADC channel 0. Depending on the ADC value, PWM duty cycle is regulated and constant current is maintained. If load increases, voltage at ADC input decreases and the PWM duty cycle increases to maintain constant current. If load decreases, voltage at ADC input increases and the PWM duty cycle decreases to maintain constant current.

Boost Converter

Boost converter generates 48 V using battery voltage (12 V) to provide power to PD which is connected to LAN. The functional voltage required by the system (5 V) is also generated by the boost converter. Boost converter is turned ON when there is no external supply voltage and is turned OFF when there is external supply.

A PWM frequency of 100 kHz is used by the boost converter. As the frequency increases, the size of inductor and capacitor used in boost converter is reduced. This frequency is generated using timer present on Z8 Encore! XP®. The same frequency is applied to the Gate of MOSFET which acts as a switch. Battery voltage is applied to the Drain of MOSFET and Source of MOSFET is grounded. In order to maintain constant voltage duty cycle is varied keeping the frequency constant. Output voltage is taken as feedback and applied to ADC channel 6 for sensing and control of boost voltage. When load increases ON time increases and when load decreases ON time is reduced to maintain constant voltage.

Communication Between Motherboard and Plug-In Board on RS-485 Network

Motherboard (Z8F082A, 28-pin) communicates with plug-in board controller (Z8F042A, 8-Pin) periodically to fetch information from PD connected to plug-in board. A multi-slave single master RS-485 network is implemented. Each plug-in board controller is allocated a device identity (ID) which is used by Motherboard controller for communication with the plug-in board.

Power Loss Detection

To avoid loss of communication due to switching between external source and boost converter, a voltage divider is connected to 48 V (external input). When voltage drops below 37 V, an interrupt is generated at port pin PA6 (in case of no external supply) and boost converter is turned ON. Boost converter is turned OFF when external supply resumes.

LCD Display

A 4*20 dot matrix LCD (TM12864DBCW8) is used to display system parameter and information about PD connected to equipment. LCD is configured for 4-bit mode. Four MSB data lines and three control lines of LCD are connected to the Motherboard controller.

Plug-In Board

The plug-in board consists of the following hardware functional blocks:

- Power Control for Individual Port
- Power Switch and Current Regulation
- Data Transmission

Power Control for Individual Port

The power control block performs the following functions:

- Controls the voltage required for power device detection, classification, and powering up of the PD connected to the DATA + POWER OUT port.
- Switch the gain of the current amplification to have a dynamic current measurement range of 0 mA to 0.05 mA or 0 mA to 500 mA.
- Measure the current flowing in the Ethernet cable connected to DATA + POWER OUT port.
- Use the measured value of current for power device detection, classification, and disconnection.
- Continuous monitoring of the power supplied for the connected PD; disconnect PD from the source power supply if the current drawn is above specified limit.

Power Switch and Current Regulation

The power switch consists of the hardware necessary to generate detection phase voltage, classification phase voltage, and finally powering the PD. The power switch and current regulation block also consists of a current regulation circuit to limit the line current to a maximum of 500 mA in case of short circuit or over load condition.

Data Transmission

Data is transmitted to the Motherboard controller. The hardware standard for communication is RS-485. The TX and RX data of the Z8 Encore! XP® 8-pin microcontroller is converted to RS-485 voltage levels using a RS-485 level converter.

Software Implementation

This section describes the software implementation of Motherboard and plug-in board.

Motherboard

The software functionalities of Motherboard are:

- System Initialization
- Power Source Check
- Check Battery Voltage and Start Battery Charging
- Power Loss Detection, Check Battery Voltage, and Start Boost Converter
- Communicate with Plug-In Boards at Regular Intervals
- LCD Display Information of Motherboard and Plug-In Board

System Initialization

The system is configured for external crystal as clock source and peripherals are initialized to the respective functionality. LCD is initialized to 20*4 configuration and 4-bit mode. Communication between Motherboard and plug-in board is initialized at 1200 baud rate. PWM frequency for battery charger is 50 kHz and PWM frequency for boost converter is 100 kHz.

Power Source Check

After system initialization is done, system power source is checked depending on the status of port pin PA6 (see Table 1 on page 11). Power source can be external power source or battery (boost converter).

Table 1. Detection of Power Source

SI No	Port Pin Status	Power Source Status
1	Low	External source absent.
2	High	External source present.

Check Battery Voltage and Start Battery Charging

If the battery voltage exceeds the nominal voltage (12 V) then CHARGING mode is set to TRICKLE CHARGE mode. Trickle charge current is 150 mA. If the voltage is below the nominal battery voltage, then CHARGING mode is set to FAST CHARGING mode. Fast charge current is 375 mA (see Table 2).

Table 2. Detection of Battery Voltage and CHARGING Mode

SI No	Battery Voltage	CHARGING Mode	Charging Current
1	>10 V	Stop charging	NA
2	>10 V and <12 V	FAST CHARGING mode	375 mA
3	>12 V	TRICKLE CHARGE mode	150 mA
4	>14.5 V	Charging stopped	NA

Initially, a default PWM duty cycle is applied and charging current is sensed on ANA0 pin. If current value is less than the defined trickle charging current/fast charging current value, then PWM duty cycle is increased to reach the defined value of current. Once that value is reached, PWM is not changed and current is monitored. If current rises above trickle charging current/fast charging current then PWM value is decreased. Thus depending on the charging current value PWM duty cycle is regulated to maintain constant current. While charging, battery voltage is also monitored. If voltage is <10 V or >14.5 V then charging is stopped.

Power Loss Detection, Check Battery Voltage, and Start Boost Converter

Boost converter is started due to loss of external power source. When voltage level of external power source drops below 37 V, an interrupt is generated and port pin PA6 status is checked. If the status of port pin PA6 is Low then boost converter is turned ON. Before starting boost converter, battery voltage is measured on AN2 pin and if the battery voltage level exceeds the nominal battery voltage, boost converter is started. Boost voltage is measured on port pin ANA6. If value of boost voltage is not as per the requirement then the PWM value is increased/decreased to achieve >48 V<. Once the defined value is reached PWM is not varied till the voltage falls below or rises above certain limit (48 V).

Battery voltage is continuously monitored and when battery voltage falls below nominal voltage then boost converter is turned OFF with indication on LCD.

Communicate with Plug-In Boards at Regular Intervals

Motherboard controller communicates with each plug-in board every second. This is done in round robin fashion. When a device is called for the first time then, the same device is called after 6 seconds. This communication is done in MULTIPROCESSOR mode. In MULTIPROCESSOR mode, initially Motherboard controller sends a plug-in ID on network with which it wants to communicate. If plug-in board with plug-in ID sent on network is present only then it responds to the next byte (that is, a command). Once the command is identified, valid response is sent by plug-in board. The response is then stored in an array on Motherboard controller which is utilized for display on LCD.

LCD Display Information of Motherboard and Plug-In Board

LCD is configured for 4-bit addressing. In this case first higher nibble is sent and then the low nibble is sent preceded by control status (read/write, RS, and Enable). LCD is refreshed every 2.5 seconds. This ensures that every time there is a data of two devices for display.

Plug-In Board

The software functionalities of plug-in board are:

- Initialization of Peripherals
- Monitoring the Line Current to Detect the Presence of PD
- Classification of the PD Based on the Value of Current Drawn
- Power-Up the PD, Monitor for PD Disconnection, and Any Over Current Condition
- Remove Power to the PD in Case of Disconnection or Fault Condition

Initialization of Peripherals

Z8 Encore! XP® peripherals are initialized when the plug-in board is turned ON. The port pin PA3 selects the operational amplifier with a gain of 125 to detect the presence of the PD. Configures analog channel input ANA2 and ANA3 for CONTINUOUS mode with an internal reference voltage of 2 V. Timer 0 is configured to generate 1 ms interrupt. Timer 1 is configured as PWM generator at a frequency of 50 kHz.

Monitoring the Line Current to Detect the Presence of PD

Whenever a PD is connected, it draws current from the Ethernet cable. This current is measured every 100 ms. The measured value of current must be between 2 mA to 10 mA (as specified in IEEE802.3af standard). If the measured current is within the limits; for device detection Timer 1 is started (controlled PWM generation) after the device is detected on the Ethernet cable.

Classification of the PD Based on the Value of Current Drawn

When a PD is detected, the PWM duty cycle is increased so that the voltage on the port to which PD is connected is set to 20 V. After a time delay for the voltage to settle down, average of 5 ADC readings are taken to identify the class. For a device to fall under a specific class it must draw current from the DATA + POWER OUT port less than 50 mA as specified in IEEE802.3af standard.

Power-Up the PD, Monitor for PD Disconnection, and Any Over Current Condition

If a specific PD class is identified by the PSE, the PWM duty cycle is raised to 100% to generate 48 V, and thus powering the PD. Now the ADC High and Low thresholds are enabled with interrupts. When either ADC High or Low threshold interrupt occurs the power to the PD is removed. Low threshold interrupt occurs when a PD is disconnected. High threshold interrupt occurs when the PD draws current >450 mA. The power to the PD is also removed after 50 ms if the power drawn by the PD exceeds its specified class limit but less than 450 mA.

Remove Power to the PD in Case of Disconnection or Fault Condition

The power to the port to which the PD is connected is switched OFF if the PD is unplugged from the port or a fault condition exists on the port.

Procedure to Operate Power Sourcing Equipment

Follow the steps below to operate PSE:

1. Connect plug-in boards to the slots provided by the Motherboard. Ensure that the Motherboard and plug-in board are loaded with the desired firmware.
2. Connect the external power supply of 48 V, 18 V, and 6 V to power connector on left-hand side of the Motherboard.
3. Turn ON the external power supplies.
4. Observe the LCD displaying various system parameters (that is, device ID, class, power, battery status, boost converter voltage, and battery voltage). Initially, as no device is connected to plug-in board, LCD displays ‘no device’ corresponding to device IDs.
5. Now connect the PoE compatible device to RJ45 connector marked DATA + POWER OUT and connect the data cable to RJ45 connector marked DATA IN.

6. After PoE compatible device is connected to the corresponding plug-in board, it gets powered up using same Ethernet cable and parameters such as class and power is sent by the plug-in board to the Motherboard for LCD display of that particular device ID. In CHARGING mode, last line of LCD displays battery voltage. In BOOST mode, last line of LCD displays boost voltage.

Summary

This Reference Design provides an easy and reliable means of sourcing Power over Ethernet using Z8 Encore! XP® devices. It provides flexibility to connect up to six PDs to the PSE. The status of individual PDs along with the battery status is displayed on the LCD. It provides effective control and monitoring of power supplied to the PDs connected to PoE which simplifies the overall design.

Appendix A—References

Table 3 provides the list of related documentation.

Table 3. List of References

Document Number	Description
PS0228	Z8 Encore! XP® 8K and 4K Series Product Specification
IEEE 802.3af	IEEE Standard Specifications

Appendix B—Glossary

Appendix B provides abbreviations and definitions used in this Application Note (see Table 4).

Table 4. List of Abbreviations

Abbreviation	Definition
ADC	Analog-to-Digital Converter
CAT-5	Category-5
GPIO	General Purpose Input/Output
IP	Internet Protocol
LAN	Local Area Network
LCD	Liquid Crystal Display
MCU	Microcontroller Unit
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
MSB	Most Significant Byte
NiMH	Nickel Metal Hydride
OCD	On-chip Debugger
OP AMP	Operational Amplifier
PD	Power Device
PoE	Power Over Ethernet
PSE	Power Sourcing Equipment
PWM	Pulse Width Modulation
RX	Receiver
TX	Transmitter
UART	Universal Asynchronous Receiver Transmitter
VOIP	Voice Over Internet Protocol
WLAN	Wireless Local Area Network

Appendix C—Schematic Diagrams

Appendix C provides the schematic diagrams for Power over Ethernet.

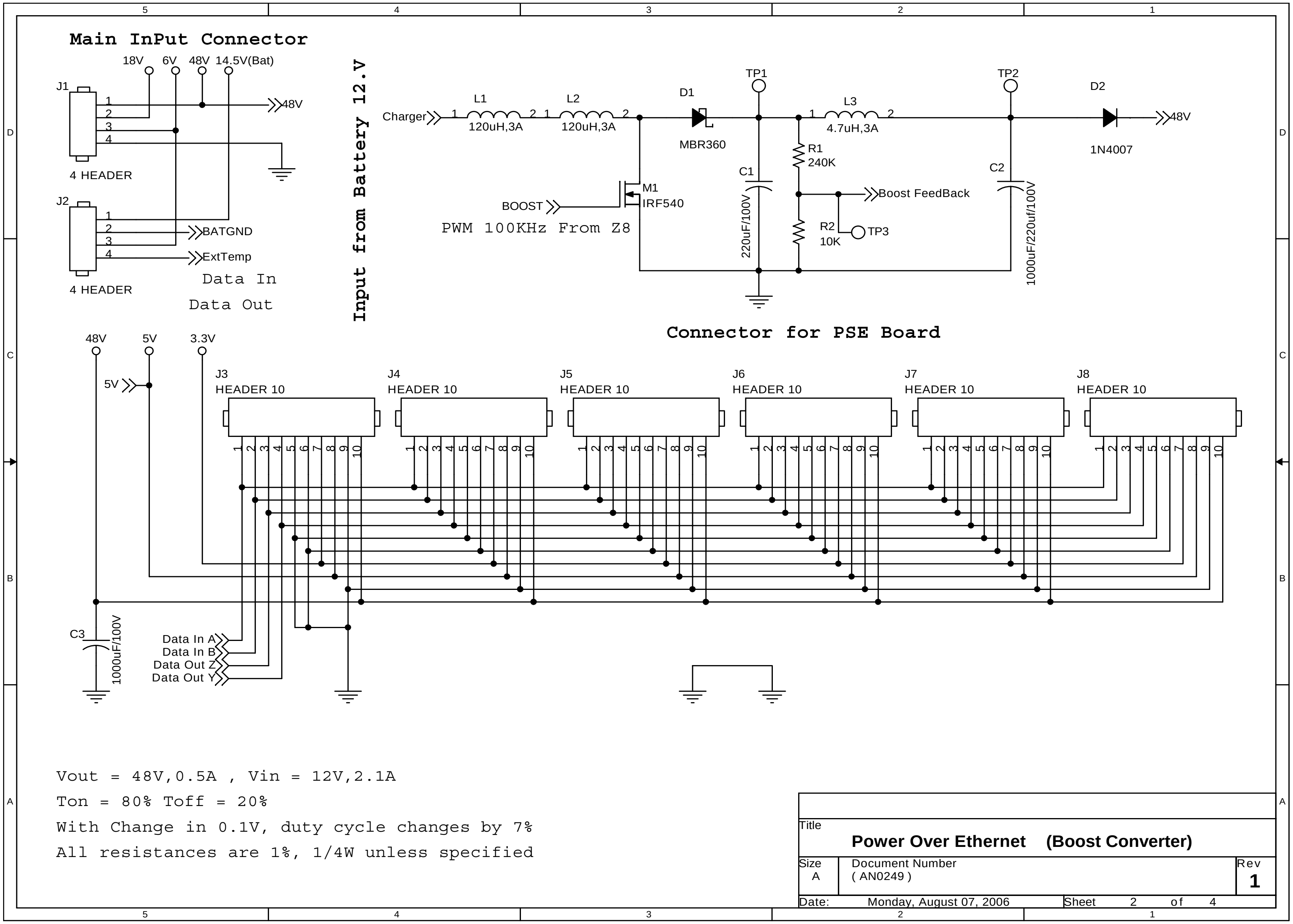


Figure 4. Schematic Diagram of Boost Converter

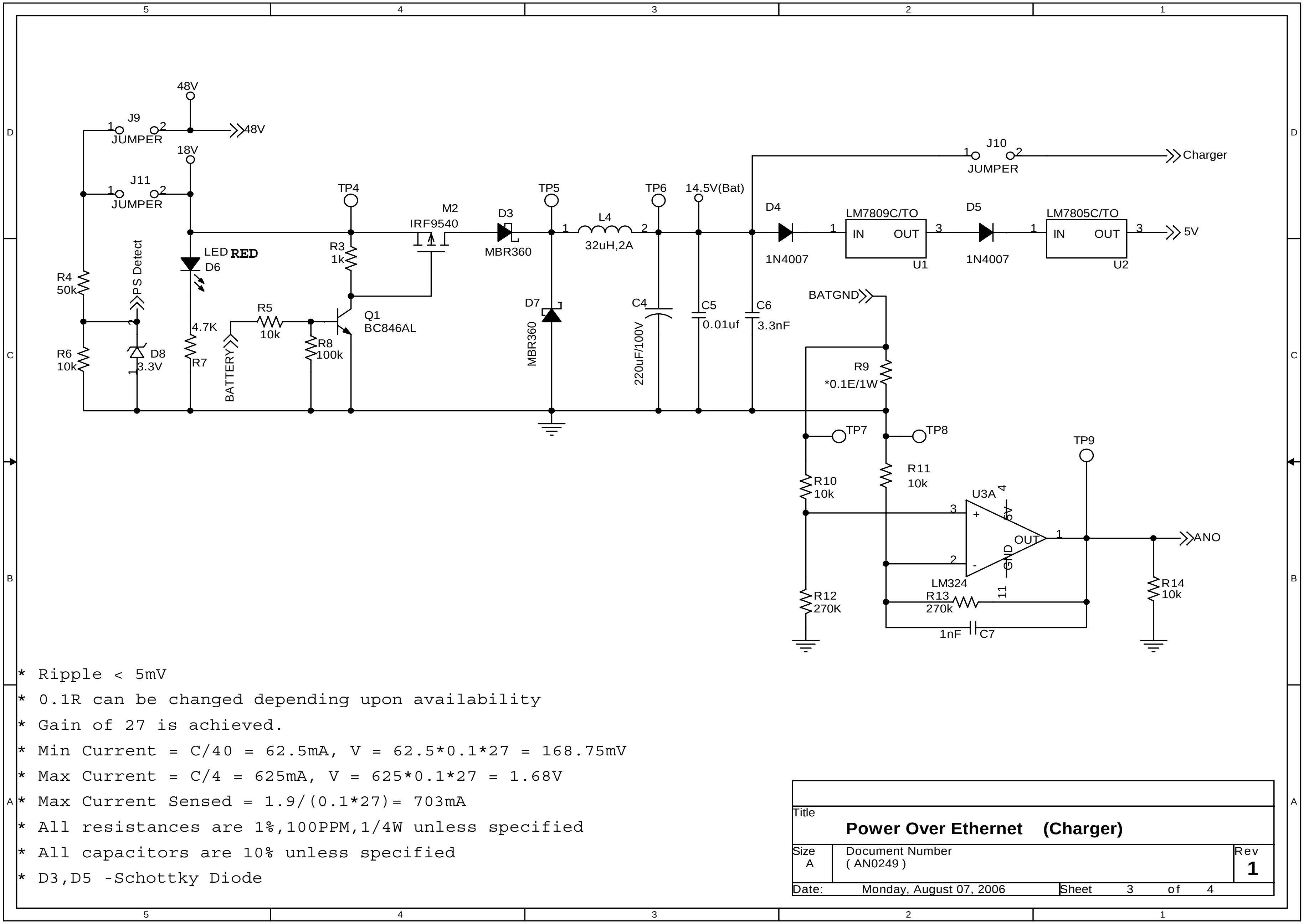


Figure 5. Schematic Diagram of Charger

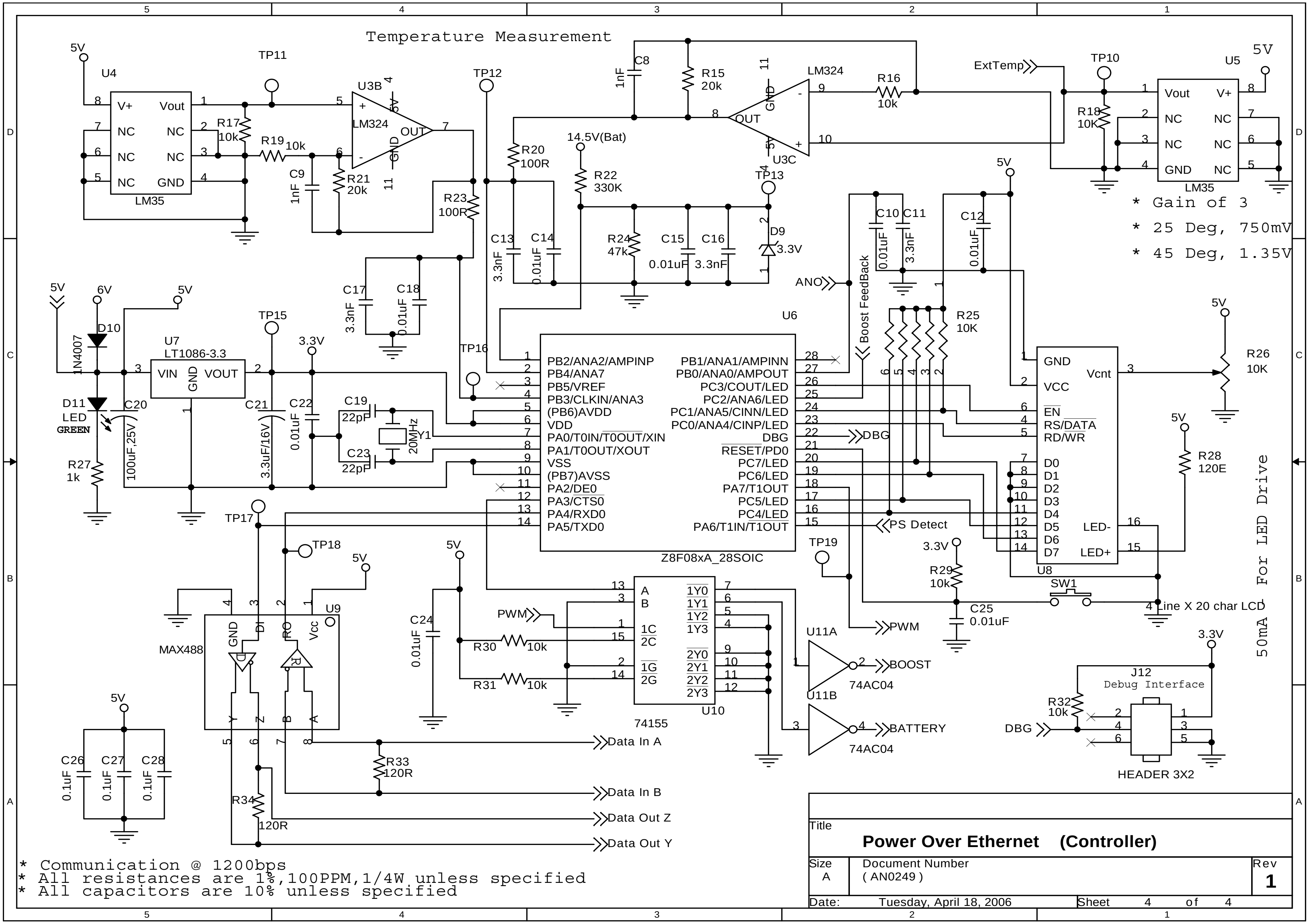


Figure 6. Schematic Diagram of Controller

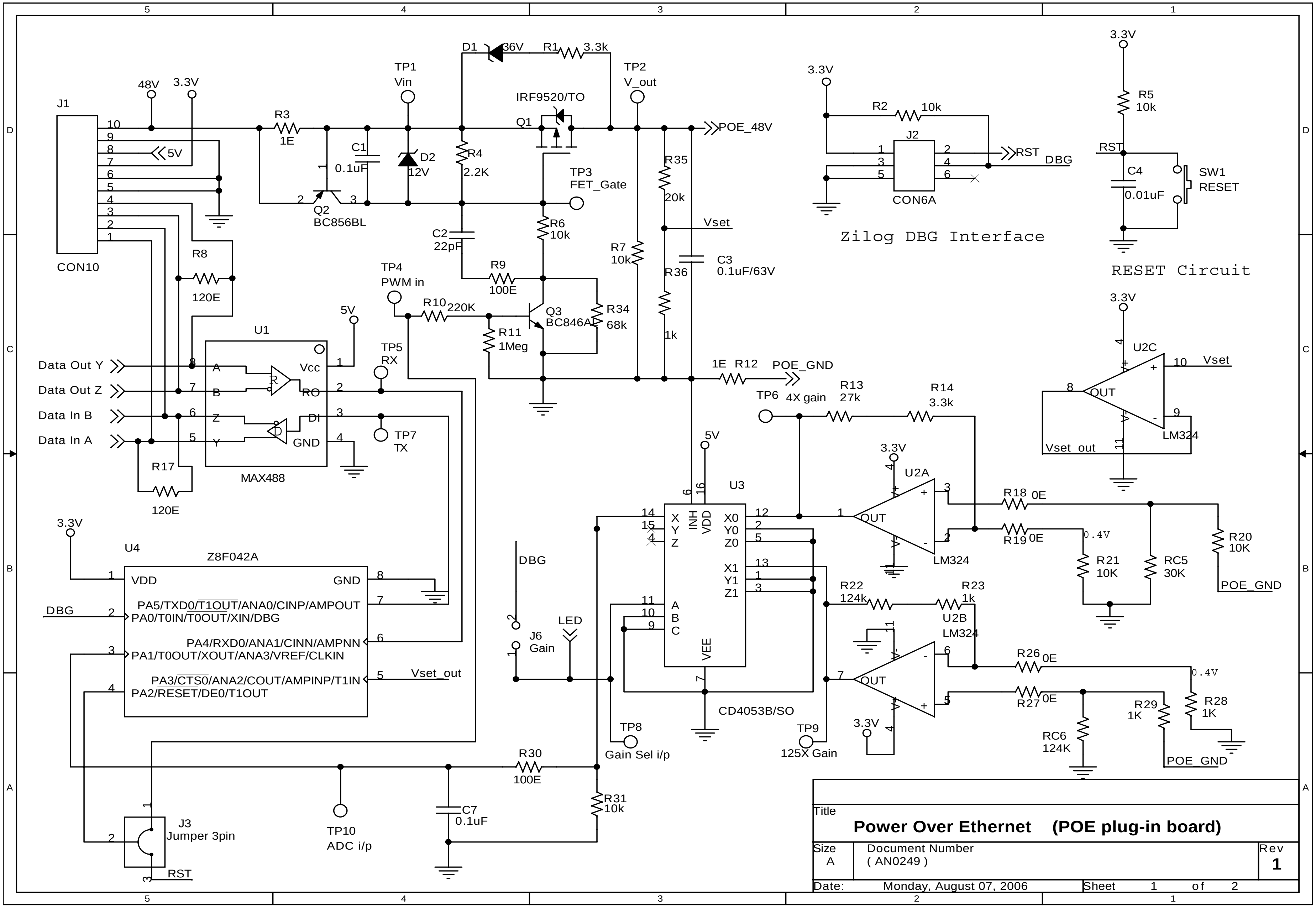


Figure 7. Schematic Diagram of PoE Plug-In Board

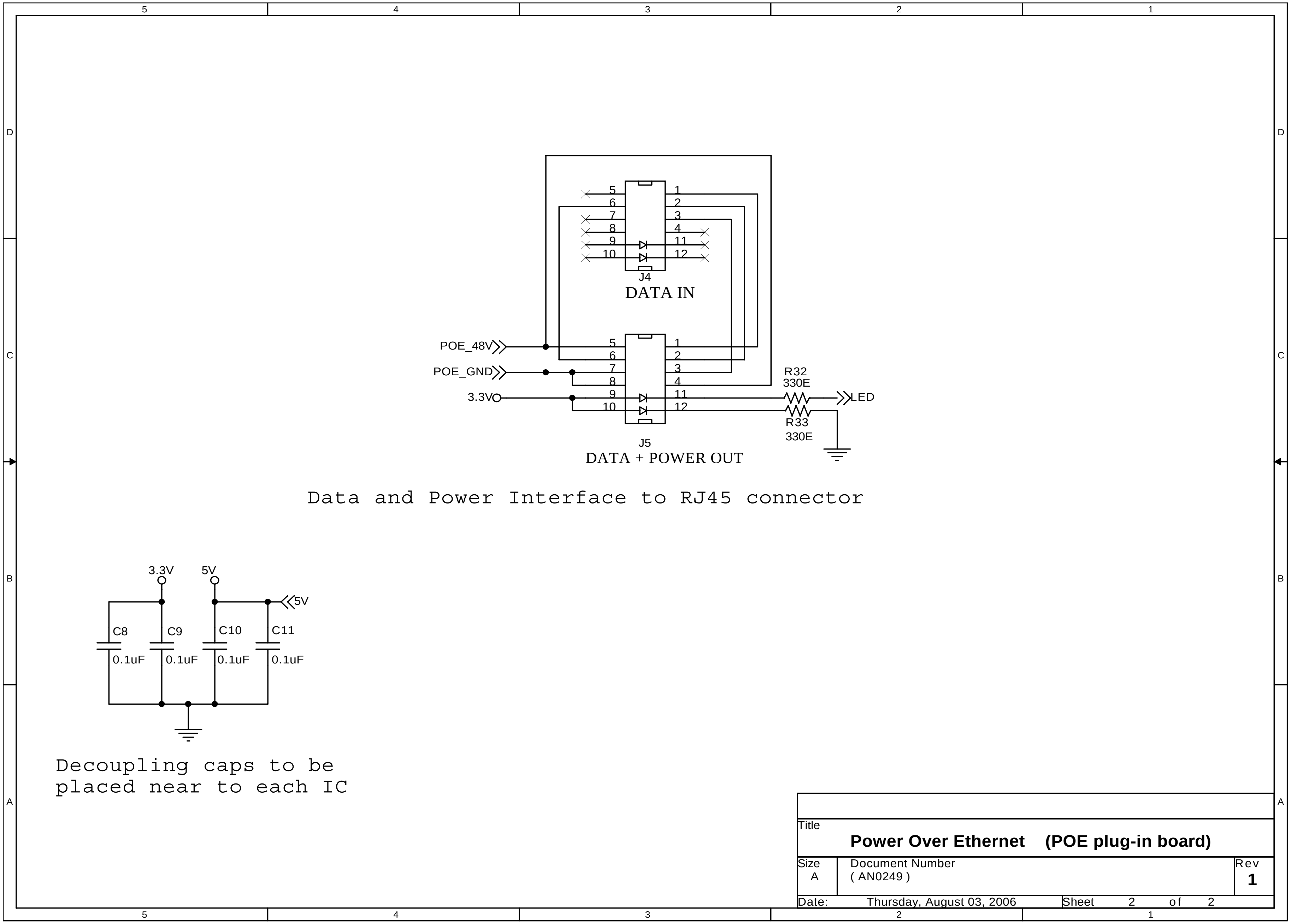
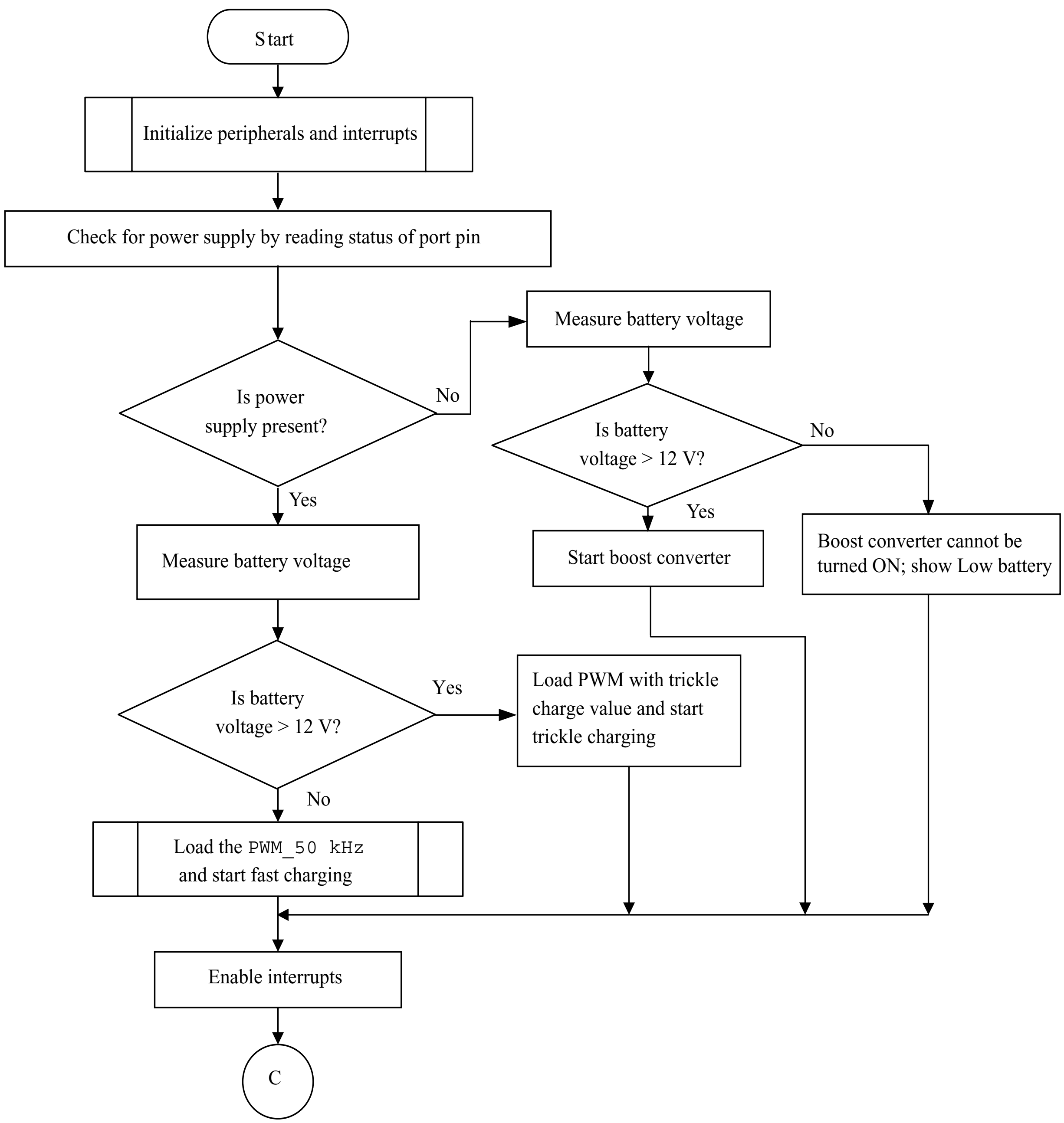


Figure 8. Schematic Diagram of Power Interface to RJ45 Connector

Appendix D—Flowcharts

Appendix D displays the flowchart of Motherboard, Port interrupt, ISR receive, ISR ADC, ISR Timer 0, and Plug-In Board.



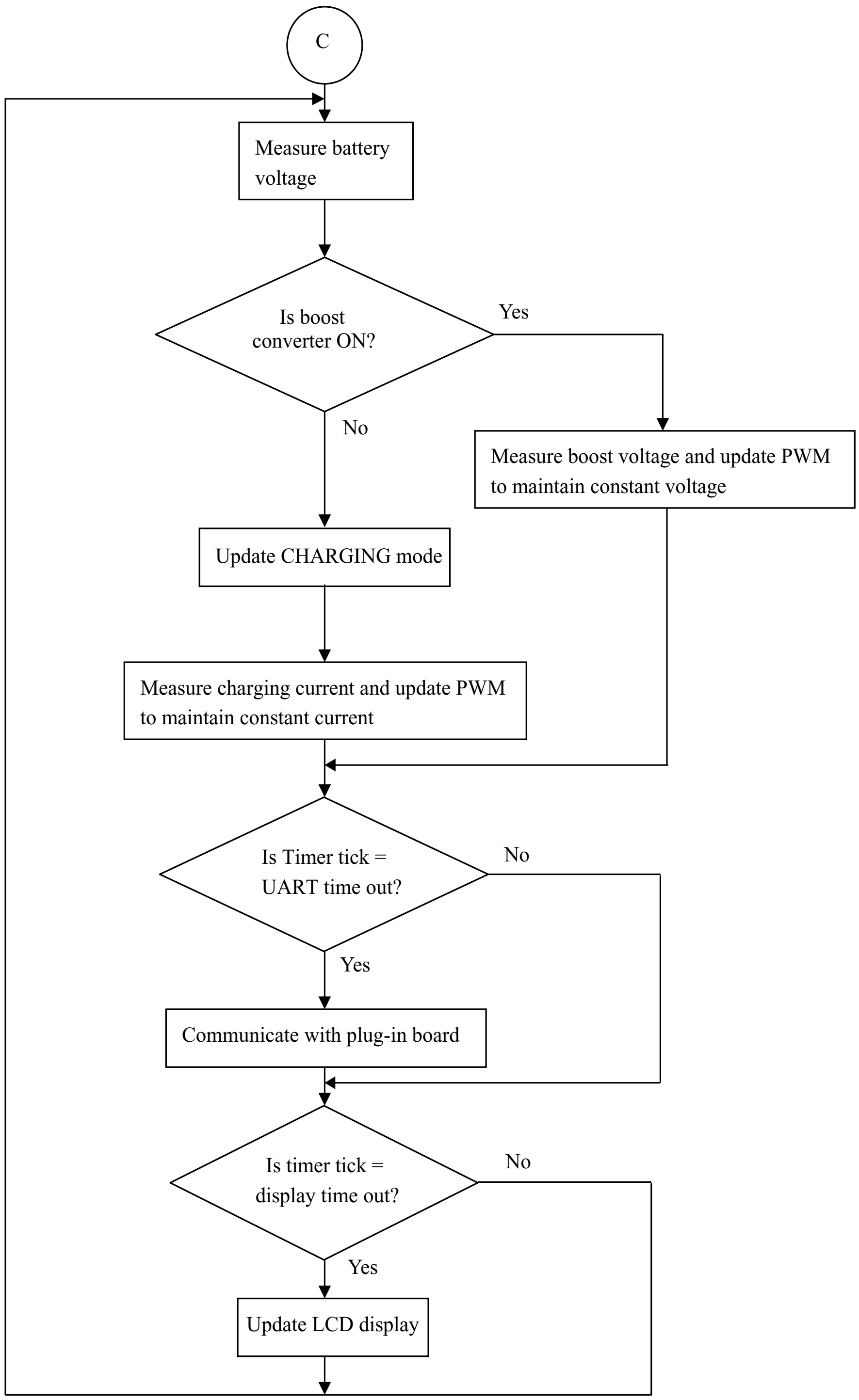


Figure 9. Flowchart of Motherboard

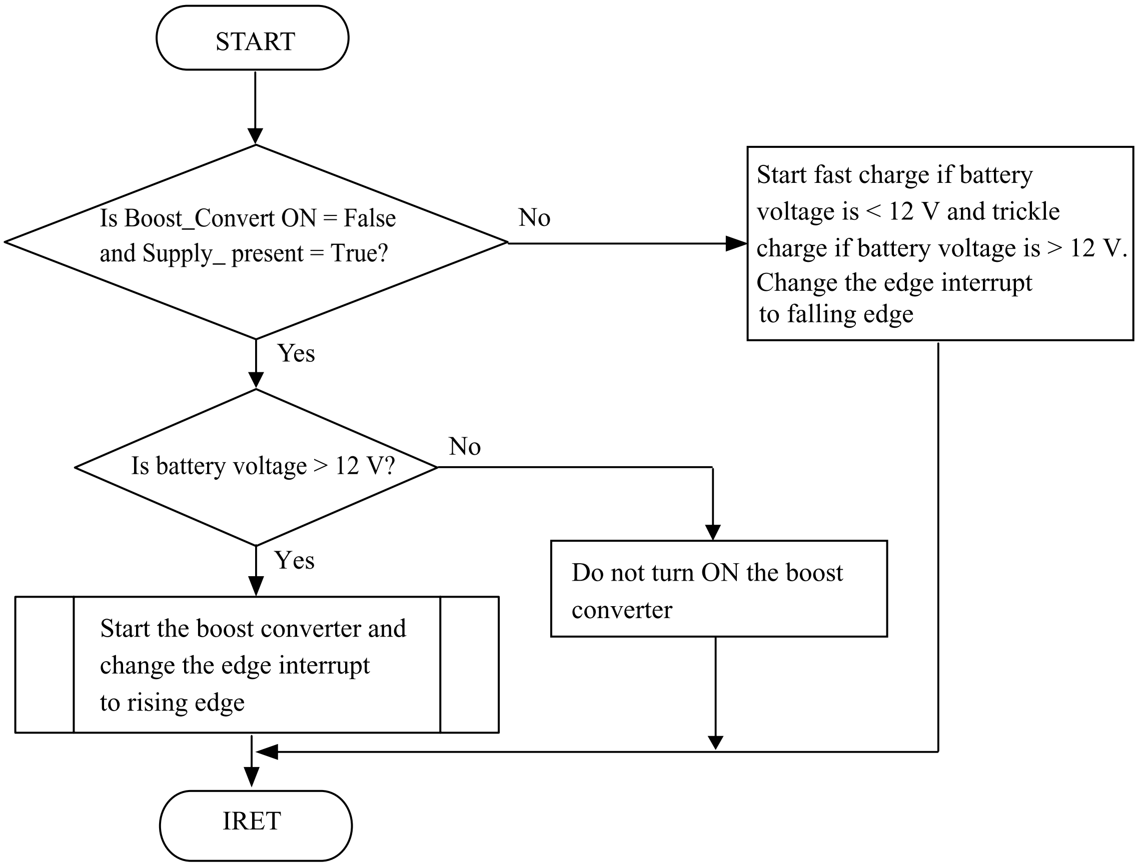


Figure 10. Flowchart of Port Interrupt (Power Loss Detection)

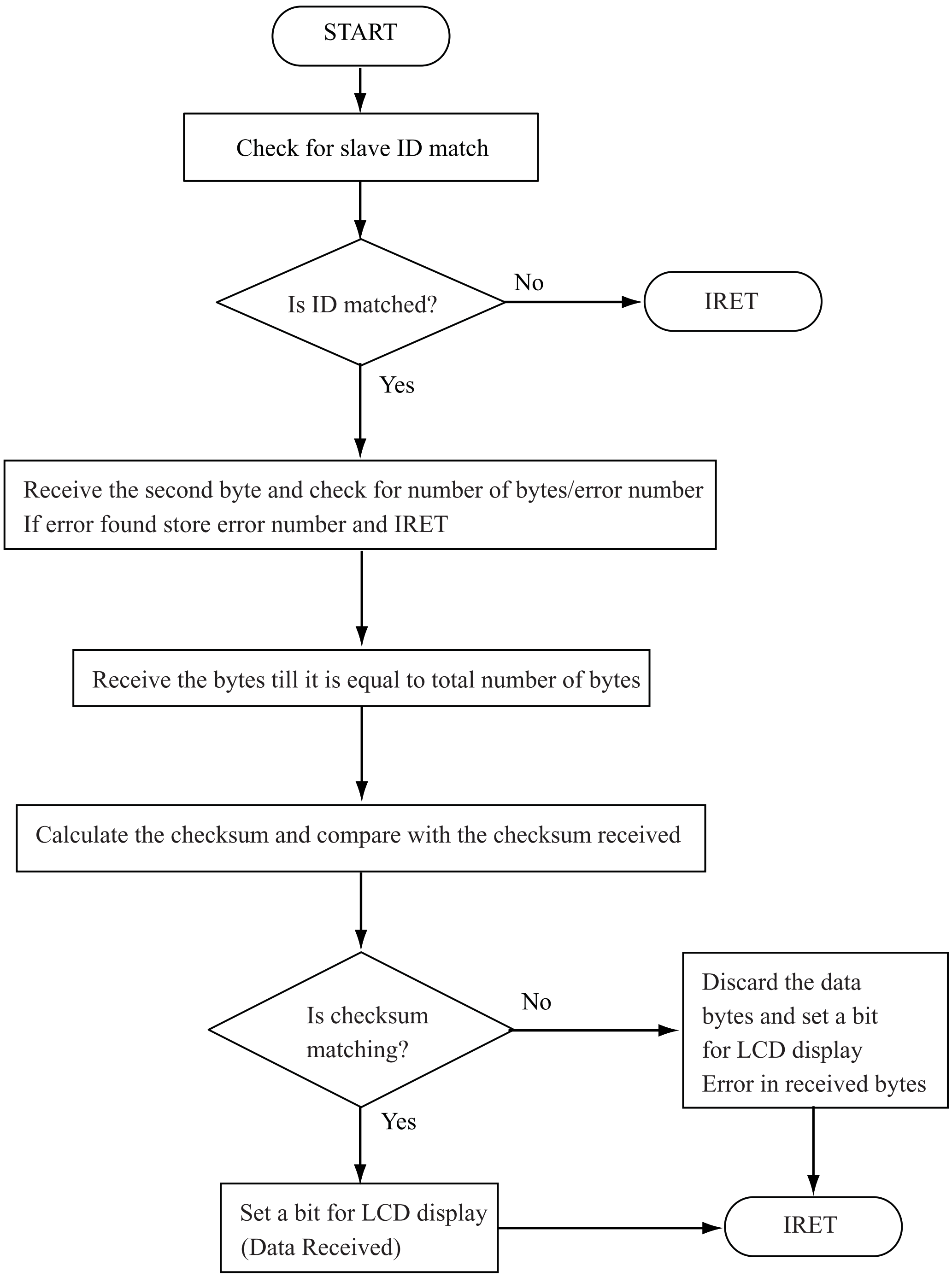


Figure 11. Flowchart of ISR Receive

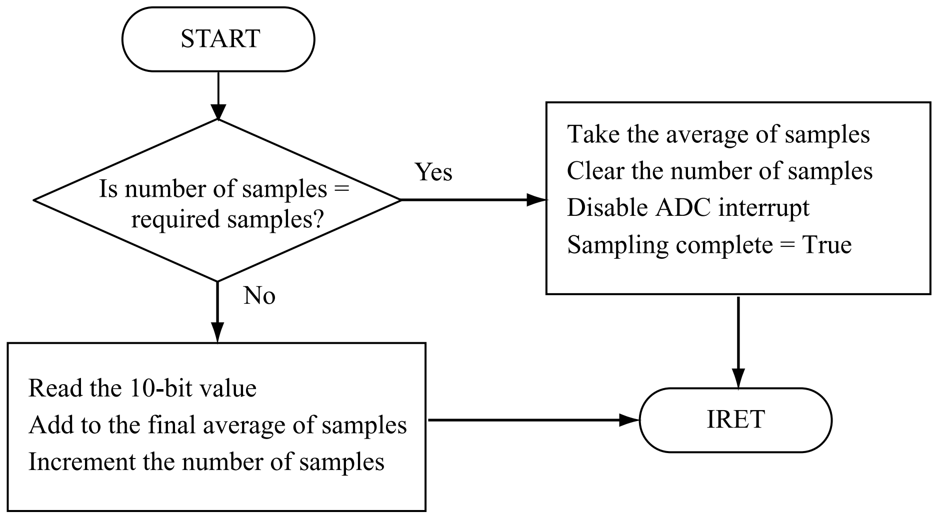


Figure 12. Flowchart of ISR ADC

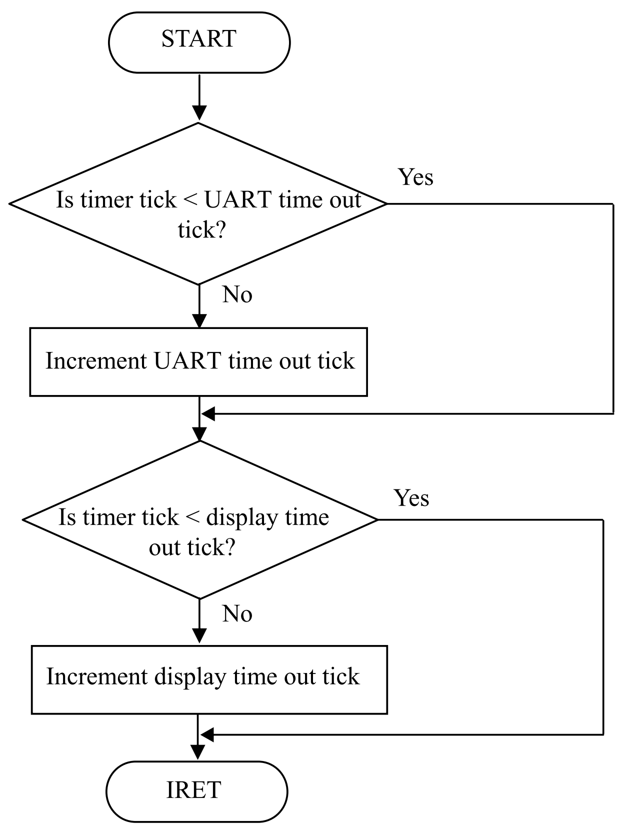
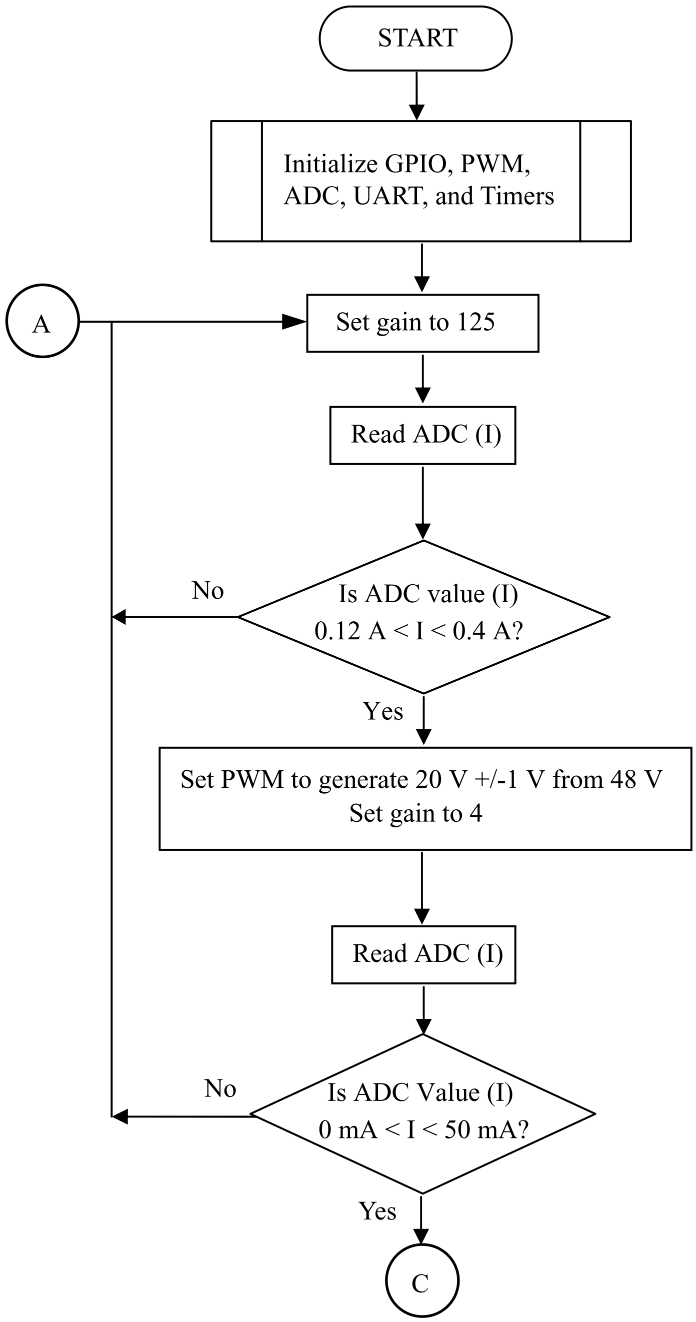


Figure 13. Flowchart of ISR Timer 0


START
Initialize GPIO, PWM, ADC, UART, and Timers
A
Set gain to 125
Read ADC (I)
No
Is ADC value (I) 0.12 A < I < 0.4 A?
Yes
Set PWM to generate 20 V +/-1 V from 48 V
Set gain to 4
Read ADC (I)
No
Is ADC Value (I) 0 mA < I < 50 mA?
Yes
C

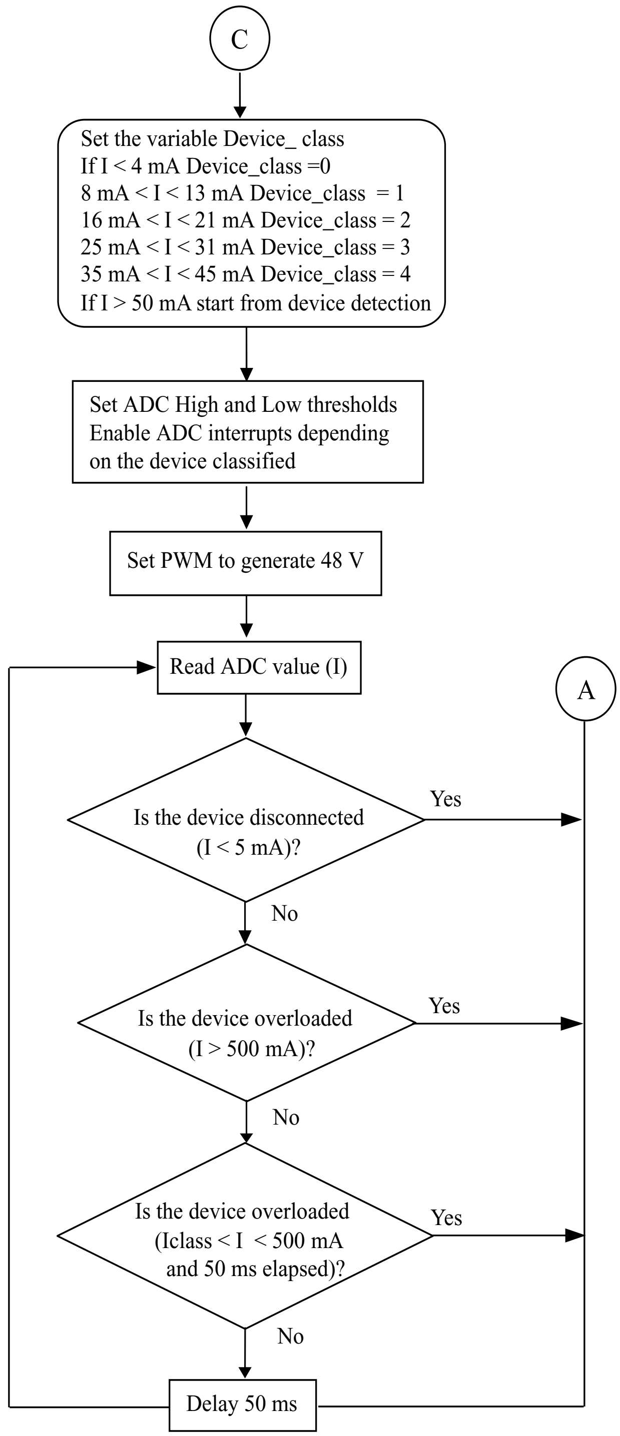


Figure 14. Flowchart of Plug-In Board