TI Designs
32-Bit ARM® Cortex®-M4F MCU-Based Small Form Factor Serial-to-Ethernet Converter

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Design Resources

TIDA-00226	Tool Folder Containing Design Files
TM4C129XNCZAD	Product Folder
TPD4E1U06	Product Folder
SN75HVD3082E	Product Folder
TPS62177	Product Folder
INA196AIDBVR	Product Folder

TI E2E™ Community

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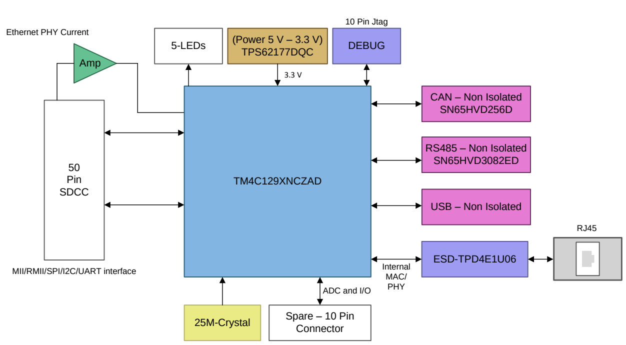
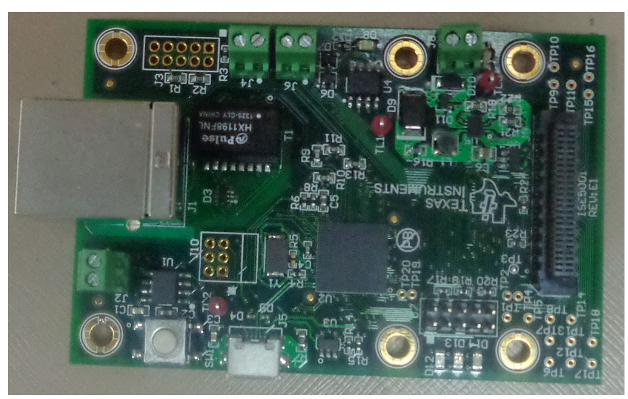
Design Features

- TM4C129XNCZAD 32-Bit ARM Cortex-M4F MCU-Based
- Integrated 10/100 Ethernet MAC and Physical Layer (PHY)
- 10/100 Ethernet MAC with Advanced IEEE 1588 PTP Hardware and Both Media Independent Interface (MII) and Reduced Media Independent Interface (RMII) Support
- Provision to Connect to External Boards for Isolated Communication Interface and POE
- Onboard Nonisolated CAN and RS-485 PHY
- 50-Pin Connector for External Interface with MII/RMII Ethernet PHY
- Expansion Connectors for Access to Communication, ADC, and GPIO Interfaces
- 1024-KB Flash Memory and 256-KB Single-Cycle System SRAM

Featured Applications

- Industrial Application: Circuit Breakers, Protection Relays, Smart Meters (AMI), and Panel Mount Multi-Function Power and Energy Meters
- Substation Automation Products: RTU, Protection Relay, IEDs, Converters, and Gateways
- Industrial Remote Monitoring: Remote I/O and Data Loggers





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1 System Description

A simple and effective design makes ethernet the most popular networking solution at the physical and data link levels of the Open Systems Interconnection (OSI) model. With high speed options and a variety of media types to choose from, ethernet is efficient and flexible. In addition, the low cost of hardware makes ethernet an attractive option for industrial networking applications. The opportunity to use open protocols such as TCP/IP over ethernet networks offers a high level of standardization and interoperability. The result has been an ongoing shift to the use of ethernet for industrial control and automation applications. Ethernet is increasingly replacing proprietary communications.

1.1 Serial-to-Ethernet Converter

Serial communications (RS-232/422/485) have traditionally been used in industrial automation to connect various instruments such as sensors and data loggers to stand alone monitoring stations such as computers. The limitations of serial communications, such as distance, accessibility, and the amount of data transferred at any one time and speed, has led to a demand for a more flexible means of communicating. When a legacy product contains only a serial port for a configuration or control interface, continuing to access the legacy product through the serial interface can become challenging over time. Newer computers, especially laptops, do not necessarily have serial ports, and a serial connection is limited by cable length (typically 10 m). Using Ethernet in place of the serial port provides many benefits.

Although slow to catch up with IT infrastructure in commercial environments, Ethernet is increasingly regarded as the defacto standard of communications in industrial markets. However, the sheer volume of existing serial-based products and the low cost and ease of integrating these ‘legacy’ protocols means that serial communication is strong in many areas of industry. Due to the minimal processing power required, the ruggedness and reliability of connectors, even relatively new products such as GPS receivers continue to adopt RS-232 and RS-485.

RS-485 has been the PHY protocol for industrial networks since Modbus was launched by Modicon in the 1970s. Other manufacturers followed Modicon and used protocols such as PROFIBUS DP and INTERBUS. Contemporary systems are Ethernet-based to allow individual "islands of automation" to share data captured throughout the plant and the company, "top floor to shop floor", and in some cases, the world. To enable legacy serial based hardware to take advantage of Ethernet, Serial-to-Ethernet device converters were designed.

Ethernet is a more common interface available on computing equipment today:

- The legacy product can be shared more easily (instead of changing a cable connection, a new connection over the existing network is made).
- 10-m cable length is no longer an issue (subject to tolerance of the increased transmission delay if the two pieces of equipment are separated by several routers or are located on a heavily loaded network segment).

1.2 Gateway

Ethernet plays a critical role in automation. One important device in the sub-station of industrial automation is the gateway . The gateway connects legacy devices with RS-485, RS-232, and CAN interface to an Ethernet-enabled network. A gateway can be used to connect the IEDs (without Ethernet connectivity) to supervision systems via Ethernet, TCP-IP, or radio communication. Web-enabled legacy devices in the substation let the designer access information on the electrical installation via a PC with a standard web browser.

The gateway functionality simplifies communications architecture and reduces leased line and connection costs.

Figure 1. Diagram of Data Flow in Gateways

1.2.1 Substation Automation Gateway

IEC61850 gateways are common applications of Ethernet gateways in substations. This communication gateway maps signals between the protection and control IEDs in industrial or utility substations and higher-level systems such as Network Control Centers (NCC) or Distributed Control Systems (DCS).

1.2.2 Modbus Gateways

Modbus gateways support the four most commonly used communication standards, RS-232/485/422 and Ethernet. Modbus is the standard used for communication between a wide range of industrial devices, including PLCs, DCSs, HMIs, instruments, meters, motors, and drives. Although Modbus can be used for both serial devices (RS-232, RS-422, and RS-485) and newer Ethernet devices, the serial and Ethernet protocols are so different that a specialized gateway is required for one protocol to communicate with the other. Modbus gateways support standard Modbus protocols and are capable of converting the Modbus protocols between Modbus RTU/ASCII (Master) to Modbus TCP (Slave).

1.3 Serial Over IP Ethernet Device Server

This converter is a bidirectional switching and transmission device from serial port to Ethernet TCP/IP protocol. The converter changes the traditional serial communication to Ethernet communication and realizes speed networking for serial device. The converter uses transparent communicate protocol so that the user does not need to understand complex Ethernet TCP/IP protocol nor modify old serial programs. The low price improves the designer product’s core competition and the easy, flexible configuration and high-availability will satisfy steep demand.

1.4 Advances in Serial-to-Ethernet Technology

- Secure data transfer: More traditional Serial-to-Ethernet device servers operated without data encryption, leaving data vulnerable. Secure Socket Layer (SSL) is now used to provide secure end to end data transfer.
- Power over Ethernet (PoE): Device servers are now available with support for PoE (802.3af). This reduces cabling and facilitates ease of installation, saving time and money.
- Redundant ring operation: Ring redundancy has become common practice in industrial networks, increasing the availability of serial-based devices. Ring redundancy also saves cost in not having to employ an additional Ethernet switch.
- Any baud rate: Serial-to-Ethernet device servers now support any data rate up to 1 Mbps, which is useful for specialist devices.
- Ethernet I/O modules and remote I/O: These modules integrate digital and analog signals to the Ethernet network to assist Supervisory Control and Data Acquisition (SCADA). Distributed I/O traditionally using RS-485 can now be connected to a Serial to Ethernet device server. These I/O modules can use Simple Network Management Protocol (SNMP) traps, allowing information about the status of digital or analog devices to be easily integrated into existing SNMP deployments (company infrastructure for example).
- Using the cellular network: GPRS, 3G, and HSPA are protocols based on IP. The use of software drivers, together with cellular routers with serial connectivity enables virtual COM ports over a cellular network. Mobile applications such as in vehicles and transport, variable message sign, and digital signage are a few examples.

This design allows an Ethernet-enabled Tiva™ microcontroller to be used as a cost-effective Serial-to-Ethernet converter. By placing a Serial-to-Ethernet converter on the serial port of a legacy product, the converter can be given the ability to operate on the Ethernet without requiring any changes to the existing hardware or software. This ability is especially useful when the legacy product cannot be modified (such as in the case of third-party products). Ethernet's simple and effective design has made it the most popular networking solution at the physical and data link levels.

This reference design platform demonstrates capabilities of TM4C129XNCZAD 32-bit ARM Cortex-M4F MCU. This design supports 10/100 Base-T and is compliant with IEEE 802.3 standards. This design operates from a single power supply (5 V with onboard regulator or 3.3 V).

The Tiva C Series ARM Cortex-M4 microcontrollers provide top performance and advanced integration. The product family is positioned for cost-effective applications requiring significant control processing and connectivity capabilities:

- Network appliances, gateways, and adapters
- Remote connectivity and monitoring
- Security and access systems
- HMI control panels
- Factory automation control
- Motion control and power inversion
- Electronic point-of-sale (POS) displays
- Smart energy and smart grid solutions
- Intelligent lighting control

An RS-485 interface is provided that can be used for the following applications:

- Energy meter networks
- Motor control
- Power inverters
- Industrial automation
- Building automation networks
- Battery-powered applications

2 Design Features

Table 1. Configuration of TIDA-00226

Microcontroller–MCU	TM4C129XNCZAD 32-bit ARM Cortex
Ethernet	10/100 internal PHY plus MAC 10/100 external MAC plus internal PHY
Ethernet LEDs	Activity Link Speed
RS-485	Half duplex transceiver: up to 200 Kbps
Power supply	Single supply: 3.3-V, 0.5-A output
External interface	MII connector: 50-pin with option for power input

3 Block Diagram

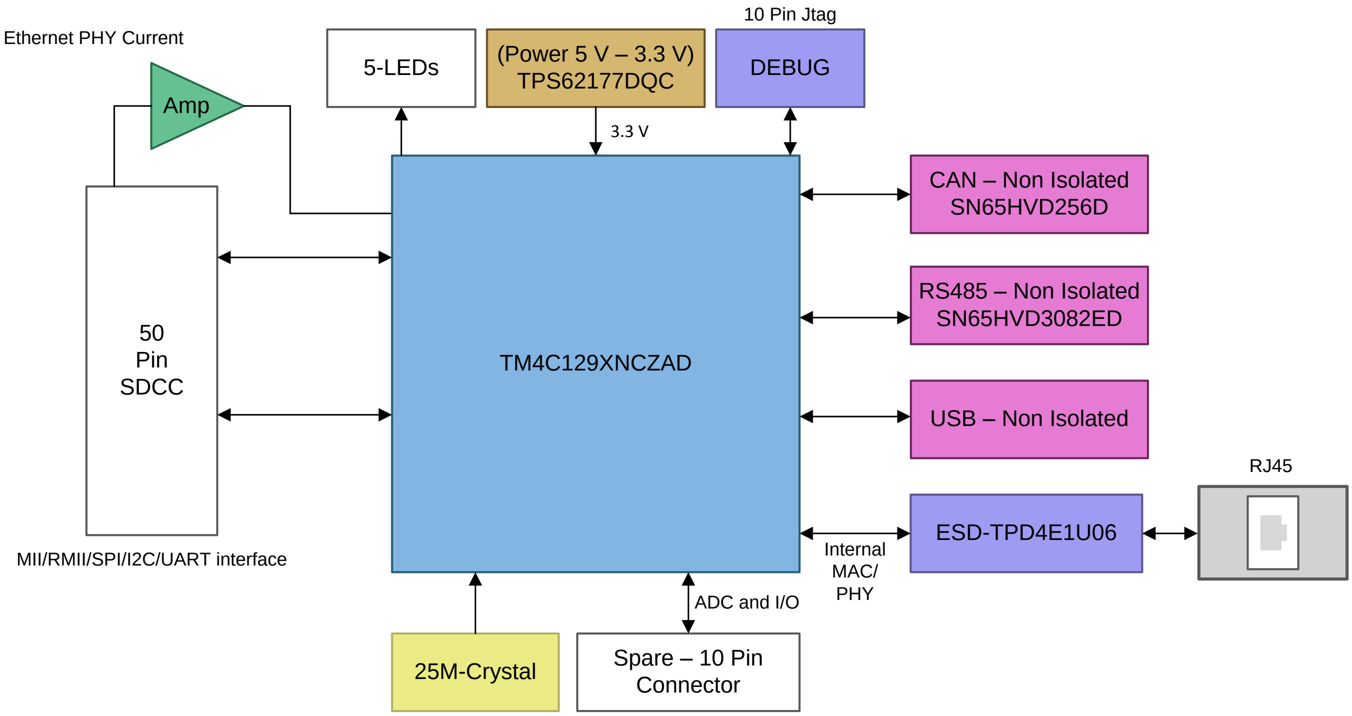

Figure 2. Tiva MCU-Based Gateway Block Diagram

3.1 MCU

The Tiva TM4C129XNCZAD is an ARM Cortex-M4-based microcontroller with 1024-KB flash memory, 256-KB SRAM, 120-MHz operation, USB host/device/OTG, Ethernet controller, integrated Ethernet PHY, hibernation module, and a wide range of other peripherals. See the TM4C129XNCZAD microcontroller data sheet for complete device details. An internal multiplexer allows different peripheral functions to be assigned to each of these GPIO pads. When adding external circuitry, the designer should consider the additional load on the development board's power rails. The Tiva PinMux Utility can be used to quickly develop pin assignments and the code required to configure them.

The TM4C129XNCZAD microcontroller is factory-programmed with a quick start weather display program. The quick start program resides in on-chip flash memory and runs each time power is applied, unless the application has been replaced with a user program.

3.2 Ethernet

TM4C129XNCZAD supports the following Ethernet interfaces:

- 10/100 Ethernet interface with internal MAC and PHY.
- 10/100 Ethernet interface with external MAC and internal PHY. The external MAC is interfaced with the MII/RMII.

3.3 Power Supply

TM4C129XNCZAD is powered by a single 5-V input power supply. TPS62177, a 28-V, 0.5-A step-down converter, is used in this design.

3.4 Nonisolated RS-485 Interface

SN75HVD3082E is the RS-485 transreceiver used .This device is a half-duplex transceiver designed for RS-485 data bus networks. Powered by a 5-V supply, the device is fully compliant with TIA/EIA-485A standards. With controlled transition times, the device is suitable for transmitting data over long twisted-pair cables. SN75HVD3082E devices are optimized for signaling rates up to 200 kbps.

3.5 Expansion Connectors

Expansion outputs have been provided for further use as required.

3.6 PCB Dimensions and PCB Physical Layout

This reference design has been designed in a small form factor, four-layer PCB with a dedicated ground and power plane.

3.7 Programming

Tiva microcontrollers support the JTAG interface for debugging and programming. The designer can place headers on the board and connect them to the chip's JTAG pins (see the TM4C129XNCZAD data sheet for pinout information). The designer would then need an external JTAG programmer to connect the PC to the board. LaunchPad™ can be used as external programmer.

4 Circuit Design and Component Selection

4.1 MCU

Tiva C Series microcontrollers integrate a large variety of rich communication features to enable a new class of highly connected designs with the ability to allow critical, real-time control between performance and power. The microcontrollers feature integrated communication peripherals along with other high-performance analog and digital functions to offer a strong foundation for many different target uses, spanning from human machine interface to networked system management controllers.

In addition, Tiva C Series microcontrollers offer the advantages of ARM's widely available development tools, System-on-Chip (SoC) infrastructure, and a large user community. Additionally, these microcontrollers use ARM's Thumb®-compatible Thumb-2 instruction set to reduce memory requirements and, thereby, cost. Finally, the TM4C129XNCZAD microcontroller is code-compatible to all members of the extensive Tiva C Series, providing flexibility to fit precise needs.

- Performance
  – ARM Cortex-M4F processor core, 120-MHz operation
  – 150 DMIPS performance, 1024-KB flash memory
  – 256-KB single-cycle system SRAM, 6 KB of EEPROM
- Communication interfaces
  – Eight universal asynchronous receivers/transmitters (UARTs)
  – Four quad synchronous serial interface (QSSI) modules with bi-, quad-, and advanced SSI support
  – Ten Inter-Integrated Circuit (I^2C) modules with four transmission speeds, including a high-speed mode
  – Two controller area network (CAN) 2.0 A/B controllers
  – 10/100 Ethernet MAC
  – Ethernet PHY with IEEE 1588 PTP hardware support
  – Universal Serial Bus (USB) 2.0 OTG/host/device with a ULPI-interface option and link power management (LPM) support
- Analog support
  – Two 12-bit analog-to-digital converter (ADC) modules, each with a maximum sample rate of one million samples per second
- Operating range (ambient)
  – Industrial (–40°C to 85°C) temperature range
  – Extended (–40°C to 105°C) temperature range
- One JTAG module with integrated ARM Serial Wire Debug (SWD)
- 212-ball BGA package

4.2 Ethernet

TM4C129x supports 10/100-Mbps Ethernet. The board is designed to connect directly to an Ethernet network using RJ45 style connectors. The microcontroller contains a fully integrated Ethernet MAC and PHY. This integration creates a simple, elegant, and cost-saving Ethernet circuit design. The example code is available for both the uIP and LwIP TCP/IP protocol stacks. The embedded Ethernet on this device can be programmed to act as an HTTP server, client, or both. The design and integration of the circuit and microcontroller also enable users to synchronize events over the network using the IEEE1588 precision time protocol.

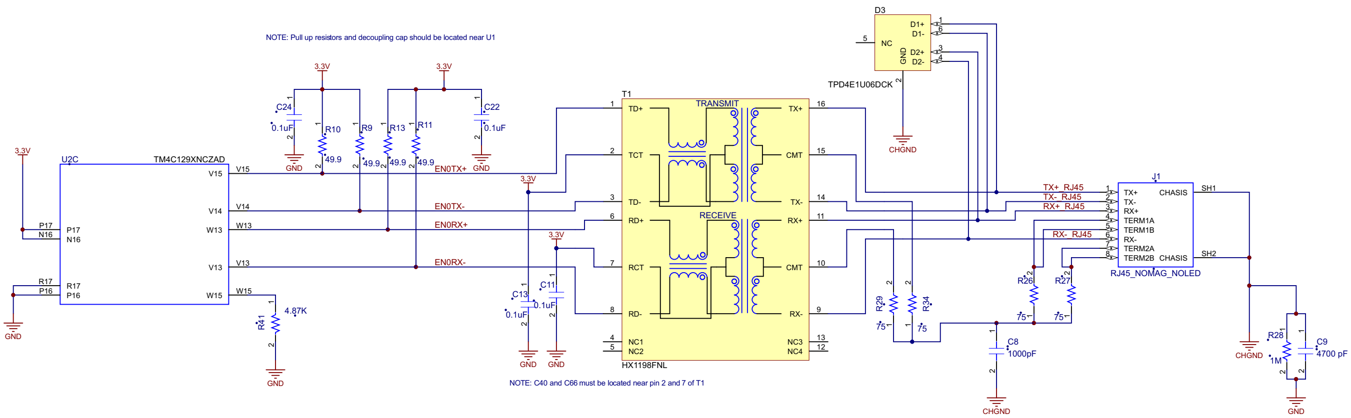

Figure 3. Section of 10/100 Ethernet USB

The PHY controls three LEDs that indicate different functions. as shown in Table 2:

Table 2. LED Pins and Functions

PIN	FUNCTION
PK4	EN0LED0 – Link
PK6	EN0LED1 – Activity
PF1	EN0LED2 – Speed

RJ45 and isolation transformer magnetics with the choke on the side of the PHY has been used.

4.3 Power Supply

TPS62177 is programmed to a fixed output voltage of 3.3 V. For the fixed output voltage version, the FB pin is pulled low internally by a 400-kΩ resistor. The designer can connect the FB pin to AGND to improve thermal resistance.

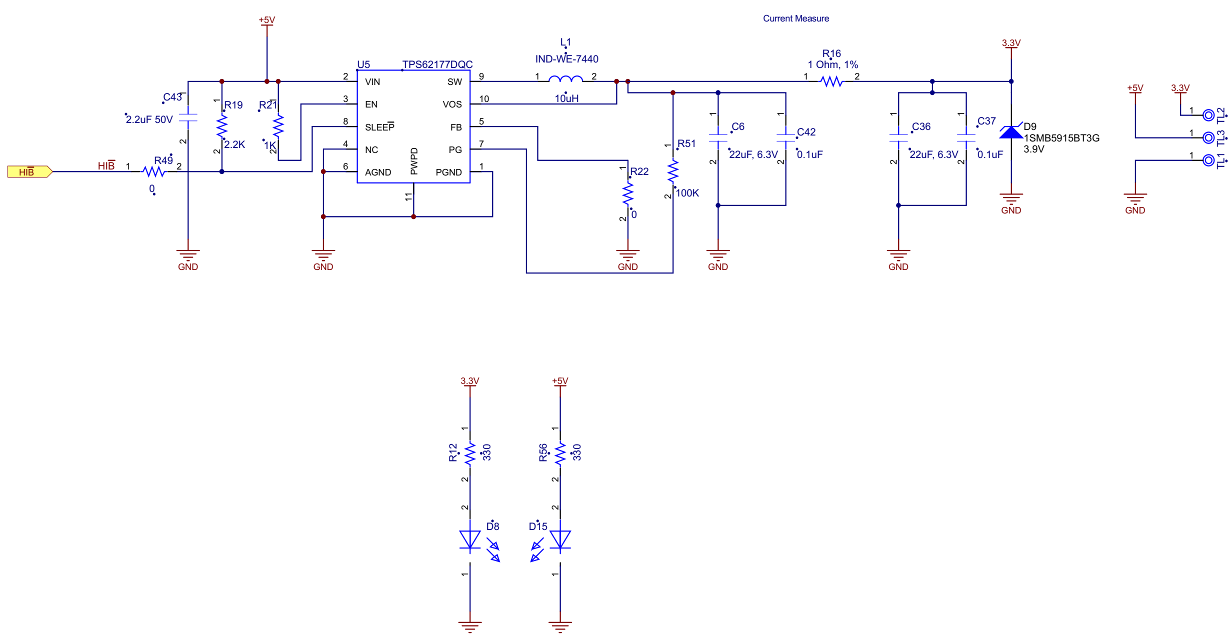

Figure 4. Schematic of TPS62177

External Component Selection

The external components have to fulfill the needs of the application, but also the stability criteria of the device's control loop. The TPS62175/7 is optimized to work within a wide range of external components. The LC output filter's inductance and capacitance have to be considered together, creating a double pole that is responsible for the corner frequency of the converter.

Layout Considerations

The input capacitor needs to be placed as close as possible to the IC pins (VIN, PGND). The inductor should be placed close to the SW pin and connect directly to the output capacitor, minimizing the loop area between the SW pin, inductor, output capacitor, and PGND pin. Also, sensitive nodes like FB and VOS should be connected with short wires, not nearby high dv/dt signals (for example, SW). The feedback resistors should be placed close to the IC and connect directly to the AGND and FB pins.

Thermal Information

The TPS62175/7 is designed for a maximum operating junction temperature (T_J) of 125°C. Therefore, the maximum output power is limited by the power losses. Since the thermal resistance of the package is given, the size of the surrounding copper area and a proper thermal connection of the IC can reduce the thermal resistance.

4.4 Nonisolated RS-485 Interface

The RS-485 can be either full-duplex or half-duplex. In a full-duplex implementation, four wires are required, and a node can simultaneously drive one pair of wires while receiving data on the second pair of wires. In half-duplex, a single pair of wires is used for both driving and receiving. In either case, the operation of all the nodes on the bus must be controlled so that at most, one driver is active on each pair of lines at any time.

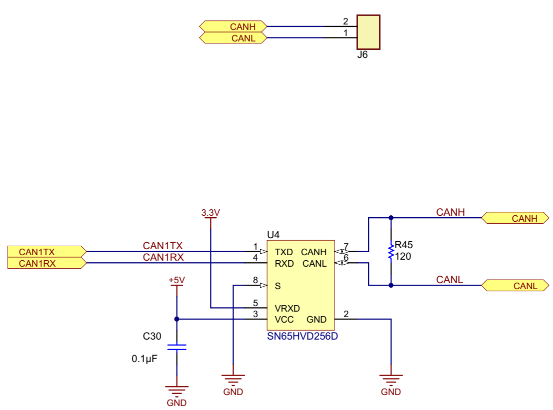

Figure 5. Schematic of SN75HVD3082E

SN75HVD3082E is a half-duplex transceiver and has the following features:

- Available in a small MSOP-8 package
- Meets or exceeds the TIA/EIA\x92485A standard requirements
- Low quiescent power
- 0.3-mA active mode
- 1-nA shutdown mode
- Bus-pin ESD protection up to 15 kV
- Industry-standard SN75176 footprint
- Failsafe receiver (bus open, bus shorted, bus idle)
- Glitch-free power-up/down bus inputs and outputs

4.5 Expansion Connectors

In the design, peripherals that are not currently used like SPI, UART, CAN, and I^2C signals have been terminated on the 50-pin SDCC connector.

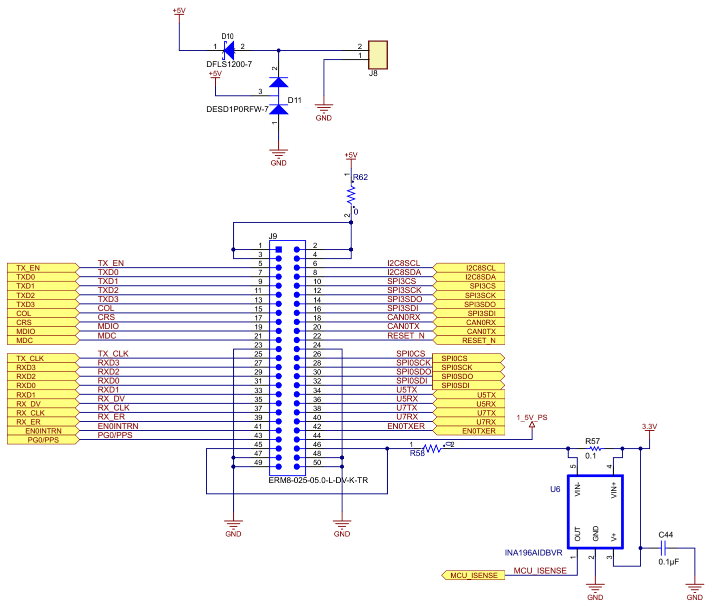

Figure 6. Schematic of 50-Pin SDCC Connector

An option to measure the power consumption of 3.3 V supplied to external PHY interface has been provided. The same 50-pin has CAN, UART, SPI, and I^2C signals.

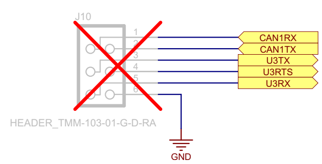

Figure 7. Interface for Isolated UART and CAN

The connector can be used to interface with high efficiency isolated CAN and PROFIBUS interface reference design (TIDA-00012).

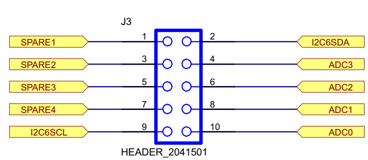

Figure 8. Interface for ADC and Spare I/Os

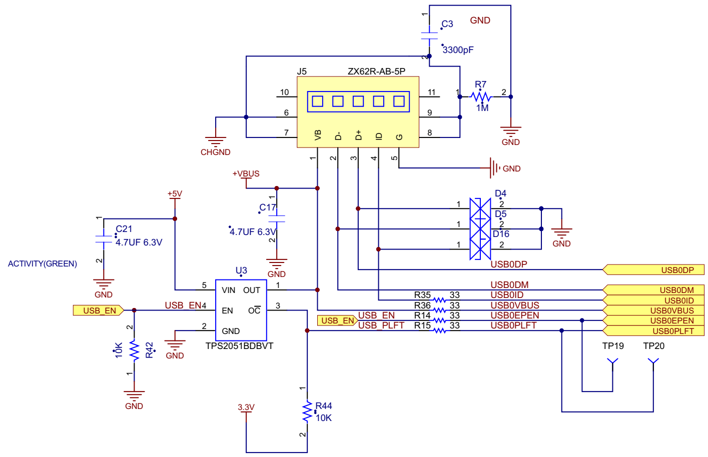

Figure 9. USB Interface

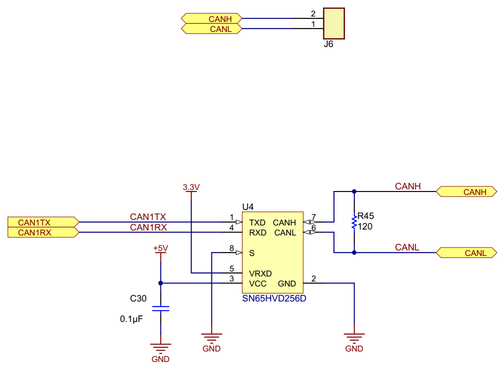

Figure 10. CAN Interface

4.6 Board Size

The complete board is designed in a 2×3-inch form-factor PCB.

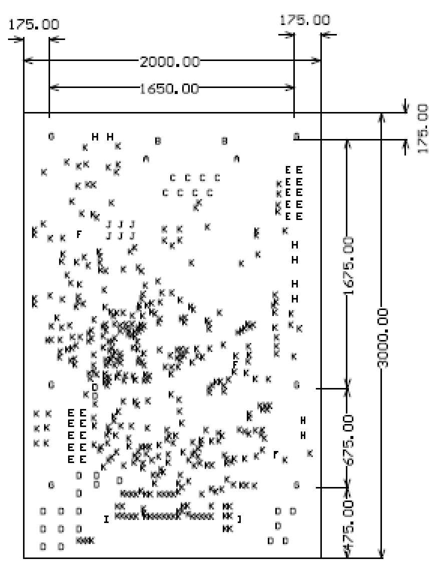

Figure 11. Assembly Drawing

4.7 Programming

A JTAG interface has been provided for programming.

Table 3. JTAG Interface Options

OPTION	FUNCTION
TCK	JTAG test clock signal. This option is also the SWCLK signal for SWD connections.
TMS	JTAG test mode select. This option is also the SWDIO signal for SWD connections.
TDO	JTAG test data out. This is also the SWO signal for SWD connections.
TDI	JTAG test data in.
EXT-DBG	Pull this pin low to tri-state the on board ICDI drive signals. This action prevents the ICDI from interfering with an external debug-in connection.
RESET	Target reset pin.
GND	The designer will need to be sure that the two boards share a common ground reference. Ground connections are available on the lower left and lower right corners of the LaunchPad.

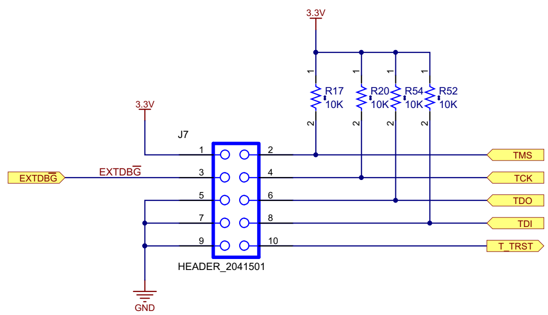

Figure 12. Schematic of JTAG Interface

5 Software Description

5.1 Modbus Basics

Modbus protocol follows a master slave mechanism. A slave cannot initiate transaction. The master requests for a read or write of a certain address in the slave. The request tells the slave what action the slave has to perform based on the function code, address, and number of registers. The error check field is used to ensure the integrity of message contents. If the slave prepares a normal message response, the function code in the response is an echo of the function code in the request. If the slave prepares an error response, the function code and data is modified to indicate the error. Modbus slaves can have an address from 1 to 247.

See the Modbus Tools website and SPMA037 for more information.

Table 4. Modbus RTU Frame Format

NAME	LENGTH	FUNCTION
Start	3.5c idle	At least 3½ character times of silence (MARK condition)
Address	8 bits	Station address
Function	8 bits	Indicates the function codes like read coils or inputs
Data	n*8 bits	Data and length will be filled, depending on the message type
CRC check	16 bits	Error checks
End	3.5c idle	At least 3½ character times of silence between frames

Function 03 (03hex) Read Holding Registers

Read the binary contents of holding registers in the slave. The holding registers consist of requests and responses.

The request message specifies the starting register and quantity of registers to be read.

Table 5. Example of a Request to Read 0...1 (Register 40001 to 40002) from Slave Device 1

FIELD NAME	RTU (HEX)
Header	None
Slave address	1
Function	3
Starting address Hi	0
Starting address Lo	0
Quantity of registers Hi	0
Quantity of registers Lo	2
CRC Lo	C4
CRC Hi	0B

The register data in the response message are packed as two bytes per register with the binary contents right justified within each byte. For each register, the first byte contains the high-order bits, and the second byte contains the low-order bits.

Table 6. Example of a Response to the Request

FIELD NAME	RTU (HEX)
Header	None
Slave address	1
Function	3
Byte count	4
Data Hi	0
Data Lo	6
Data Hi	0
Data Lo	5
CRC Lo	DA
CRC Hi	31

Table 7. Modbus TCP Frame Format

NAME	LENGTH	FUNCTION
Transaction identifier	2 bytes	For synchronization between messages of server and client
Protocol identifier	2 bytes	Zero for Modbus/TCP
Length field	2 bytes	Number of remaining bytes in this frame
Unit identifier	1 byte	Slave address (255 if not used)
Function code	1 byte	Function codes as in other variants
Data bytes	n byte	Data as response or commands

5.2 *MDC/MDIO Interface*

The MDC/MDIO Interface is used by the MAC to speak to the PHY and set or read its configuration.

MDC is a clock that is active when there is traffic and is shut down when there is no traffic. MDIO is a bidirectional communication line that is used to configure or read the status of PHY.

For example, the proper PHY ID is set in the firmware the device and a reset is issued. On reading the BMSR register, the designer should read the default register values. If it is not the case, then something is wrong and should be debugged. If the MDC/MDIO or PHY ID is not configured properly, the designer may not be able to read or write any PHY register values.

It is possible that PHY can function with a default mode, (even respond to a ping) without being able to read or write the PHY registers. The user should habitually read registers (for example, BMSR) and ensure that the user reads the default values after the reset delay.

MII_MODE

The MII_MODE is selected by the pin 26 (RX_DV). This pin has internal weak pull down defaults to MII mode. External pull up makes the PHY to operate in RMII mode.

PHY ID

PHY ID is decided by the pull-up registers (see the Bootstrap section of the TLK105L/106L data sheet). Care has to be taken that appropriate PHY ID is used for appropriate hardware bootstrap configuration (as per pull-up registers). The values of pins 29, 30, 31, 32, and 1 (PHYAD0/COL, PHYAD1/RXD0, PHYAD2/RXD1, PHYAD3/RXD2, and PHYAD4/RXD3, respectively) are latched into an internal register at hardware reset.

5.3 Processor Initialization (as a Black Box)

The following steps initialize the processor:

1. Configure the clock.
2. Enable the peripheral clock gating for Ethernet MAC pins.
3. Initialize the peripherals according to proper pin multiplexing configuration for Ethernet MAC pins.
4. Configure the reset pin as output and toggle the reset to an appropriate level with a 10-µs delay.
5. Enable the peripheral clock gating for Ethernet MAC and issue a system control reset.
6. Wait for the reset to complete.
7. Select external MII mode and issue a MAC reset.
8. Initialize the MAC and set the DMA mode if applicable.

5.4 External MII PHY Initialization

1. Set the external PHY address (as per the boot strap configuration).
2. All the read and write requests to the PHY shall use the configured external PHY address.
3. Reset the PHY.
4. Set the BMCR (0x00) register bit 15 to one to reset the MII.
5. Set PHYRCR (0x1F) data register bit 15 and bit 14 to one for a software or digital reset.
6. Issue a delay of 500 microseconds.
7. Set the BMCR (0x00) register auto negotiation enable and auto negotiation restart by setting bit 12 and bit 8 to one.
8. Poll the BMSR (0x01) register bit 5 to check if auto negotiation is complete.
9. To configure the LEDs, issue an extended write to configure the MLEDCR (0x25) register to set the value 0x060B. This action disables COL, routes the LED to pin 29, and sets up the link and activity LEDs.

5.5 LED Configuration

Pins 17 and 29 can be used for LED configuration either as pull up or pull down. Pin 17 indicates link status (fully lit) by default and activity is indicated by blinking the same LED. If the design needs to use pin 29 for indicating LED status, MLEDCR has to be configured. MLEDCR provides an option to route the activity signal to pin 29 instead of 17. For this to happen, the COL signal has to be disabled. For further details, see section 3.8 of the TLK105L/106L data sheet.

NOTE: If the Bootstrap address (in the software) does not match with that of the hardware, MDIO commands will not work properly.

5.6 Flashing the Board

The PC software used to download the firmware to the board can be found here: http://www.ti.com/tool/lmflashprogrammer. Follow these steps to program the flash:

1. Configuration tab: <> development board (For example, <TM4C129X> development board)
2. Copy the bin files into computer
3. Program tab: Select .bin file
   (a) Select the path of binary file that needs to be flashed
   (b) Select Erase entire flash
   (c) Select Verify after program
   (d) Program address offset 0
   (e) Leave others blank
   (f) Select Program to flash the code

6 Test Results

6.1 Functional Testing

Table 8. Functional Testing Values

Clock	25 Mhz
V_{CC} (3 to 3.6 V)	3.31 V
Internal 1.55 V	1.55
MII	OK
Link and activity LED	OK

6.2 Communication Interface Testing (Computer to Device)

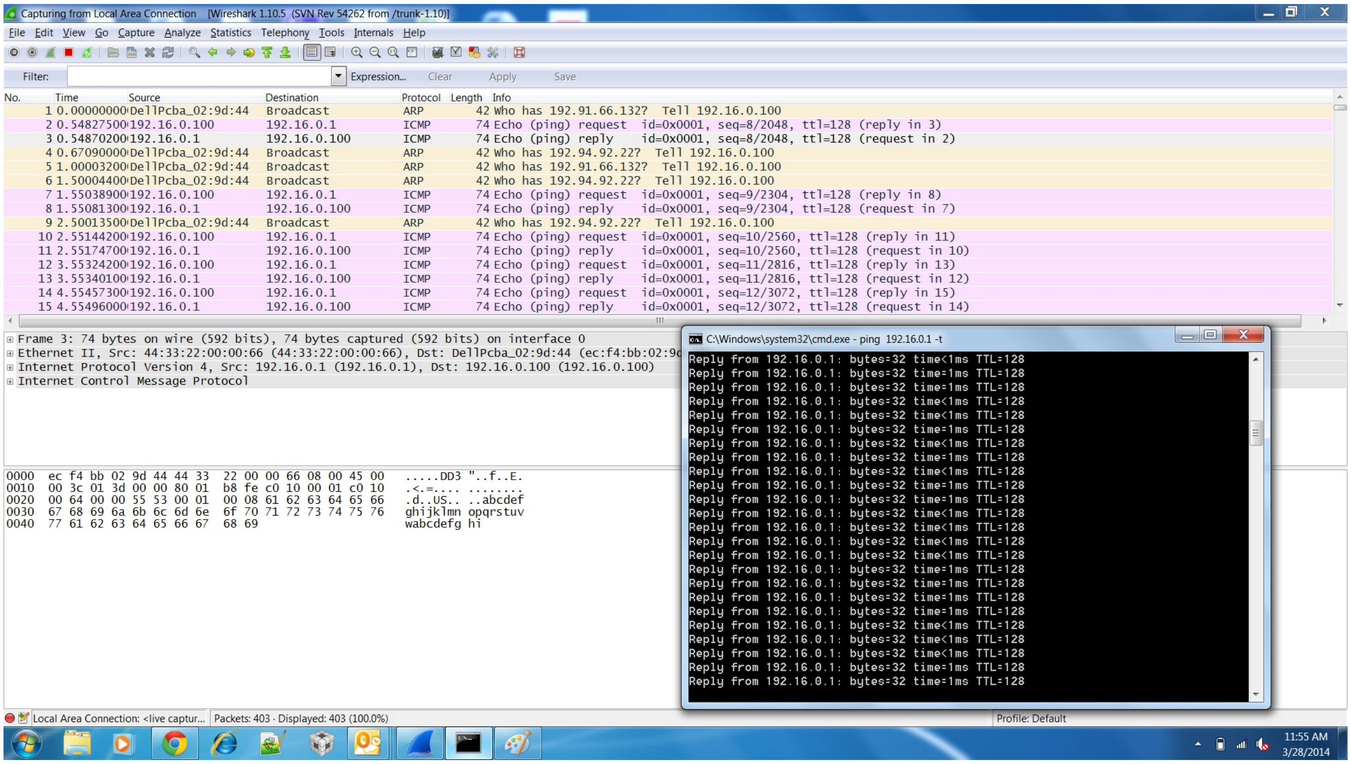

Figure 13. Screen Capture of Ping Test

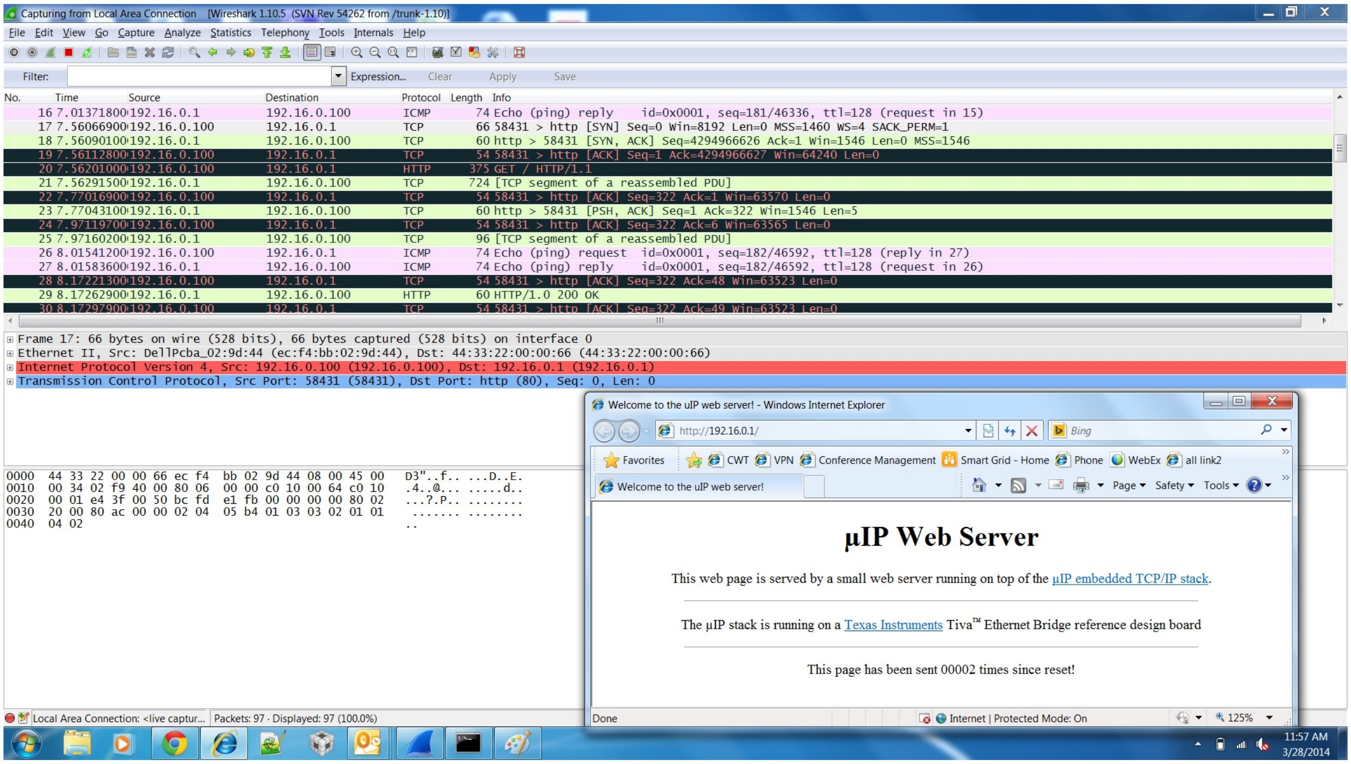

Figure 14. Screen Capture of µIP Web Server Test

6.3 Gateway Testing

Test setup:

- PC-based Modbus software (such as Mod Poll) works as a Modbus client requesting for information
- The board acts as a transparent gateway and converts the Modbus TCP data into Modbus serial
- Serial port monitor (such as Teraterm) to monitor Modbus RTU (serial) data
- Packet sniffer (such as Wireshark) to monitor Modbus TCP packets

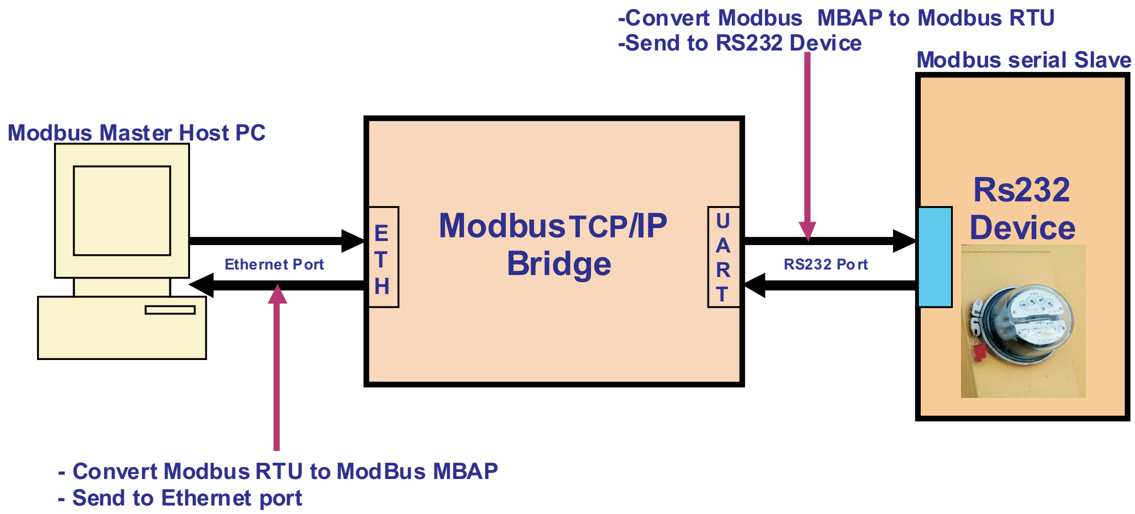

Figure 15. Test Setup Diagram

Modbus client setup:

1. Configure the IP address of gateway (board), delay between polls, response timeout and port number.
2. Set up the slave ID, function (read holding register, write holding register, and so on), and register starting address, length, and scan rate.

Modbus server:

1. Set the Modbus server as a black box, which receives Modbus RTU requests and replies back with data.
2. Set the board as a gateway.
3. With the board, convert data from Modbus RTU to Modbus TCP and vice versa.

6.4 EMI-Radiated Emission

The test distance for radiated emission from EUT to Antenna is 10 m. The test was performed in a semianeochic chamber, which conforms to the volumetric normalized site attenuation (VNSA) for ten-meter measurements.

Table 9. Specifications for Radiated Emissions

FREQUENCY RANGE	CLASS A LIMITS QUASI-PEAK	CLASS B LIMITS QUASI-PEAK
30 to 230 MHz and 230 MHz to 1 GHz	40 and 47 dB µV/m	30 and 37 dB µV/m

Table 10. Observation for Radiated Emissions

REQUIREMENTS	FREQUENCY	RESULT
EN 55011:2009+A1:2010, Class “A”	30 to 1000 MHz	Pass

6.5 Test Result Graphs

Figure 16 and Figure 17 show the results from testing the TM4C129XNCZAD 32-bit ARM Cortex-M4F MCU with internal MAC+PHY enabled.

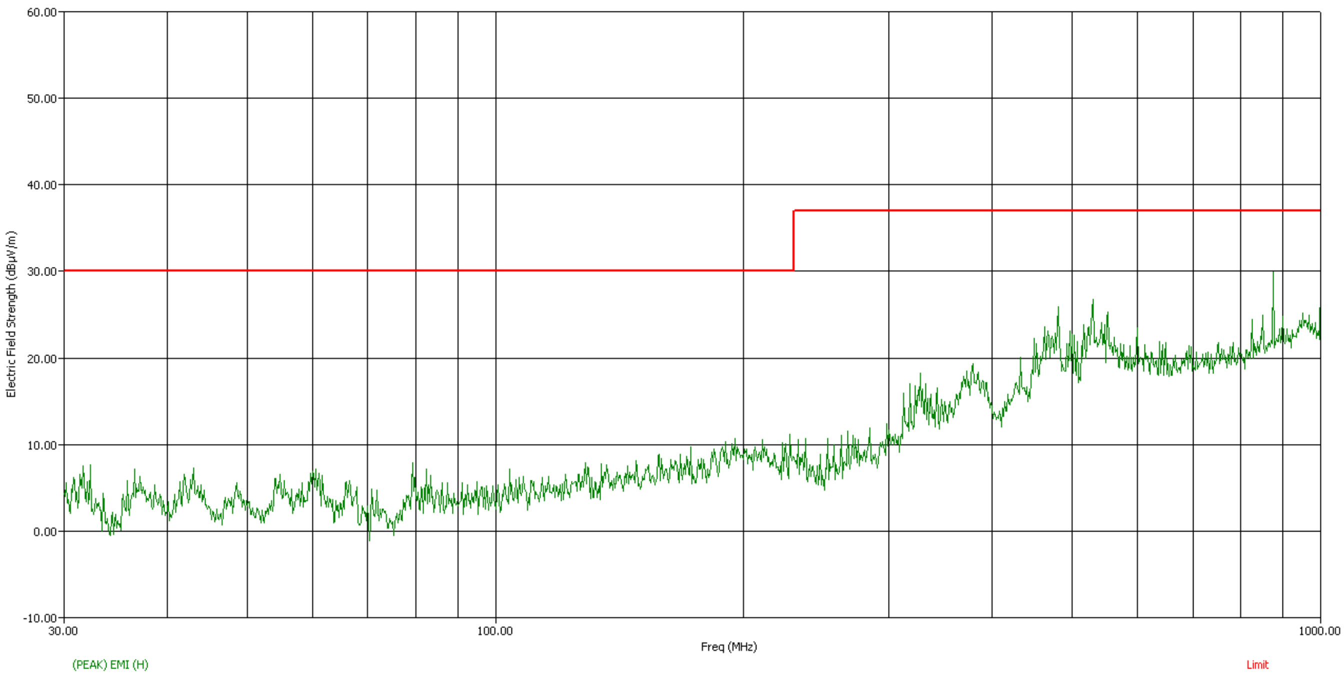

Figure 16. Horizontal Polarization

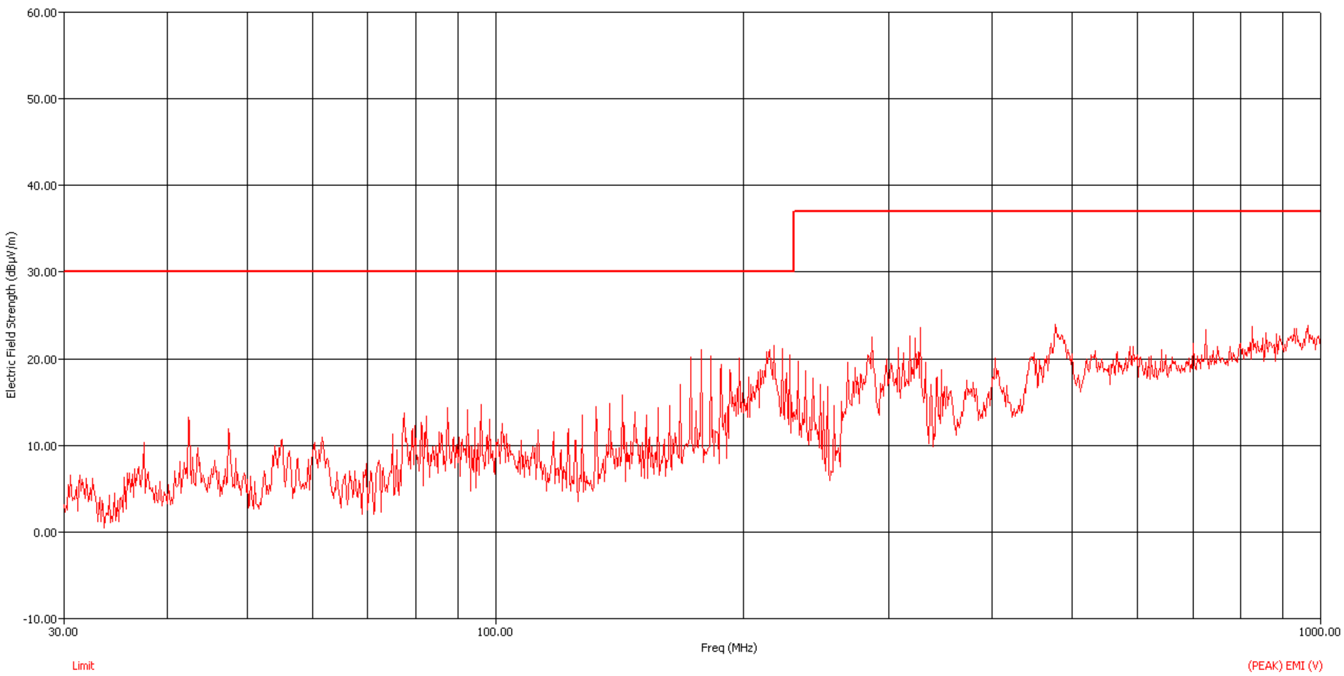

Figure 17. Vertical Polarization

6.6 ESD EMI-EMC Recommendations and Design Guidelines

The following recommendations are provided to improve EMI performance:

- Guard ring for crystal.
- Use a metal shielded RJ-45 connector, and connect the shield to chassis ground.
- Use magnetics with integrated common-mode choking devices with the choke on the side of the PHY (for example, PULSE HX1198FNL).
- Do not overlap the circuit and chassis ground planes: keep the planes isolated. Connect chassis ground and system ground together using one 4700 pF NPO 2000 V 10% across the void between the ground planes on the 1, 2 pair side of the RJ-45.

See the Tiva TM4C1292NCZAD microcontroller data sheet for more information.

7 Design Files

7.1 Schematics

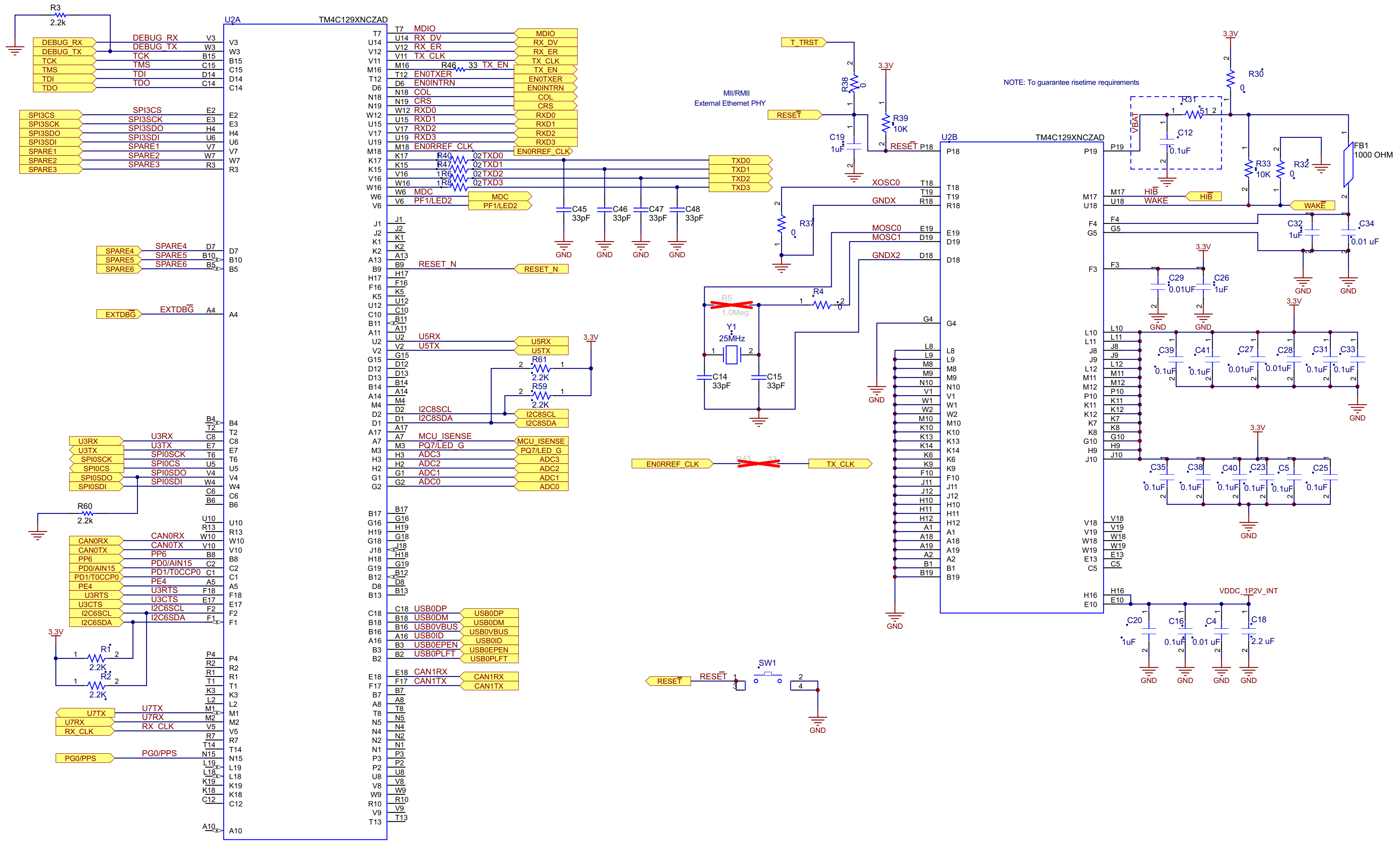

Figure 18. Microcontroller

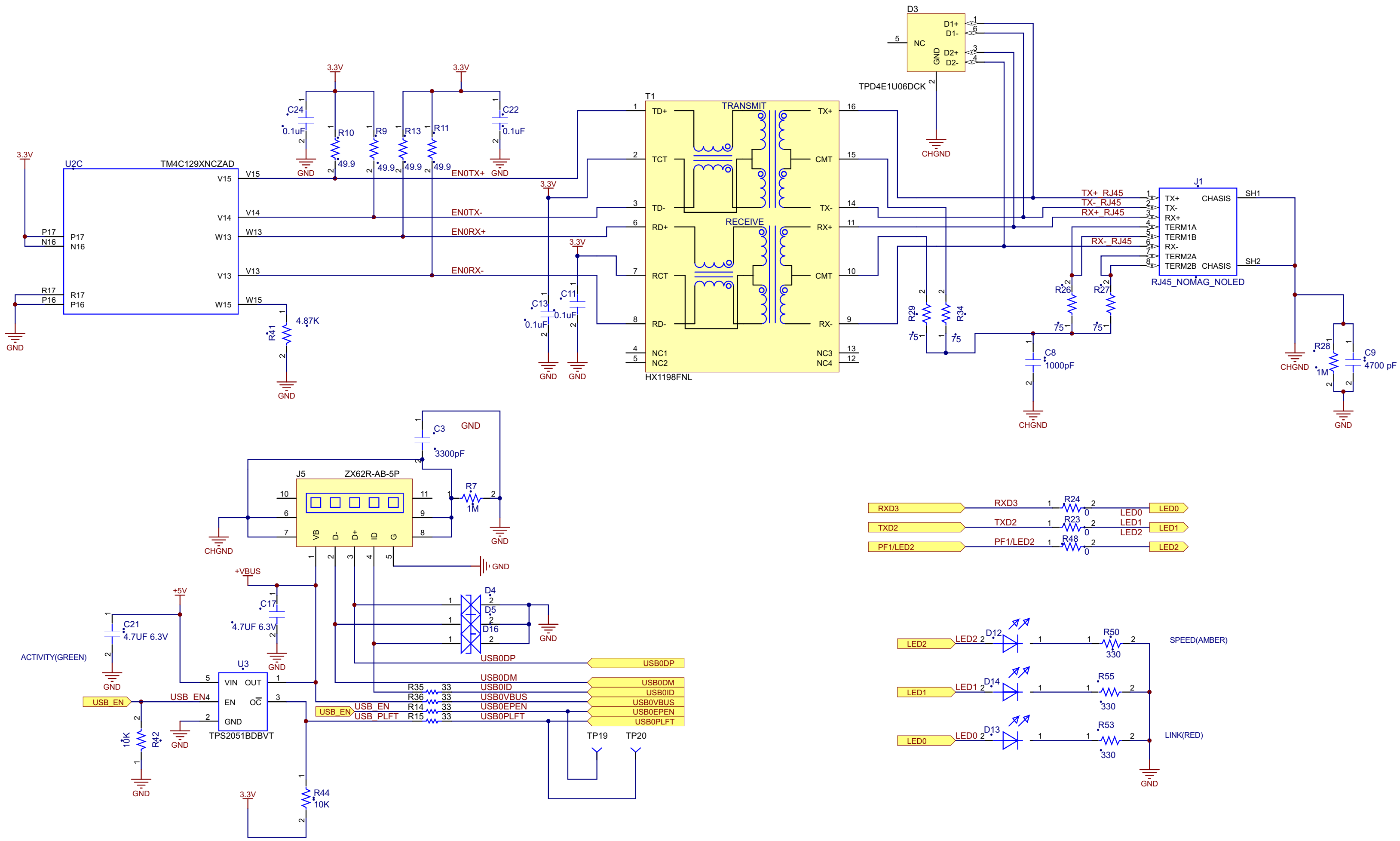

Figure 19. 10/100 Ethernet USB

NOTE: Pull-up resistors and decoupling cap should be located near U1.

C40 and C66 must be located near pin 2 of T1.

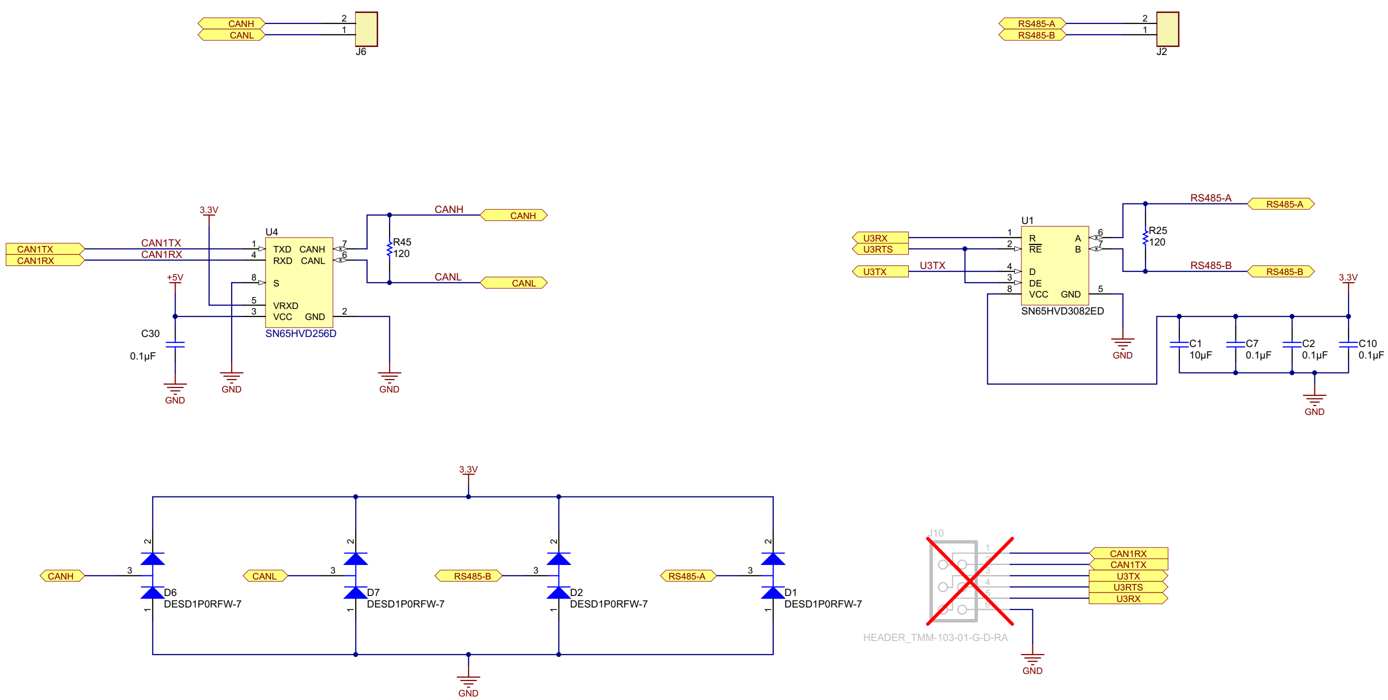

Figure 20. CAN RS-485

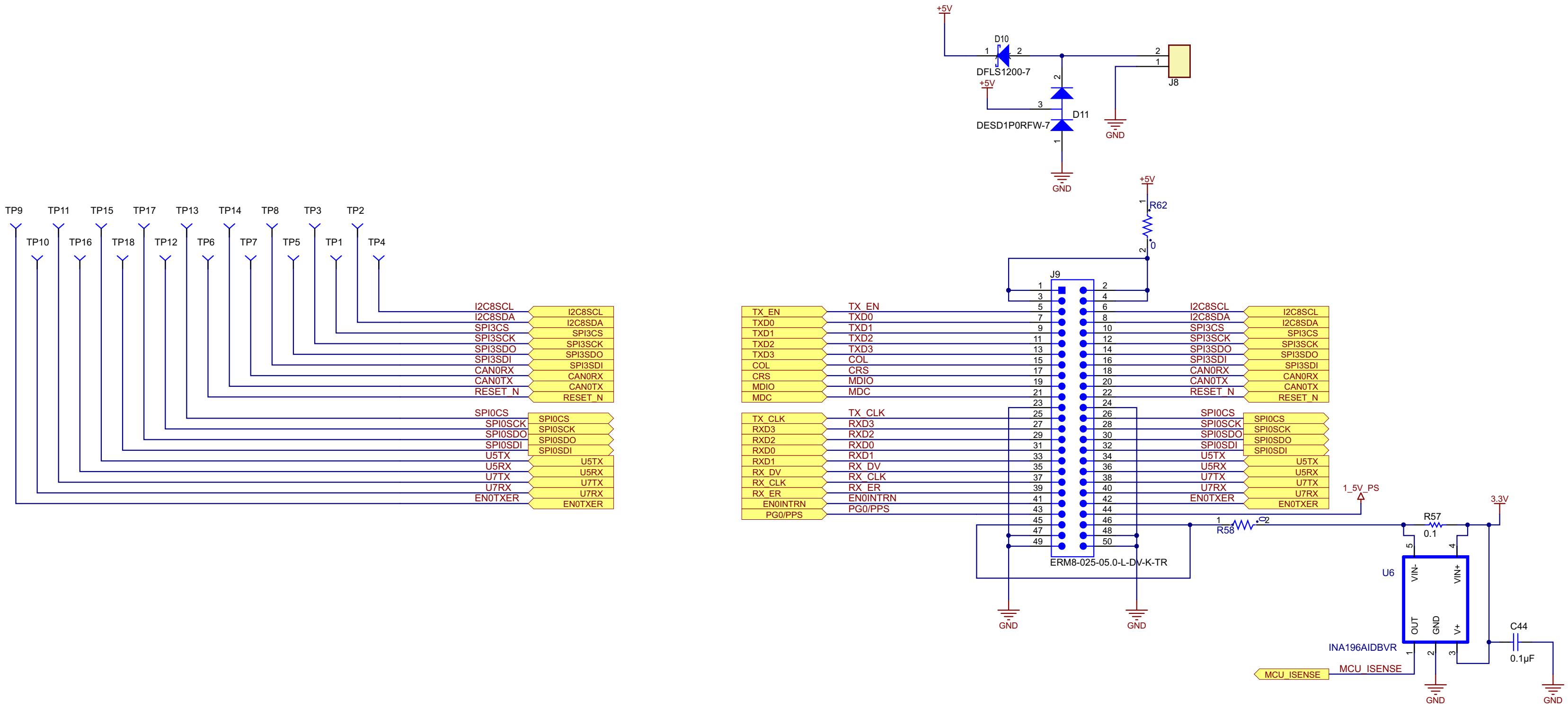

Figure 21. MII/RMII

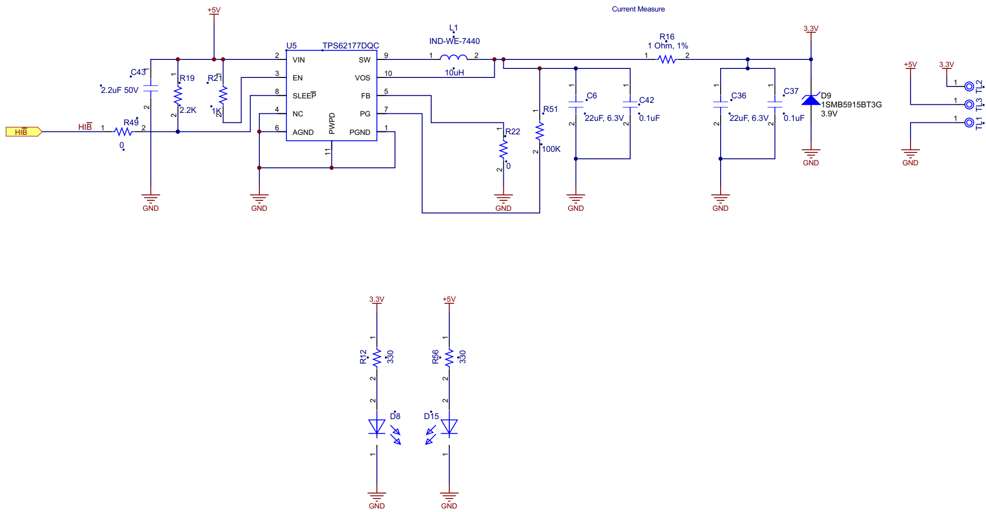

Figure 22. Power Supply

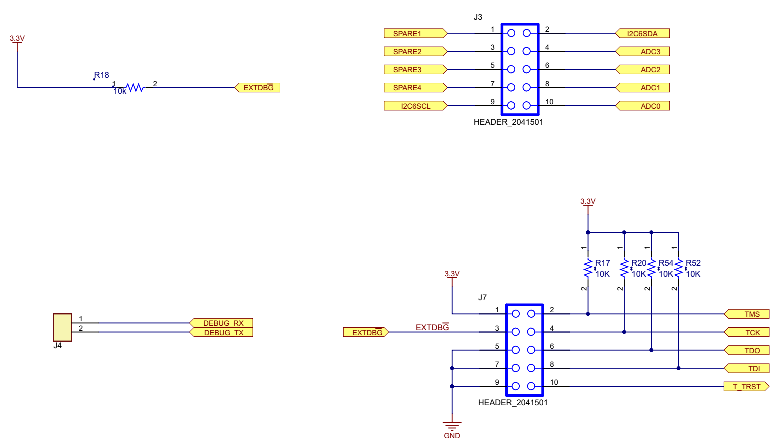

Figure 23. Spare and Debug

7.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-00226.

Table 11. BOM

FITTED	QTY	REFERENCE	PART DESCRIPTION	MANUFACTURER	PARTNUMBER
Fitted	1	C1	CAP, CERM, 10 µF, 6.3 V, ±20%, X5R, 0603	Kemet	C0603C106M9PACTU
Fitted	3	C2, C7, C10	CAP, CERM, 0.1 µF, 16 V, ±10%, X5R, 0603	MuRata	GRM188R61C104KA01D
Fitted	1	C3	Capacitor, 3300 pF, 50 V, 10%, X7R, 0603	TDK Corporation	C1608X7R1H332K
Fitted	4	C4, C27, C28, C34	Capacitor, 0.01 µF, 25 V, 10% 0402 X7R	Taiyo Yuden	TMK105B7103KV-F
Fitted	16	C5, C11, C12, C13, C16, C22, C23, C24, C25, C35, C37, C38, C39, C40, C41, C42	Capacitor, 0.1 µF, 50 V, 20% 0603 X7R	TDK Corporation	C1608X7R1H104M
Fitted	1	C6	Capacitor, 22 µF, 6.3 V 20% X5R 0805	TDK Corporation	C2012X5R0J226M
Fitted	1	C8	CAP CER 1000 pF, 2 kV, 20% X7R, 1210	KEMET	C1210C102MGRACTU
Fitted	1	C9	Capacitor, 4700 pF, 2 kV, 10%, X7R, 1812	AVX	1812GC472KAT1A
Fitted	6	C14, C15, C45, C46, C47, C48	CAP, CERM, 33 pF, 50 V, ±5%, C0G/NP0, 0402	MuRata	GRM1555C1H330JA01D
Fitted	2	C17, C21	Capacitor, 4.7 µF, 6.3 V, 10%, 0805, X5R	Taiyo Yuden	JMK212BJ475KG-T
Fitted	1	C18	Capacitor, 2.2 µF, 16 V, 10%, 0603, X5R	Murata	GRM188R61C225KE15D
Fitted	4	C19, C20, C26, C32	Capacitor, 1 µF , X5R, 10 V, 0402	TDK Corporation	C1005X5R1A105M050BB
Fitted	3	C29, C31, C33	Capacitor, 0.1 µF 16 V, 10%, X7R, 0402	Taiyo Yuden	EMK105B7104KV-F
Fitted	2	C30, C44	CAP, CERM, 0.1 µF, 25 V, ±5%, X7R, 0603	AVX	06033C104JAT2A
Fitted	1	C36	Capacitor, 22 µF, 6.3 V, 20%, X5R, 0805	TDK Corporation	C2012X5R0J226M/1.25
Fitted	1	C43	Capacitor, 2.2 µF, 50 V, 10%, X5R, 0805	TDK Corporation	C2012X5R1H225K
Fitted	5	D1, D2, D6, D7, D11	Diode, P-N, 70 V, 0.2 A, SOT-323	Diodes Inc	DESD1P0RFW-7
Fitted	1	D3	Quad Channel High-Speed ESD Protection Device, DCK0006A	Texas Instruments	TPD4E1U06DCK
Fitted	3	D4, D5, D16	Diode, 5.6-V ESD Suppressor 0402	Epcos	B72590D0050H160
Fitted	2	D8, D14	LED, Green 565 nm, Clear 0805 SMD	Lite on	LTST-C171GKT
Fitted	1	D9	Diode, Zener, 3.9 V, 550 mW, SMB	ON Semiconductor	1SMB5915BT3G
Fitted	1	D10	Diode, Schottky, 200 V, 1 A, PowerDI123	Diodes Inc.	DFLS1200-7
Fitted	2	D12, D15	LED AMBER CLEAR 0805 SMD	Lite on	LTST-C170AKT
Fitted	1	D13	LED, Red 630 nm, Clear 0805 SMD	Lite on	LTST-C171EKT
Fitted	1	FB1	FERRITE CHIP 1000 Ω, 300 mA 0603	TDK Corporation	MMZ1608B102C
Fitted	6	FID1, FID2, FID3, FID4, FID5, FID6	Fiducial mark. There is nothing to buy or mount.	N/A	N/A
Fitted	6	H1, H2, H3, H4, H5, H6	Machine Screw, Round, 4-40 × ¼, Nylon, Philips Panhead	B&F Fastener Supply	NY PMS 440 0025 PH
Fitted	1	J1	Connector, RJ45 NO MAG, shielded THRU HOLE	TE connectivity	6116526-1
Fitted	4	J2, J4, J6, J8	Terminal Block, 4×1, 2.54 mm, TH	On Shore Technology Inc	OSTVN02A150

Table 11. BOM (continued)

FITTED	QTY	REFERENCE	PART DESCRIPTION	MANUFACTURER	PARTNUMBER
Fitted	2	J3, J7	Header, 2×5 2-mm spacing	Harwin Inc	M22-2020505
Fitted	1	J5	Connector, USB micro AB Receptacle Reversed SMD	HIROSE ELECTRIC CO. LTD.	ZX62R-AB-5P
Fitted	1	J9	CONN MICRO HS TERM STRP HDR 50 POS	Samtec	ERM8-025-05.0-L-DV-K-TR
Not Fitted	0	J10	Header, 2 mm, Low Profile 2×3	Samtec	TMM-103-01-G-D-RA
Fitted	1	L1	Inductor 10uH, SMD 2.8×2.8 mm, 0.5 A, 0.47 Ω	Wurth Electronics Inc	744029100
Fitted	000 per roll	LBL1	Thermal Transfer Printable Labels, 0.650 W x 0.200" H - 10	Brady	THT-14-LBL1
Fitted	5	R1, R2, R19, R59, R61	Resistor, 2.2 KΩ, 1/10 W 5% 0603 SMD	Vishay-Dale	CRCW06032K20JNEA
Fitted	2	R3, R60	RES, 2.2 kΩ, 5%, 0.063 W, 0402	Vishay-Dale	CRCW04022K20JNED
Fitted	12	R4, R6, R8, R23, R24, R30, R32, R37, R38, R40, R47, R48	Resistor, 0 Ω, 1/10 W, 5%, 0402	Panasonic Electronic Components	ERJ-2GE0R00X
Not Fitted	0	R5	RES, 1.0 MΩ, 5%, 0.063 W, 0402	Vishay-Dale	CRCW04021M00JNED
Fitted	1	R7	Resistor, 1 MΩ, 1/10 W, 5%, 0603 SMD	Panasonic Electronic Components	ERJ-3GEYJ105V
Fitted	4	R9, R10, R11, R13	Resistor, 49.9 Ω, 1/10 W, 1%, 0603 Thick	Panasonic Electronic Components	ERJ-3EKF49R9V
Fitted	2	R12, R56	Resistor, 330 Ω, 1/10W, 5%, 0402	Panasonic Electronic Components	RC0402FR-07330RL
Fitted	5	R14, R15, R35, R36, R46	RES, 33 Ω, 5%, 0.063 W, 0402	Vishay-Dale	CRCW040233R0JNED
Fitted	1	R16	Resistor, 1 Ω, 1/10 W 1%, 0603, Thick	Panasonic Electronic Components	ERJ-3RQF1R0V
Fitted	8	R17, R18, R20, R33, R39, R44, R52, R54	Resistor, 10 kΩ, 1/10 W, 5%, 0402 Thick Film	Yageo America	RC0402FR-0710KL
Fitted	1	R21	Resistor, 1 kΩ, 1/10 W, 5%, SMD, Thick	Panasonic Electronic Components	ERJ-3GEYJ102V
Fitted	4	R22, R49, R58, R62	Resistor, 0 Ω, 1/10 W, 0603 SMD	Panasonic Electronic Components	ERJ-3GEY0R00V
Fitted	2	R25, R45	RES, 120 Ω, 1%, 0.25 W, 1206	Yageo America	RC1206FR-07120RL
Fitted	4	R26, R27, R29, R34	Resistor, 75 Ω, 1/10 W, 1%, SMD, Thick	Panasonic Electronic Components	ERJ-3EKF75R0V
Fitted	1	R28	Resistor, 1 MΩ, 5%, 1206 TF	Panasonic Electronic Components	ERJ-8GEYJ105V
Fitted	1	R31	Resistor, 51 Ω, 1/10 W, 5%, 0402	Panasonic Electronic Components	ERJ-2GEJ510X
Fitted	1	R41	Resistor, 4.87 kΩ, 1/10 W, 1%, SMD, Thick	Panasonic Electronic Components	ERJ-3EKF4871V
Fitted	1	R42	Resistor, 10 kΩ, 1/10 W, 5%, 0603 SMD	Panasonic Electronic Components	ERJ-3GEYJ103V

Table 11. BOM (continued)

FITTED	QTY	REFERENCE	PART DESCRIPTION	MANUFACTURER	PARTNUMBER
Not Fitted	0	R43	Resistor, 33 Ω, 5%, 0.063 W, 0402	Vishay-Dale	CRCW040233R0JNED
Fitted	3	R50, R53, R55	Resistor, 330 Ω, 1/10 W, 5%, 0603 SMD	Panasonic Electronic Components	ERJ-3GEYJ331V
Fitted	1	R51	Resistor, 100 kΩ, 1/10 W, 5%, 0603 Thick	Panasonic Electronic Components	ERJ-3GEYJ104V
Fitted	1	R57	Resistor, 0.1 Ω, 1%, 0.1 W, 0603	Panasonic	ERJ-3RSFR10V
Fitted	1	SW1	Switch, Tact 6-mm SMT, 160gf	Omron Electronics Inc-EMC Div	B3S-1000
Fitted	1	T1	Transformer, MDL, XFMR SGL ETHR LAN, SOIC-16	Pulse Electronics	HX1198FNL
Fitted	1	U1	IC, RS-485 Transceiver LP, 8-SOIC	Texas Instruments	SN65HVD3082ED
Fitted	1	U2	Stellaris MCU TM4C129XNCZAD 212 BGA, Super	Texas Instruments	TM4C129XNCZAD
Fitted	1	U3	Load Switch, 5.5 V, SOT23-5, TPS2051BDBV	Texas Instruments	TPS2051BDBVT
Fitted	1	U4	CAN Transceiver with Fast Loop Times for Highly Loaded Networks, 85 mA, 5 V, –40 to 125°C, 8-pin SOIC (D), Green (RoHS and no Sb/Br)	Texas Instruments	SN65HVD256D
Fitted	1	U5	Regulator, Step Down 3.3 V, 0.5 A	Texas Instruments	TPS62177DQC
Fitted	1	U6	IC, Current Shunt Monitor, –16 to 80-V Common-Mode Range	Texas Instruments	INA196AIDBVR
Fitted	1	Y1	Crystal, 25.00 MHz 5.0×3.2-mm SMT	CTS-Frequency Controls	445I23D25M00000

7.3 PCB Layer Plots

To download the layer plots, see the design files at TIDA-00226.

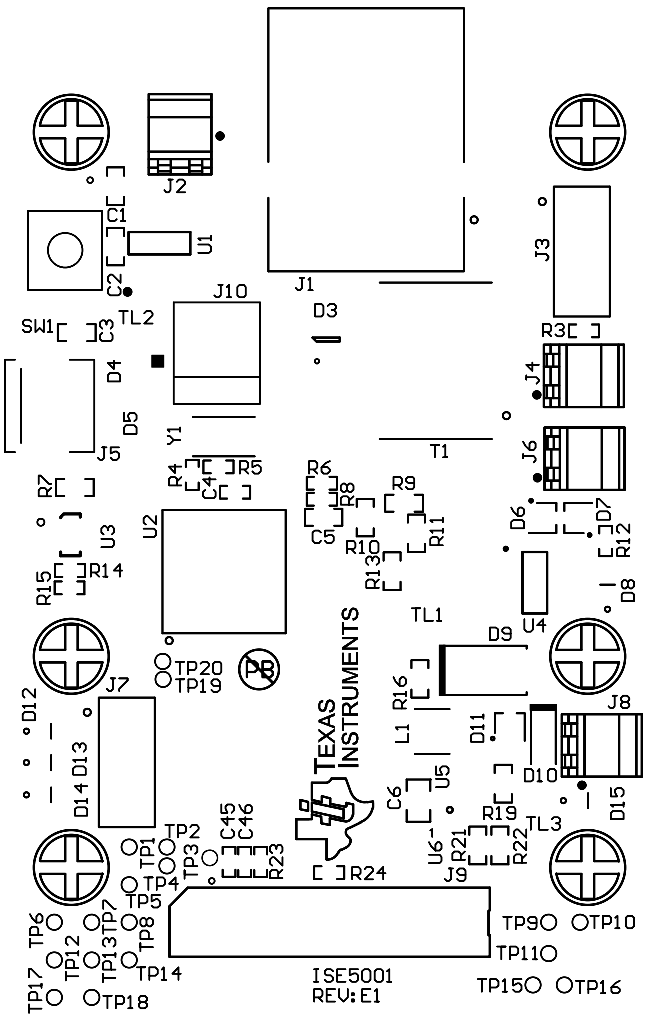

Figure 24. Top Overlay

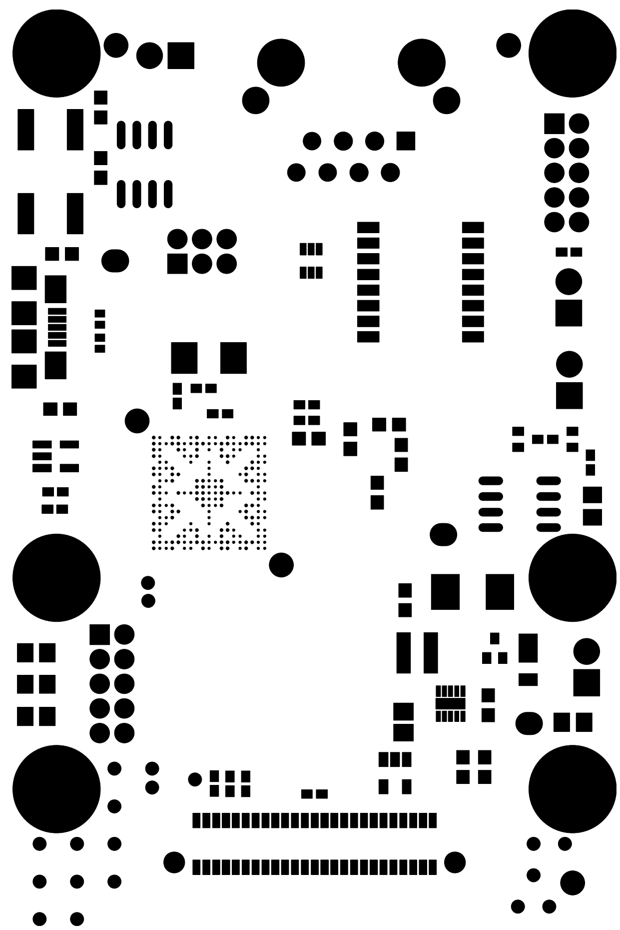

Figure 25. Top Solder Mask

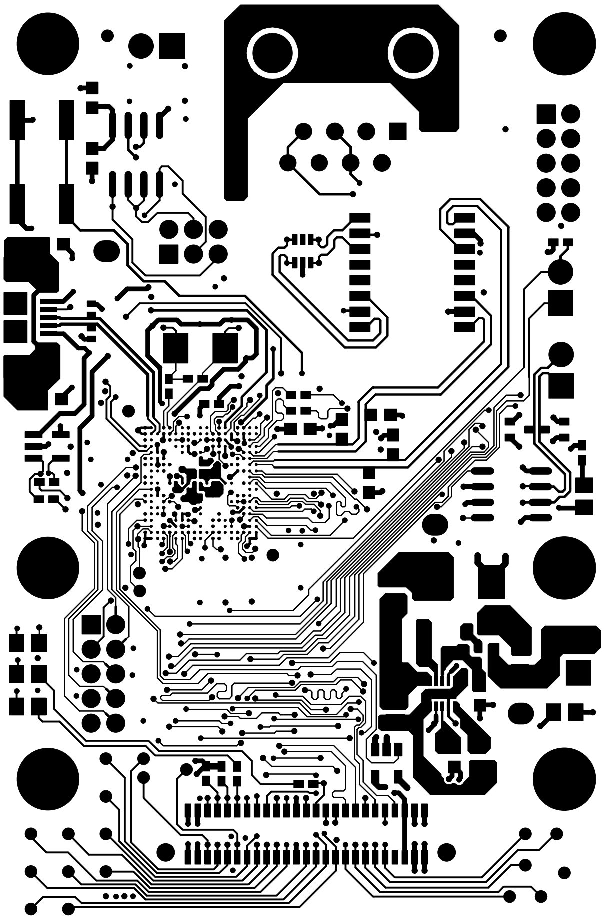

Figure 26. Top Layer

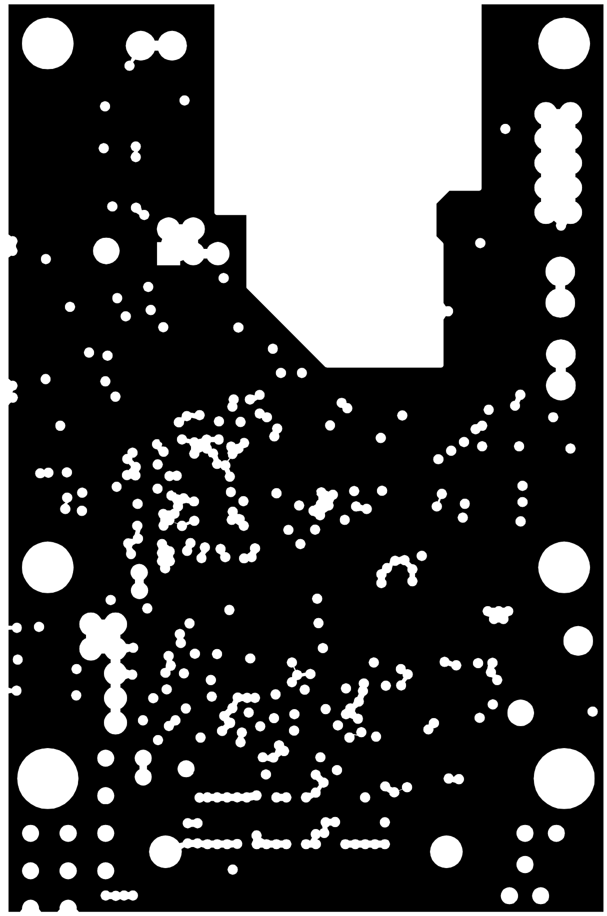

Figure 27. Layer 2: GND Plane

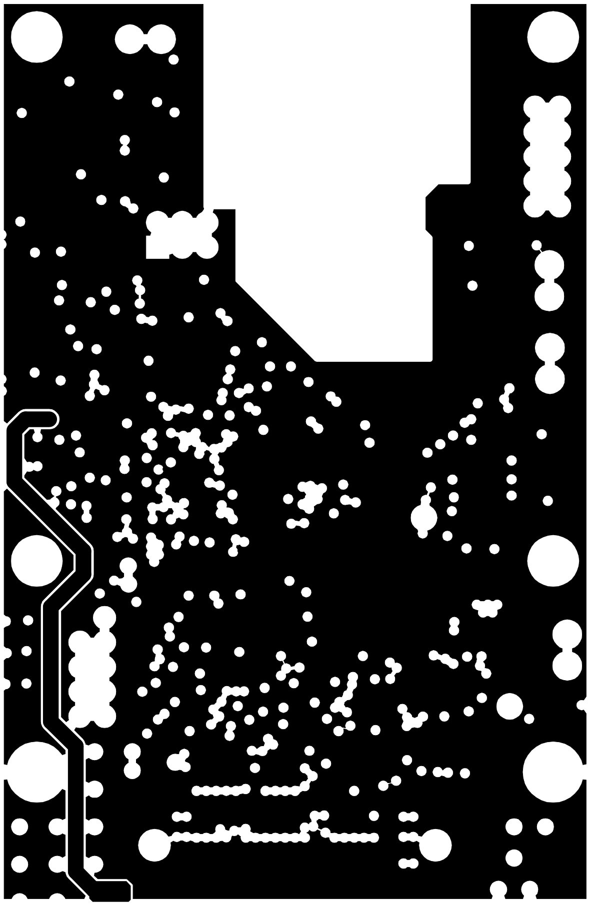

Figure 28. Layer 3: Power Plane

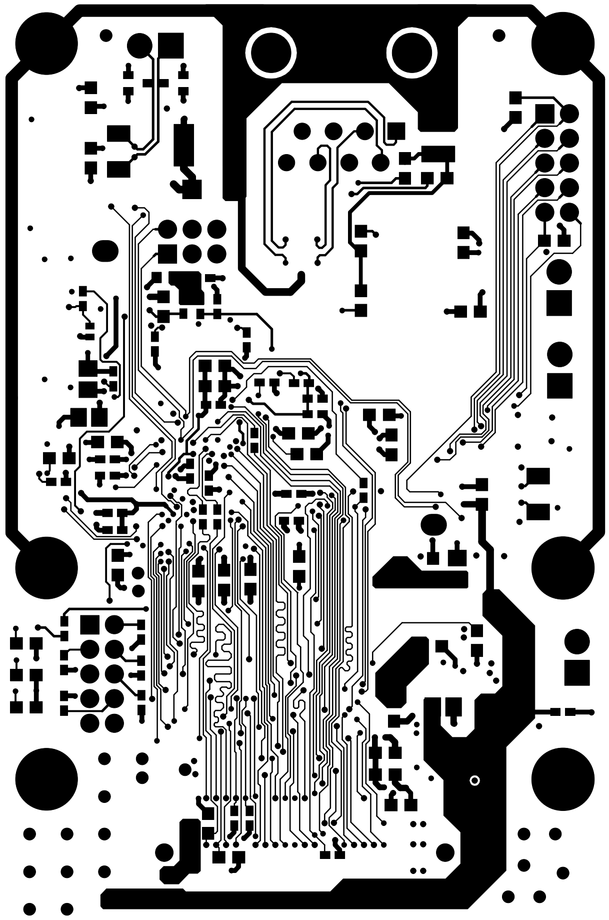

Figure 29. Bottom Layer

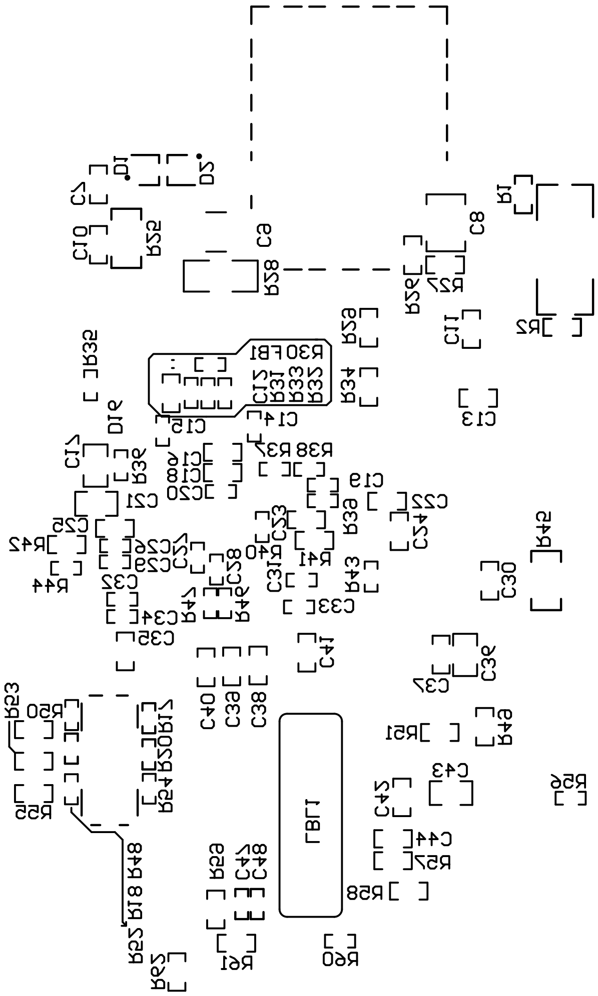

Figure 30. Bottom Overlay

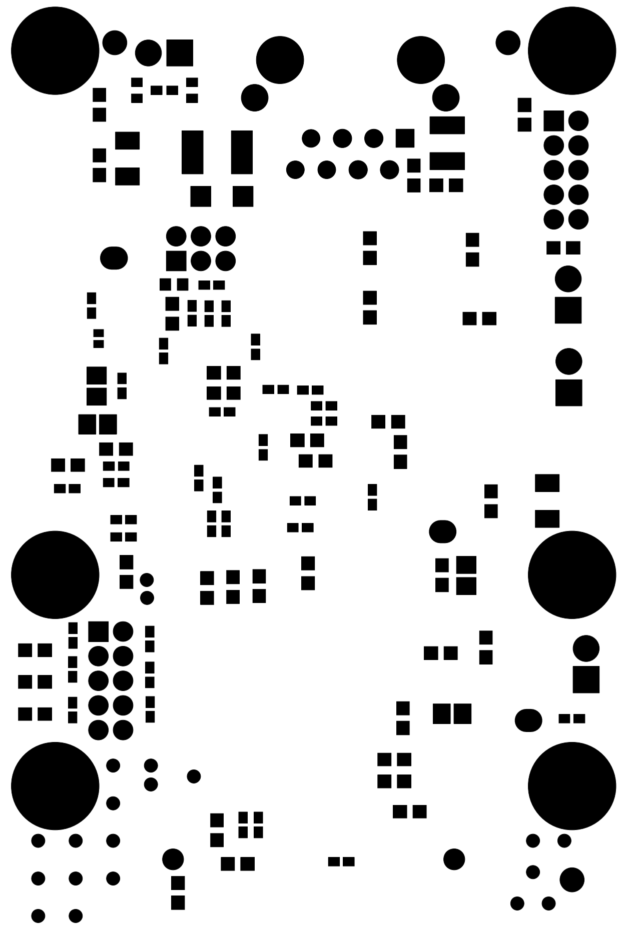

Figure 31. Bottom Solder Mask

7.4 Altium Project

To download the Altium project files, see the design files at TIDA-00226.

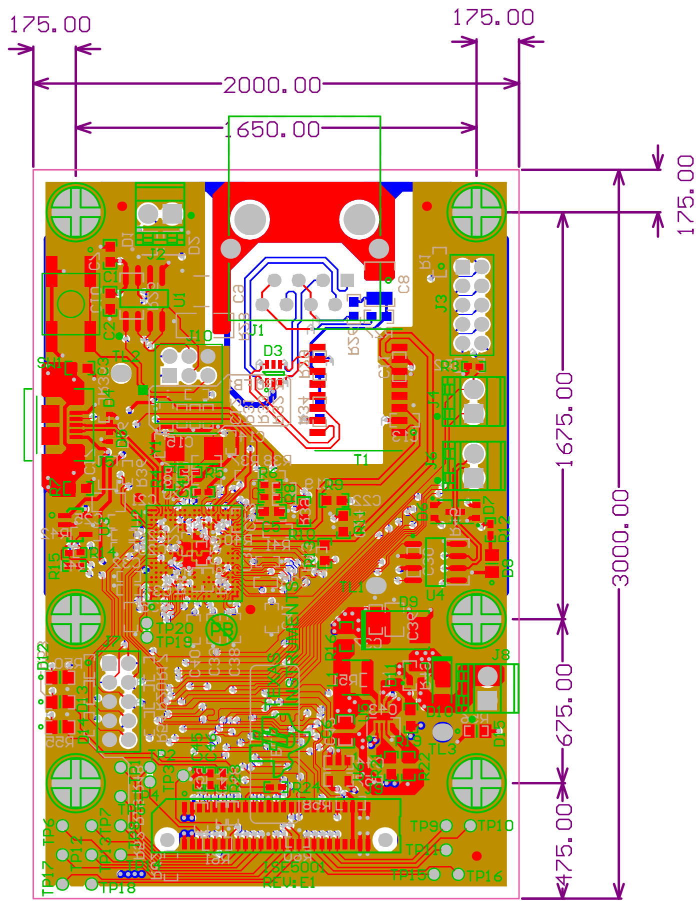

Figure 32. Multilayer Composite Print

7.5 Gerber Files

To download the Gerber files, see the design files at TIDA-00226.

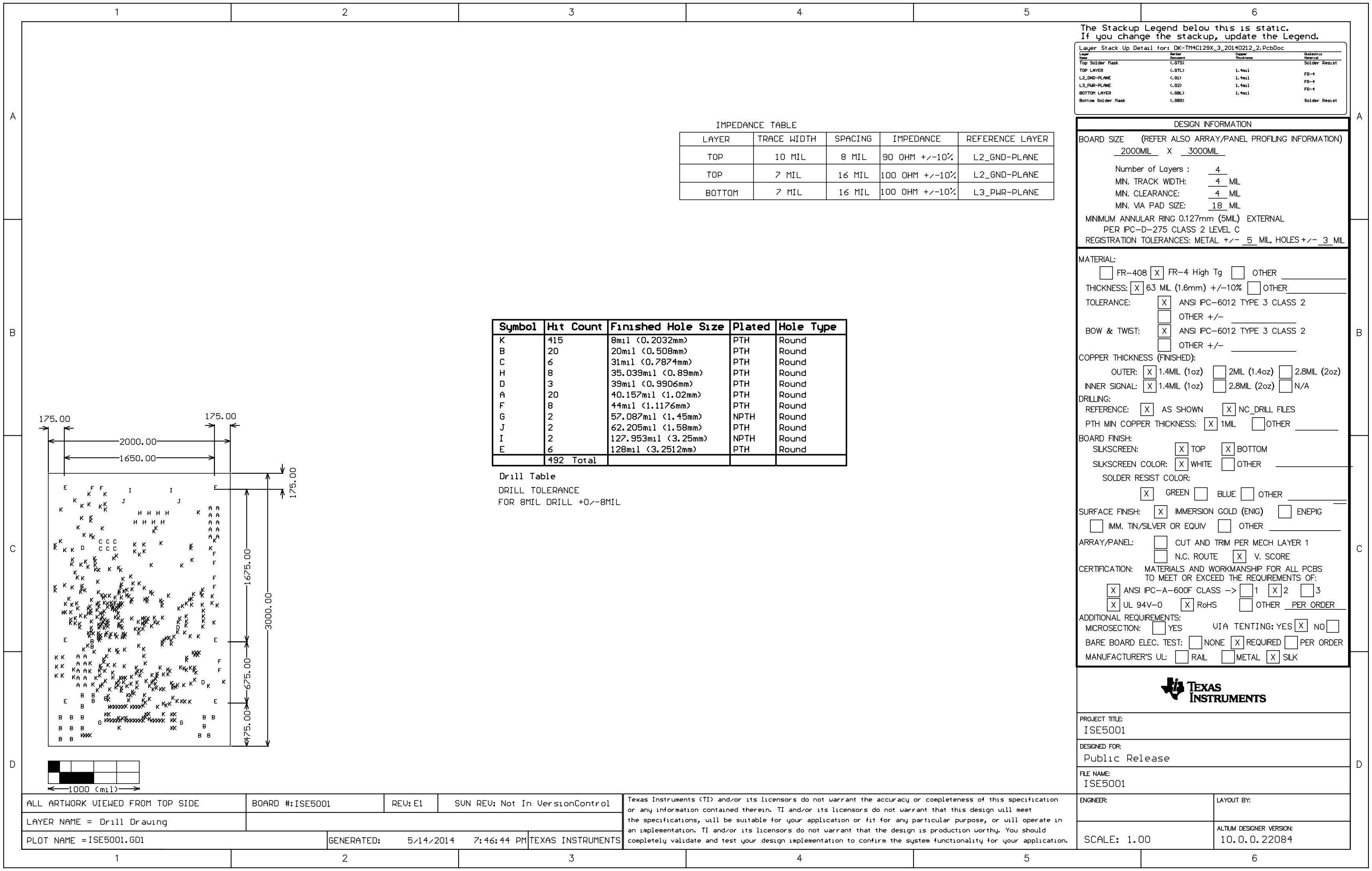

Figure 33. Drill Drawing

7.6 Assembly Drawings

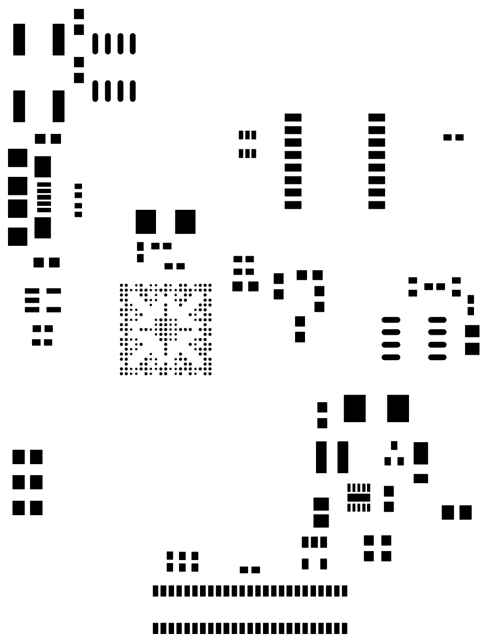

Figure 34. Top Paste

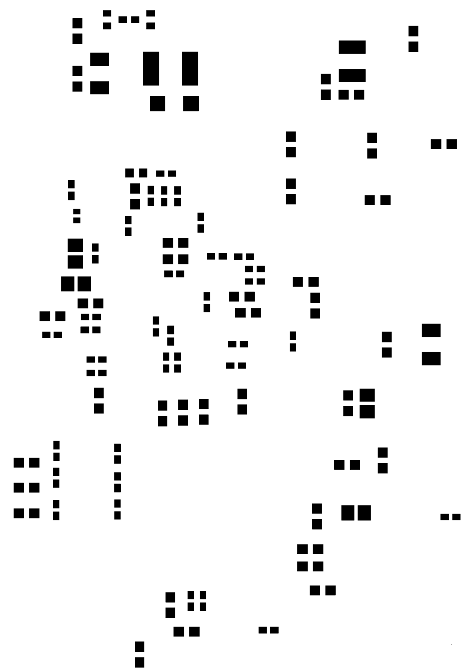

Figure 35. Bottom Paste

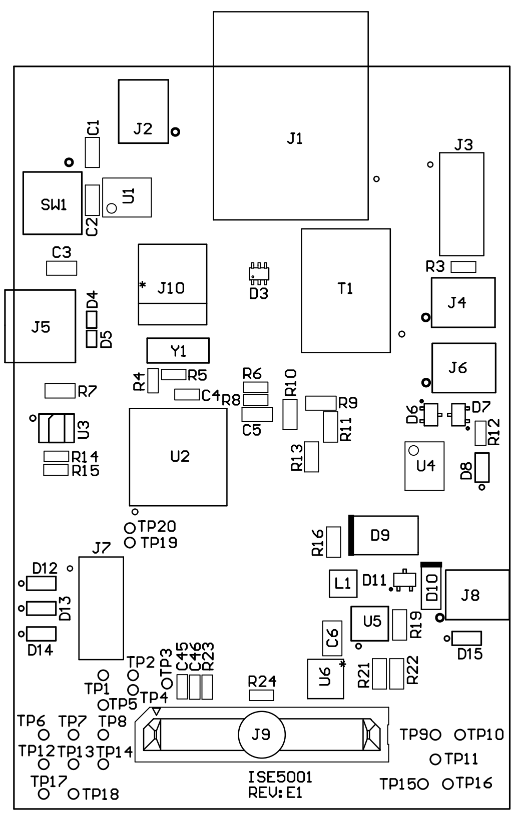

Figure 36. Assembly Top

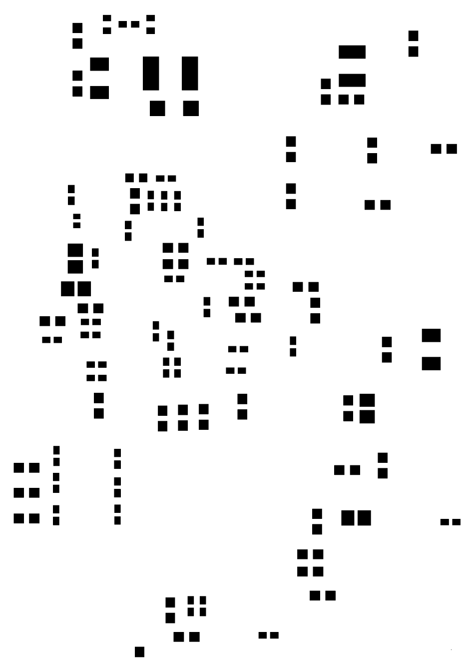

Figure 37. Assembly Bottom

8 References

1. System Design Guidelines for the TM4C129x Family of Tiva C Series Microcontrollers, (SPMA056).
2. Tiva TM4C129x Development Board User's Guide, (SPMU360).
3. Tiva TM4C1292NCZAD Microcontroller Data Sheet, (SPMS432A).
4. Tiva C Series TM4C1294 Connected LaunchPad Evaluation Kit, (SPMU365A).

9 About the Author

KALLIKUPPA MUNIYAPPA SREENIVASA is a systems architect at Texas Instruments where he is responsible for developing reference design solutions for the industrial segment. Sreenivasa brings to this role his experience in high-speed digital and analog systems design. Sreenivasa earned his Bachelor of Electronics (BE) in electronics and communication engineering (BE-E&C) from VTU, Mysore, India.

IMPORTANT NOTICE FOR TI REFERENCE DESIGNS

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265