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RTOS-Based Configurable Serial-to-Ethernet Converter on High Performance Microcontrollers Design Guide



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Design Resources

TIDM-TM4C129XS2E	Tool Folder Containing Design Files
TM4C1294NCPDT	Product Folder
TM4C123GH6PM	Product Folder
TPD4S012	Product Folder
TPS2052B	Product Folder
TPS73733-Q1	Product Folder
MAX3232	Product Folder
EK-TM4C1294XL	Product Folder
TIDA-00226	Product Folder



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Design Features

- Two Serial-to-Telnet Port Pairs to Connect Two Different Serial Devices at the Same Time
- HTTP Configuration Web Server to Dynamically Manage IP Address, Serial Port, and Telnet Port Settings (at Runtime)
- Configuration Parameters Stored in Electrically Erasable Programmable Read-Only Memory (EEPROM) With Provision to Restore Factory Settings
- Software Uses FreeRTOS[™] for Task Scheduling, IwIP TCP/IP Stack, and TI's TivaWare[™] for C Series Software (Includes Driver Library and Locator Service) to Simplify Application Development
- Software Designed to Work on EK-TM4C129XL (Connected LaunchPad) and DK-TM4C129X (With Minimal Modifications) for Supported Toolchains like TI's Code Composer Studio™ Software, Keil® MDK, IAR™ Embedded Workbench, and GNU
- Optional Board With RS-232 PHY for Easy Connections to EK-TM4C129XL and DK-TM4C129X

Featured Applications

- Industrial Application and Automation
- Smart Grid and Energy
- Test and Measurement





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System Description www.ti.com



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1 System Description

When a legacy product only contains a serial port for configuration or control, continuing to access the legacy product through the serial interface can become challenging over time due to:

- The inability to add multiple products of this type to a shared network
- The inability to access the legacy product from long distances
- · Modern PCs generally do not have RS-232 serial ports

Using Ethernet in place of the serial port provides the following benefits:

- The legacy product is easier to share over a network connection (instead of changing a cable connection, a new connection is made over the existing network)
- The ability to access from longer distances, making cable length no longer an issue
- Ethernet is a more common interface available on today's computing equipment

The software accompanying this design allows an Ethernet-enabled TM4C129x microcontroller to be used as a serial-to-Ethernet converter. By connecting a serial-to-Ethernet converter to the serial port of a legacy product, the legacy product can be given the ability to operate on Ethernet without requiring any changes to the existing hardware or software. This ability is especially useful when the legacy product can not be modified (such as in the case of third-party products).

The software accompanying this design works out of the box on an EK-TM4C1294XL board. With minor modifications, the software can run on the DK-TM4C129X board. For details, see Section 4.3.

FreeRTOS has been used for scheduling the various tasks. Although a real-time operating system (RTOS) is not a requirement for this application, it has been used to make the application easily scalable.



www.ti.com System Description

1.1 TM4C1294NCPDT

The TM4C1294NCPDT is a 120-MHz, high-performance microcontroller with a 1-MB on-chip flash and a 256-KB on-chip SRAM and features an integrated Ethernet MAC+PHY for connected applications. The device has high-bandwidth interfaces like a memory controller and a high speed USB 2.0 digital interface. With the integration of a number of low- to mid-speed serial peripherals, a 12-bit analog-to-digital converter (ADC) with up to 4 million samples per second (MSPS), and motion control peripherals, the TM4C1294NCPDT makes for a unique solution for a variety of applications ranging from industrial communication equipments to smart energy and smart grid applications.

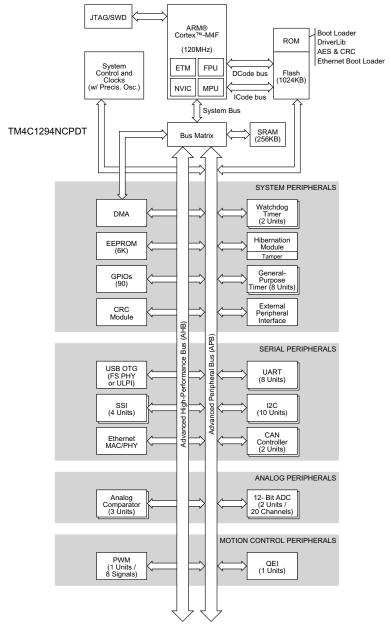


Figure 1. TM4C1294NCPDT Microcontroller High-Level Block Diagram



Block Diagram www.ti.com

2 Block Diagram



Figure 2. Serial-to-Ethernet Converter Block Diagram

3 Getting Started Hardware

Because the EK-TM4C1294XL Connected LaunchPad board does not have an RS-232 level shifter to level shift the universal asynchronous receiver/transmitter (UART) signals to the RS-232 level, the RS-232 level-shifting daughter board can be used for this purpose. For the test setup described in Section 5, the RS-232 level-shifting daughter board must be interfaced with the EK-TM4C1294XL board.

The design files for the RS-232 level-shifting daughter board are detailed in Section 6. Only one UART port with hardware flow control can be used with this board.

Section 3.1 describes the jumper settings and the necessary connections from the EK-TM4C1294X (or DK-TM4C129XL) to the RS-232 level-shifting daughter board.

3.1 RS-232 Level-Shifting Daughter Board

The following connections are required to interface the RS-232 level-shifting daughter board to the EK-TM4C1294XL board.

- One of the following two options can be used to connect the VCC and GND of both boards:
 - Connect J1.1 and J1.4 of the daughter board respectively to X6.1 and X6.4 on the EK-TM4C1294XL board.
 - Plug the daughter board into the "BoosterPack 1" header as Figure 3 shows.
- Follow the connections in Table 1 to level shift the UART signals to the RS-232 level. Figure 3 shows these connections for Port 0.
- J3 (or J4) of the daughter board can be connected to a DB9 cable.

Table 1 lists the connections from the RS-232 level-shifting daughter board to the EK-TM4C1294XL boards to achieve RS-232 level shifting of the UART signals. The table also contains, the UART signal name with the associated general purpose input and output (GPIO) and the port number used by the software.

Table 1. Connections from RS-232 Level-Shifting Daughter Board to EK-TM4C1294XL Board

enet_s2e PORT NUMBER	UART SIGNAL NAME - GPIO	RS-232 LEVEL- SHIFTING DAUGHTER BOARD	EK-TM4C1294XL
Port 0	U4RX – PK0	URX – J6.1	X6.10
	U4TX – PK1	UTX – J5.1	X6.12
	U4RTS – PK2	URTS – J7.1	X6.14
	U4CTS - PK3	UCTS – J8.1	X6.16
Port 1 ⁽¹⁾	U3RX – PA4	URX – J6.1	X6.18
	U3TX – PA5	UTX – J5.1	X6.20
	U3RTS - PN4	URTS – J7.1	X6.19
	U3CTS - PN5	UCTS - J8.1	X6.17

⁽¹⁾ Use another RS-232 level-shifting daughter board for Port 1.



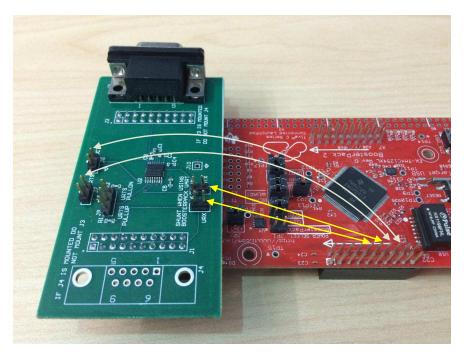


Figure 3. Port 0 Connections Between EK-TM4C1294XL and RS-232 Level-Shifting Daughter Board

NOTE: Figure 3 and Figure 4 only display Port 0 connections between the TM4C129x evaluation boards and RS-232 level-shifting daughter board. For Port 1 connections, please follow Table 1 and Table 2.

The following connections are required to interface the RS-232 level-shifting daughter board to the DK-TM4C129X board.

- One of the following two options can be used to connect the VCC and GND of both boards:
 - Connect J1.1 and J1.4 of the daughter board respectively to J29.1 and J29.4 on the DK-TM4C129X
 - Plug the daughter board into one of the "BoosterPack" headers (Figure 4 shows this for Port 0 connections).
- Follow connections in Table 2 to level shift the UART signals to the RS-232 level (Figure 4 shows these connections for Port 0).
- J3 (or J4) of the daughter board can be connected to a DB9 cable.



Table 2 lists the connections from the RS-232 level-shifting daughter board to the DK-TM4C129X board to achieve RS-232 level shifting of the UART signals. This table also contains the UART signal name with the associated GPIO and the port number used by the software.

Table 2. Connections from RS-232 Level-Shifting Daughter Board to DK-TM4C129X Board

enet_s2e PORT NUMBER	UART SIGNAL NAME - GPIO	RS-232 LEVEL-SHIFTING DAUGHTER BOARD	DK-TM4C129X
Port 0	U4RX – PK0	URX – J6.1	J29.10
	U4TX – PK1	UTX – J5.1	J29.12
	U4RTS – PK2	URTS – J7.1	J29.14
	U4CTS - PK3	UCTS - J8.1	J29.16
Port 1 ⁽¹⁾	U3RX – PA4	URX – J6.1	J9.6 ⁽²⁾
	U3TX – PA5	UTX – J5.1	J9.7 ⁽²⁾
	U3RTS - PN4	URTS – J7.1	J27.16
	U3CTS - PN5	UCTS - J8.1	J36.1 ⁽³⁾

⁽¹⁾ Use another RS-232 level-shifting daughter board for Port 1.

⁽³⁾ Remove the jumper on J36.

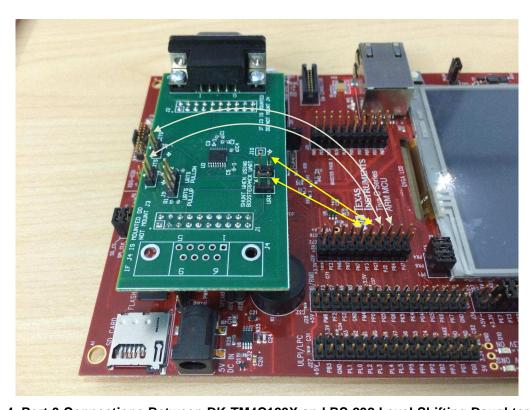


Figure 4. Port 0 Connections Between DK-TM4C129X and RS-232 Level-Shifting Daughter Board

⁽²⁾ Pins 2 and 3 on J16 and J17 must be connected.



4 Getting Started Software

The software accompanying this design is called *enet_s2e*. The main function of this software is to transfer information between serial peripherals and Ethernet. Telnet protocol is used to transfer information over Ethernet. A number of features are provided in the application to make this process easy to use and robust. The following are some of these features.

- Two serial-to-telnet port pairs (Port 0 and Port 1)
- Dynamic configuration of serial and Telnet port settings
- · Dynamic internet protocol (IP) address configuration
- HTTP server to manage dynamic configuration parameters
- Locator service to find the IP address of the board (to access HTTP server)
- EEPROM access to store configuration data

The following subsections give more details about the software, how to set up and program the software, and the required software modifications to work compatibly with the DK-TM4C129X board.

4.1 Software Description

The application runs a web server to manage the dynamic/run-time configuration of many parameters. For more details of the configuration web server and the different settings, see Section 5.2.

This application uses two serial peripherals and two telnet ports. The serial peripheral and telnet port are configured such that each serial peripheral can transmit and receive data to and from only one telnet port. There are two such serial-telnet pairs, represented by Port 0 and Port 1. By default, the serial interface of Port 0 and Port 1 are assigned to UART4 and UART3 peripherals, respectively. This default peripheral assignment can be modified in the *config.h* file. If the default assignment is modified, then the assignment of the interrupt handlers "SerialPort0IntHandler" and "SerialPort1IntHandler" in the vector table must also be modified. The vector table is located in the start-up file.

The telnet ports can be configured in both server and client modes along with the necessary parameters like port number and IP address. By default, both the telnet ports are configured as server. The telnet ports used by Port 0 and Port 1 are 23 and 26, respectively.

The *enet_s2e* application uses FreeRTOS to run multiple tasks in a concurrent fashion, a TCP/IP stack called *lwIP* to handle the TCP/IP packets, and Tl's TivaWare for C Series software that includes a peripheral driver library and other utilities that simplify application development. Figure 5 shows the interaction between different software layers of this application.

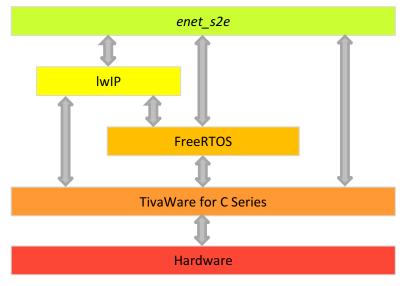


Figure 5. Software Layers of enet_s2e Application



The *enet_s2e.c* file contains the main function and performs the initialization before handing over control to the FreeRTOS scheduler. The tasks and their responsibilities are as follows:

- A TCP/IP task (created by lwIP library) to run the lwIP stack and manage all of the TCP/IP packets
- An Ethernet task (created by lwIP library) to manage the Ethernet interface and its interrupt
- A serial task to manage the serial peripherals and their interrupts
- An idle task (automatically created by FreeRTOS) to manage changes to IP address

The data transfer between the serial peripherals and telnet sockets is handled by the *TelnetHandler()* function (present in the *telnet.c* file), which is called by the *IwIPHostTimerHandler()* function (present in the Iwip_task.c file). The IwIPHostTimerHandler() function runs in the TCP/IP task context.

4.2 Configuration Web Server

The enet_s2e application hosts an embedded web server that provides a convenient configuration interface. The web server hosts pages that give information about TI, Tiva™ C Series Microcontrollers, the TM4C1294NCPDT device, and the EK-TM4C1294XL board apart from the status and configuration pages that show the S2E status and configuration options. The status and configuration pages are covered in more detail in the following sections.

4.2.1 S2E Status Page

The "S2E Status Page" shows the current status and configuration information (see Figure 6). Included are the name, IP address, and MAC address of the S2E module as well as the current port settings for both port 0 and port 1.

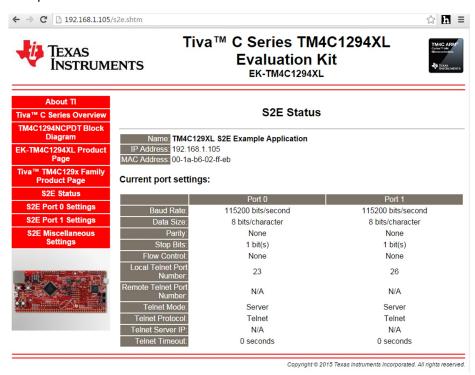


Figure 6. S2E Status Page



4.2.2 S2E Port 0 and Port 1 Settings Page

The "S2E Port 0 Settings" page allows the configuration of port 0 of the S2E module. Similarly, the "S2E Port 1 Settings" page allows the configuration of port 1 of the S2E module. The following configuration options are provided:

- Baud Rate Specifies the baud rate to be used by the serial port. There are several options up to 230400 bits/s.
- Data Size Configures the number of data bits per character. The options are 5 to 8 bits per character.
- Parity Specifies the generation and checking of the parity bit in the data frame and the type of parity used. The options are "None", "Odd", "Even", "Mark", and "Space".
- Stop Bits Specifies the number of stop bits at the end of a frame. The options are 1 and 2 bits per character.
- Flow Control Specifies the use of flow control. The options are "None" and "Hardware".
- Local Telnet Port Number Specifies the local telnet port number to be used.
- Remote Telnet Port Number Specifies the remote telnet port number to be used when the "Telnet Mode" is set to "Client".
- Telnet Mode Specifies whether the telnet mode for that port will be "Server" or "Client".
- Telnet Protocol Specifies whether the data for the port will be "Telnet" or "Raw".
- Telnet Server IP Specifies the IP address of the telnet server when the "Telnet Mode" is set to "Client".
- Telnet Timeout Specifies the telnet timeout in seconds. The default is 0 and specifies that no timeout is to be used.

After changing the settings, click the "Submit" button. If the "Make these the default settings" checkbox is checked before clicking the "Submit" button, then the new settings are applied each time the S2E module is reset. Otherwise, the existing defaults are used when the module is reset next. Figure 7 shows the S2E Port 0 Settings page.

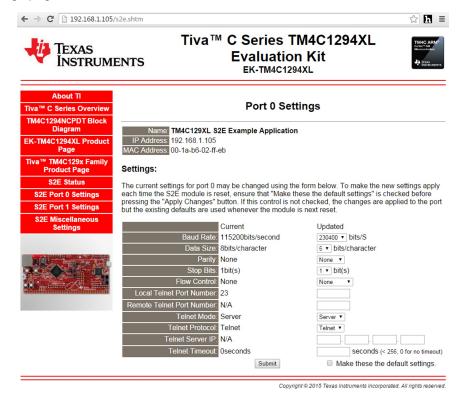


Figure 7. S2E Port 0 Settings Page

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4.2.3 S2E Miscellaneous Settings Page

Figure 8 shows the S2E Miscellaneous Settings page, which is divided into three parts: "IP Address Selection", "General Configuration Settings", and "Restore Factory Defaults".

The *IP Address Selection* section of the page allows the configuration of the S2E module to automatically obtain an IP address or use a static IP address at start-up. If the "DHCP/AutoIP" option is chosen, the S2E module first attempts to get an IP address from a DHCP server. If a DHCP server cannot be located, the S2E module obtains a link local IP address using the AutoIP protocol. If the "Static IP" option is chosen, then the "Static IP Address", "Subnet Mask", and "Default Gateway" fields must be filled in. Clicking the "Update Settings" button saves the settings.

The "General Configuration Settings" section of the page allows modification of the "Module Name" that is used by the "Finder Utility" to show the available S2E modules in the network. Clicking the "Update Settings" button saves the settings.

The "Restore Factory Defaults" section of the page allows restoring all of the options to their factory default states.

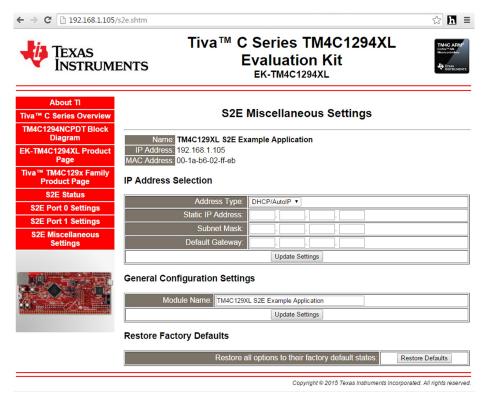


Figure 8. S2E Miscellaneous Settings Page

4.3 Access the Configuration Web Server

The configuration web server of the S2E module can be accessed by:

- Using the debug port
- Using the Finder utility



4.3.1 Using the Debug Port

To access the configuration web server using the debug port:

- 1. Open a terminal window (like HyperTerminal or TeraTerm) and connect to the *Stellaris Virtual Serial Port* COM port.
- 2. Select the Baud rate as 115200, Data Bits as 8, Parity as none, Stop bits as 1 and Flow Control as none.
- 3. Program and run the enet_s2e application. For detailed instructions to program the enet_s2e application, see Section 4.4.
- 4. As soon as the IP address is acquired, it is printed on the terminal as shown in Figure 9.
- 5. Start a web browser and type the IP address that is displayed on the terminal into the address bar to load the different pages on the S2E configuration web server.

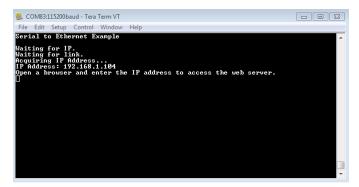


Figure 9. Debug Port Shows IP Address of S2E Module

4.3.2 Using the Finder Utility

To access the configuration web server using the Finder utility:

- 1. Program and run the enet_s2e application. For detailed instructions to program the enet_s2e application, see Section 4.4.
- 2. Browse to the .../TivaWare_C_Series-2.1.0.12573/tools/bin/ directory.
- 3. Double click on the *finder.exe* file. The Finder utility starts and you should see the S2E module in the list of *Available Tiva Boards* as shown in Figure 10.
- 4. Start a web browser and type the IP address that is displayed in the Finder utility into the address bar to load the different pages on the S2E configuration web server.

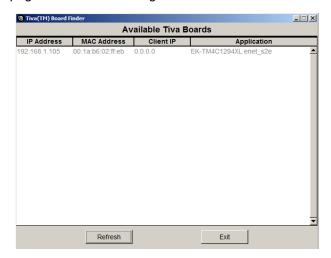


Figure 10. Finder Utility Shows Available Boards on Network



4.4 Flow Control

The enet s2e application can be configured to use request to send and clear to send (RTS/CTS) hardware flow controls using the configuration web server.

While receiving data, in Flow Control Mode, the S2E module asserts the RTS signal when it is capable of receiving data and the module de-asserts the signal when transmission by the remote serial device must be paused. In the S2E module, the RTS signal is asserted and de-asserted by the UART peripheral.

While transmitting data, the CTS signal is monitored by the UART peripheral for state changes. When the state changes to asserted, transmission is allowed or resumed. When the state changes to de-asserted, transmission is paused.

The polarity of the CTS and RTS signal is interpreted in the same way. If the CTS signal is 1 (or high level), it is considered to be de-asserted, and the UART transmitter is disabled (the current byte, if any, is completed). When the signal is 0 or low level, it is considered to be asserted, and the transmitter is reenabled.

4.5 Software Download and Program Instructions

The following steps detail how to download, set up, and program the accompanying enet s2e application.

- 1. Download and install the TivaWare for C Series software v2.1.0.12573 or later from the URL: http://www.ti.com/tool/SW-TM4C.
- 2. Download the enet s2e application source code from the URL: http://www.ti.com/tool/TIDM-TM4C129XS2E. The .zip file has two folders that must be extracted: enet s2e and utils.
- 3. Copy the enet s2e folder to the EK-TM4C1294XL board folder in the TivaWare for C Series software. The default installation path for the software is C:/ti and the folder for the EK-TM4C1294XL board is located at .../TivaWare C Series-2.1.0.12573/examples/boards/ek-tm4c1294xl/.
- 4. The utils folder has two files: eeprom pb.c and eeprom pb.h. Copy these files into the utils folder in the TivaWare for C Series directory located in .../TivaWare C Series-2.1.0.12573/utils.
- 5. Open the project in one of the toolchains and build the project to create a binary file. The supported toolchains are Code Composer StudioTM, Keil® MDK, IARTM Embedded Workbench and GNU.
- 6. Power-up the microcontroller by connecting the micro (smaller) end of the USB cable to the USB connector on the EK-TM4C1294XL board. Then connect the other end of the USB cable to a free USB port on the PC.
- 7. As soon as the EK-TM4C1294XL board is powered-up, the ICDI and Stellaris Virtual Serial Port drivers are installed.
- 8. Program the binary to the microcontroller by using the programming utility of the toolchain or by using LM Flash Programmer. Download LM Flash Programmer from the URL: http://www.ti.com/tool/LMFLASHPROGRAMMER.
- 9. Then reset the board to run the enet s2e application. Now the EK-TM4C1294XL board starts behaving as an S2E module.

NOTE: To verify whether the ICDI drivers are installed correctly (or if there is trouble programming the binary), see the Stellaris® In-Circuit Debug Interface (ICDI) and Virtual COM Port Driver Installation Instructions (SPMU287).





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4.6 Software Modifications for DK-TM4C129X

Use the following steps to modify the default enet_s2e application to run on the DK-TM4C129X board:

- 1. Download and extract the .zip file as described in Section 4.2. Then copy the enet_s2e folder into the DK-TM4C129X board's folder located at .../TivaWare C Series-2.1.0.12573/examples/boards/dktm4c129x/.
- 2. Open the project in one of the supported toolchains and modify the project settings as follows:
 - (a) Replace the defines PART_TM4C1294NCPDT and TARGET_IS_TM4C129_RA1 with PART_TM4C129XNCZAD and TARGET_IS_TM4C129_RA0 in the project settings.
 - (b) Uncomment the line that defines the label DK_TM4C129X in the enet_s2e.c file.
- 3. Rebuild the project.



Test Setup www.ti.com

5 Test Setup

The hardware setup involves interfacing the EK-TM4C1294XL board with the RS-232 level-shiftting daughter board and having the right connections to level shift the UART signals to RS-232 levels. This is needed as the EK-TM4C1294XL board will be connected to a PC.

The software set up involves opening the enet_s2e source code with one of the supported toolchains, building the application and executing the application on the EK-TM4C1294XL board. The user can choose to program and execute the pre-built binary files, which are provided for all the supported toolchains, instead of building the application from scratch.

5.1 Hardware Setup

Follow the steps below to set up the hardware. Also see Figure 11 for test set up.

- 1. Connect one end of the Ethernet cable to the Ethernet jack on the EK-TM4C1294XL board and the other end of the cable to the local area network (LAN) with the Dynamic Host Configuration Protocol (DHCP) server present (such as a router).
- See Section 3.1 for details on interfacing the EK-TM4C1294XL and RS-232 level-shifting daughter board.
- Connect one end of a DB9 cable to the RS-232 level-shifting daughter board (as described in Section 3.1) and the other end to the PC. If the PC does not have a DB9 port, then use a DB9 to USB converter cable.
- 4. Connect the micro (smaller) end of the USB cable to the USB connector on the EK-TM4C1294XL board. Then connect the other end of the USB cable to a free USB port on the PC. This connection is responsible for powering-up the board.

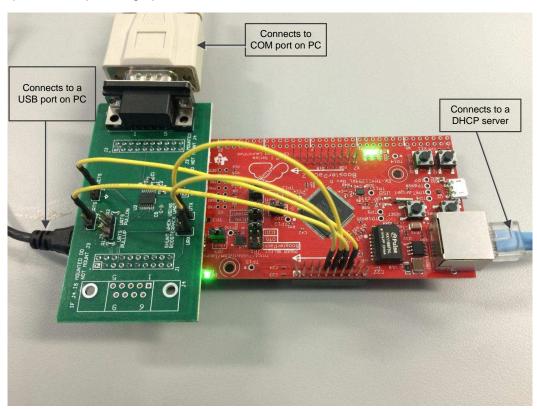


Figure 11. Test Assembly With Connections Between EK-TM4C1294XL Board and RS-232 Level-Shifting Daughter Board



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5.2 Software Setup

Follow the steps below to set up the software:

1. Follow first 4 steps of Section 4.5 to download, install and set up the necessary source code to build the enet_s2e application.

2. Import the enet_s2e application into Code Composer Studio (CCS) v6.0.1 or later. For the purpose of the document we are using CCS but any other supported toolchain can be used. To import a project into CCS use the menu options Project → Import CCS Projects. This action opens a window as shown in Figure 12. Browse to the directory where enet_s2e application is located. See Section 4.5 to download and set up the enet s2e application. Select the folder and then click the "Finish" button.

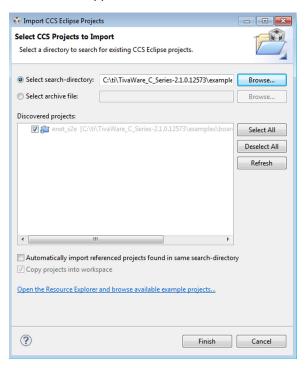


Figure 12. Importing Project into Code Composer Studio

3. The enet_s2e project is displayed on the left pane of CCS, as Figure 13 shows. Build the projects by right-clicking on the project and then selecting "Rebuild Project". The projects should compile without any errors.

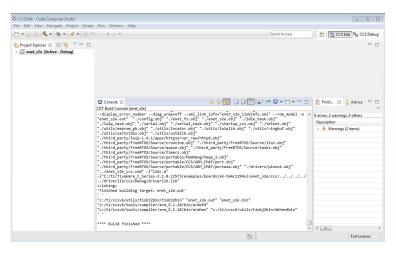


Figure 13. Building Project With Code Composer Studio



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- Program the binary by using the menu Run → Debug (to run in debug mode) or by using LM FLASH Programmer. Download LM Flash Programmer from the URL: http://www.ti.com/tool/LMFLASHPROGRAMMER.
- 5. Open a terminal window (like Hyperterminal or TeraTerm) and connect to the Stellaris Virtual Serial Port COM port. This port is used as a debug terminal to show the IP address and status messages. From now on this terminal is referred to as debug terminal.
- 6. Select the Baud rate as 115200, Data Bits as 8, Parity as none, Stop bits as 1, and Flow Control as none.
- 7. Run the enet_s2e application.
- 8. A banner and status messages are printed on the debug terminal. Proceed only after the IP address is acquired and displayed on the debug terminal (see Figure 14).

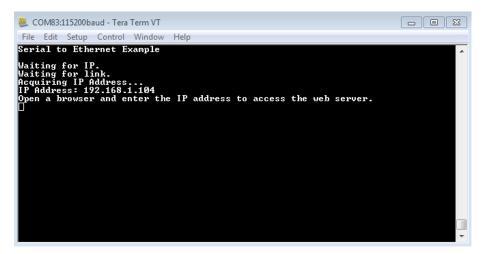


Figure 14. Debug Terminal Window While Running enet_s2e Example

- 9. Open a second terminal window and connect to the COM port associated with the port that the DB9 cable is connected to on the PC. This terminal is known as the serial terminal.
- 10. Select the Baud rate as 115200, Data Bits as 8, Parity as none, Stop bits as 1, and Flow Control as none (see Figure 15).
- 11. Open a third terminal window to connect to the TCP/IP port 23 (or telnet). This terminal is known as the telnet terminal.
- 12. Select TCP/IP. If a particular protocol is required, choose telnet. Set the Port number to 23. Set the Host IP address to the IP address shown on the debug terminal (see Figure 15).



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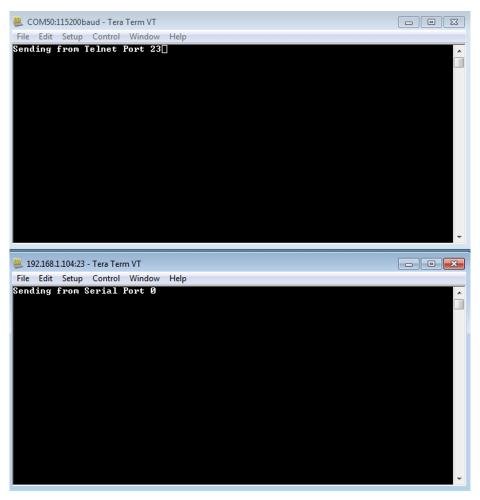


Figure 15. Serial and Telnet Terminal Windows After Data Transmission from Serial and Telnet Ports

13. Test the setup by checking if information typed on either serial or telnet terminals shows on the other terminal and vice versa. The text may not display in the transmitting window based on the terminal windows setting.



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6 Design Files

6.1 Schematics

To download the schematics for RS-232 level-shifting daughter board and EK-TM4C1294XL board, see the design files at TIDM-TM4C129XS2E.

6.2 Bill of Materials

To download the bill of materials for the RS-232 level-shifting daughter board and EK-TM4C1294XL board, see the design files at TIDM-TM4C129XS2E.

6.3 PCB Layout Recommendations

No specific layout recommendations are required for the RS-232 level-shifting daughter board.

6.3.1 Layout Prints

To download the layout prints for the RS-232 level-shifting daughter board and EK-TM4C1294XL board, see the design files at TIDM-TM4C129XS2E.

6.3.2 Altium Project

To download the Altium project files for the RS-232 level-shifting daughter board and EK-TM4C1294XL board, see the design files at TIDM-TM4C129XS2E.

6.3.3 Gerber Files

To download the Gerber files for the RS-232 level-shifting daughter board and EK-TM4C1294XL board, see the design files at TIDM-TM4C129XS2E.

7 Software Files

To download the software files for this reference design, please see the link at TIDM-TM4C129XS2E.

8 References

- 1. Texas Instruments, Stellaris® In-Circuit Debug Interface (ICDI) and Virtual COM Port Driver Installation Instructions, Driver Installation Instructions, (SPMU287)
- 2. Texas Instruments, *TivaWare™ for C Series (Complete)*, TivaWare MCU Software Folder, http://www.ti.com/tool/sw-tm4c
- 3. FreeRTOS.org[™], FreeRTOS[™]: http://www.freertos.org/
- 4. Wikia.com, IwIP Wiki, http://lwip.wikia.com/

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