TI Designs
Sub-1 GHz–Enabled IoT Node on High-Performance Microcontrollers Design Guide

TI Designs

This design shows how to create a Sub-1 GHz IoT slave node using the TM4C123 high-performance microcontroller and the CC1310 device. Sub-1 GHz node is used in home and building automation, AMT, and low-power long-range sensor applications.

Design Resources

TIDM-TM4C123XSUB1GHZ	TI Design Files
TM4C123GH6PM	Product Folder
TM4C1294NCPDT	Product Folder
SimpleLink™ CC1310	Product Folder
EK-TM4C123GXL	Tools Folder
CC1310EMK	Tools Folder
BOOST-CCEM ADAPTER	Tools Folder
CC1310DK	Tools Folder

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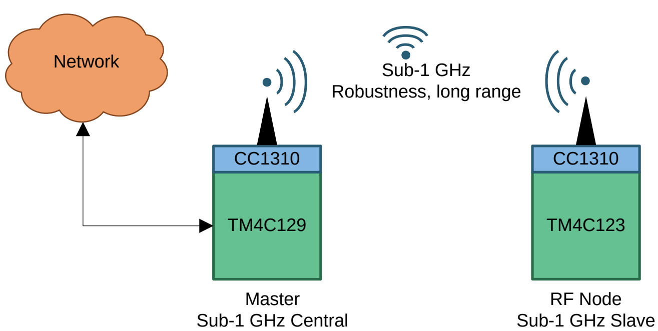
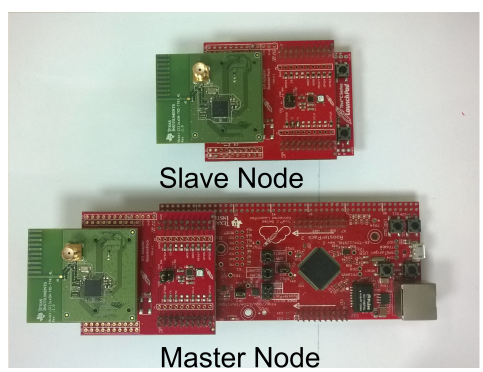
Design Features

- TM4C123 MCU With CC1310 Device is Configured as Slave Sub-1 GHz Internet of Things (IoT Node).
- TM4C1294 MCU With CC1310 Device is Configured as a Master Sub-1 GHz Device for Demonstration.
- Simple UART-Based Interface is Between the TM4C MCU and CC1310.
- AES-CCM-Based Encryption and Authentication Ensures Secure Data Communication Between IoT Node and the Master.
- The LWIP-Based Web Server Runs on the Master Side TM4C1294 MCU That Helps Control the Slave Sub-1 GHz IoT Node Operation From a Web Browser.
- Code Composer Studio™ (CCS) is Used for Development and Debugging.
- TI-RTOS is Used for Task Scheduling and Peripheral Access.

Featured Applications

- Industrial Automation and Control
- Home and Building Automation
- Smart Grid and Energy
- Long-Range Sensor Application





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1 System Description

Low-power wireless data communication has become an essential part of Internet of Things with sensors and nodes deployed in the field that must work for years powered by a single coin-cell battery. Most popular wireless protocols like *Bluetooth*® and Wi-Fi® use a 2.4-GHz radio frequency spectrum, which is overcrowded and might not give good link reliability and have limited range capability. Using Sub-1 GHz frequencies of ISM (industrial, scientific and medical) band offers reliable propagation characteristic inside buildings and is ideally suitable for applications such as smart metering, industrial lighting, and environmental controls. This reference design shows how to create a *Sub-1 GHz* IoT slave node using the TM4C123 high-performance microcontroller and the CC1310. For demonstration purposes, this reference design also consists of a *Sub-1 GHz* master node using CC1310 and TM4C129 with lwIP web server application. The software accompanying this design works on 2 different sets: one with EK-TM4C123GXL LaunchPad™ integrated with a CC1310EMK act as slave IoT node and the other with EK-TM4C1294XL LaunchPad integrated with a CC1310EMK act as master node. TI-RTOS is used for scheduling various tasks in the slave Sub-1 GHz IoT node. TI recommends using an RTOS to distribute the load and make the application scalable.

1.1 TM4C1294NCPDT

The TM4C1294NCPDT device is a 120-MHz high-performance microcontroller with 1MB of on-chip flash and 256KB of on-chip SRAM. The service features an integrated Ethernet MAC+PHY for connected applications. The device has high-bandwidth interfaces such as a memory controller and a high-speed USB2.0 digital interface. With the integration of numerous low-to-mid speed serials (up to 4 million samples per second [MSPS]), a 12-bit analog-to-digital converter (ADC), and motion control peripherals, the TM4C1294NCPDT microcontroller is ideal for use applications ranging from with industrial communication equipment applications to Smart Energy or Smart Grid applications. For more information, see Figure 1.

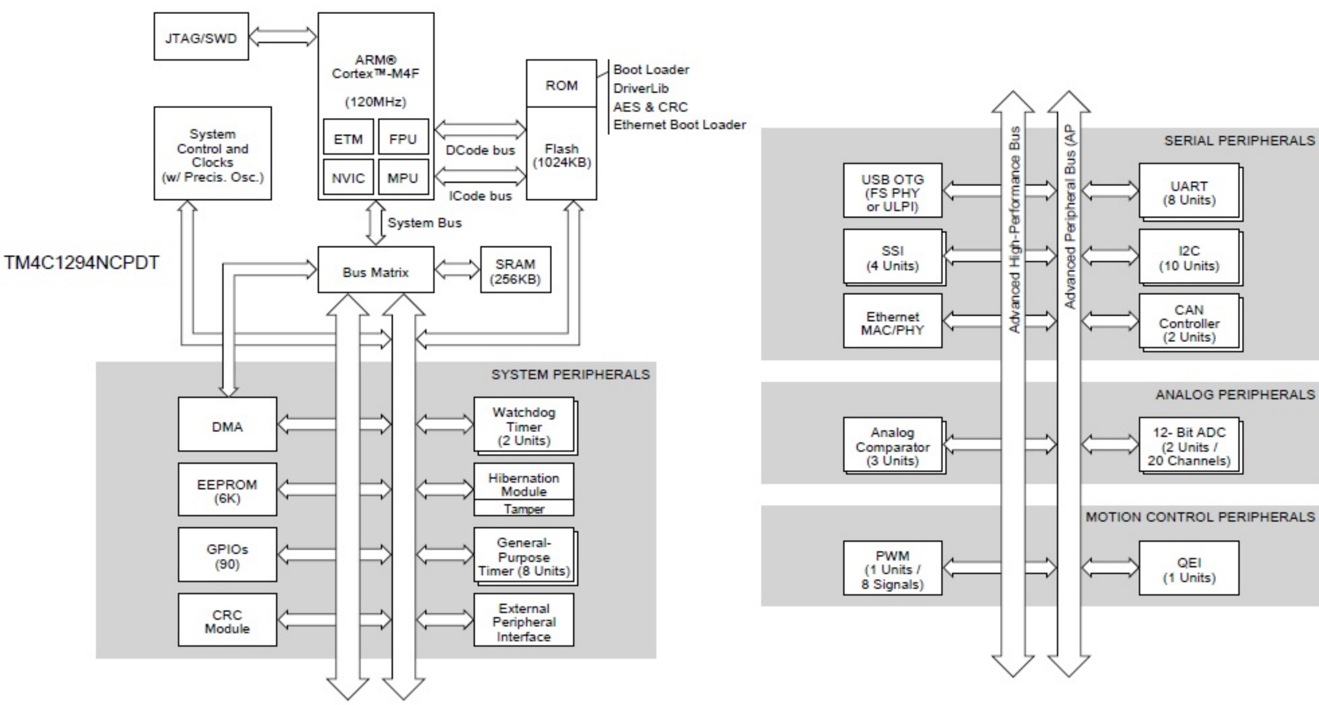

Figure 1. TM4C1294NCPDT Microcontroller High-Level Block Diagram

1.2 TM4C123GH6PM

The TM4C123GH6PGE microcontroller targets industrial applications, including the following:

- Remote monitoring
- Electronic point-of-sale (POS) machines
- Test and measurement equipment
- Network appliances and switches
- Factory automation
- HVAC and building control
- Gaming equipment
- Motion control
- Transportation
- Fire
- Security

This device has a 32-bit ARM® Cortex®-M4F 80-MHz core with a system timer (SysTick), integrated nested vectored interrupt controller (NVIC), wake-up interrupt controller (WIC) with clock gating, memory protection unit (MPU), IEEE754-compliant single-precision floating-point unit (FPU), embedded-trace macro and trace port, system-control block (SCB) and Thumb®-2 instruction set. The device also has on-chip memory, featuring 256KB of single-cycle flash up to 40 MHz (a prefetch buffer improves performance greater than 40 MHz), 32KB of single-cycle SRAM, internal ROM loaded with TivaWare™ software, and 2KB of EEPROM. For more information, see Figure 2.

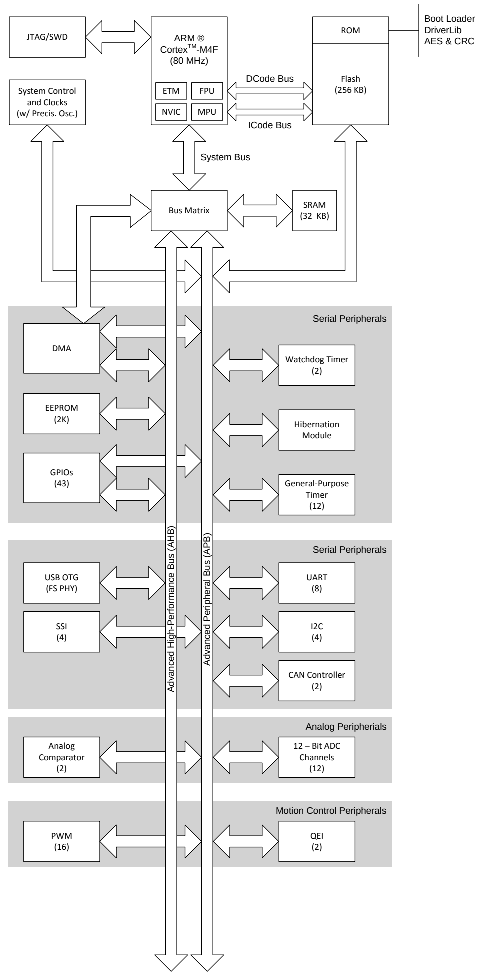

Figure 2. TM4C123GH6PM Microcontroller High-Level Block Diagram

1.3 CC1310

The CC1310 device is a member of the CC26xx and CC13xx family of cost-effective, ultra-low-power, 2.4-GHz and Sub-1 GHz RF devices. Very low-active RF, MCU current, and low-power mode current consumption provide excellent battery lifetime and allow operation on small coin-cell batteries and in energy-harvesting applications. The CC1310 device is the first part in a Sub-1 GHz family of cost-effective, ultra-low-power wireless MCUs. The CC1310 device combines a flexible, very low-power RF transceiver with a powerful 48-MHz ARM® Cortex®-M3 microcontroller in a platform supporting multiple physical layers and RF standards. A dedicated radio controller (ARM® Cortex®-M0) handles low-level RF protocol commands that are stored in ROM or RAM, ensuring ultra-low-power and flexibility.

The low-power consumption of the CC1310 device does not hinder RF performance; the CC1310 device has excellent sensitivity and robustness (selectivity and blocking) performance. The CC1310 device is a highly integrated, true single-chip solution, incorporating a complete RF system and an on-chip DC-DC converter. Sensors can be handled in a low-power manner by a dedicated autonomous ultra-low-power MCU that can be configured to handle analog and digital sensors. This configuration lets the main MCU (Cortex-M3) maximize sleep time. The CC1310 power and clock management and radio systems require specific configuration and handling by software to operate correctly. This configuraton has been implemented in the TI RTOS, and TI recommends using this software framework for all application development on the device. The complete TI-RTOS and device drivers are offered for free in source code. For more information, see Figure 3.

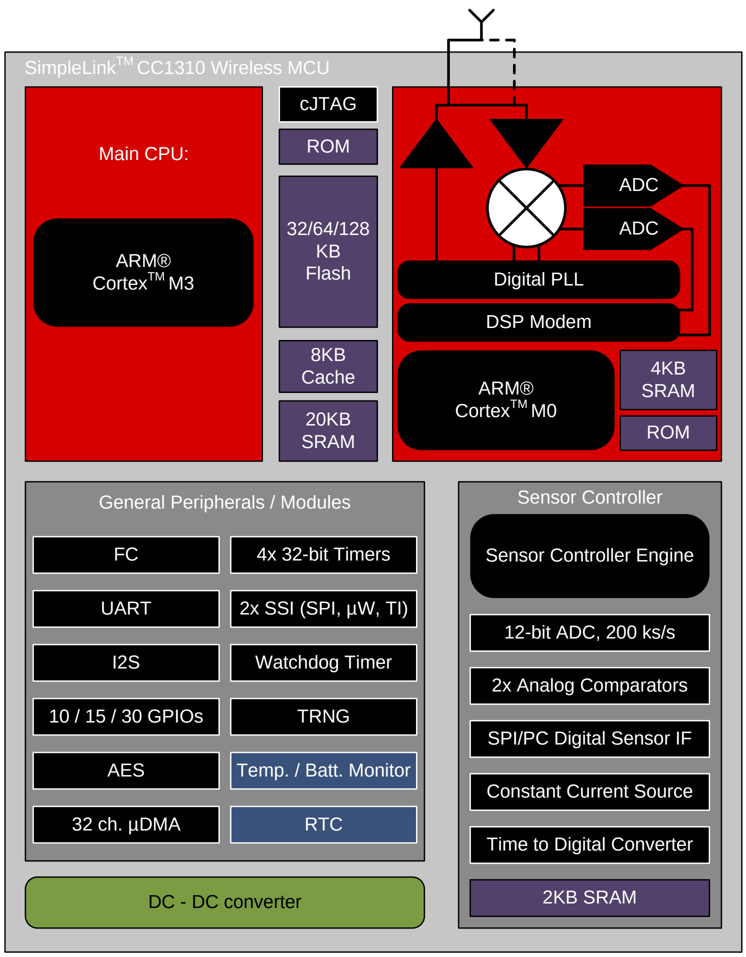

Figure 3. CC1310 Hardware Overview

1.4 TM4C129 and CC1310 Interface

Figure 4 and Figure 5 show the interface between TM4C1294 (TM4C1294 on the master side and TM4X123G on the slave side) and CC1310. TM4C1294 communicates to CC1310 through the UART. Simple command response protocol is implemented for this demo. UART0 is used in CC1310 and UART7 is used in TM4C for this demo.

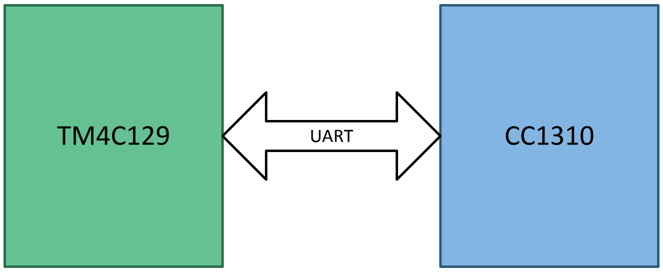

Figure 4. TM4C129–CC1310 Interface Overview

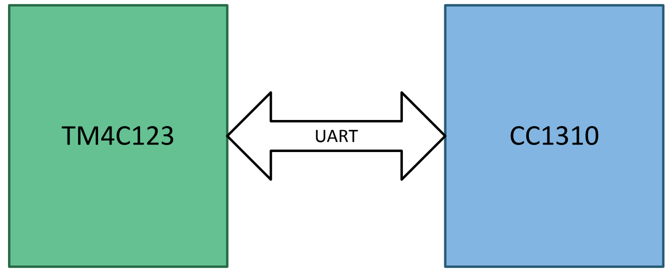

Figure 5. TM4C123–CC1310 Interface Overview

2 System Functionality Block Diagram

On the master node side, TM4C129 is connected (wired connection) to the network. It collects the commands from the web server and directs it to the CC1310 Sub-1 GHz node through UART. On the slave node side, TM4C123 receives the commands from CC13xx (commands received on the air from the master node) through UART and responds back.

For more information, see Figure 6.

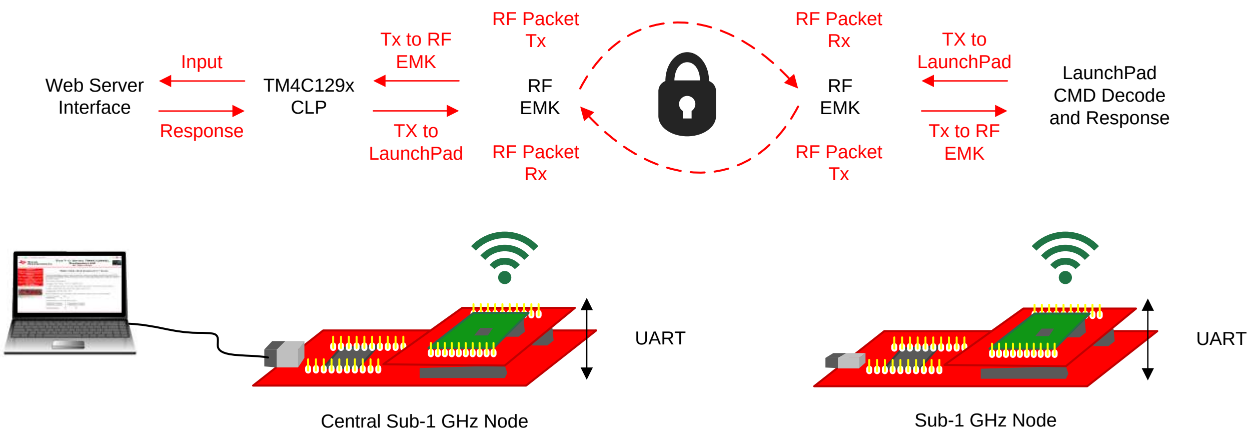

Figure 6. General Setup and Data Flow for Sub-1 GHz–Enabled IoT Node

Details on Secure Data Communication

- CCM mode (counter with CBC-MAC) is used for the authentication and encryption of the data communication between master and slave nodes.
- 128-bit keys are hardcoded in the master and slave node
- For ensuring no packet loss and interference, every data packet contains the sequence number which is encrypted along with the data.
- Encryption and decryption of data packets uses Hardware the AES-128 security module in CC1310.

2.1 Master Sub-1 GHz Node

TM4C129 performs the following tasks:

- Runs an LWIP Ethernet-based web server
- Displays an assigned IP address through UART0
- Receives user commands requested through hosted web page
- Sends user commands to the CC1310 device through the UART and waits for a response
- Responds to the web page http request for the selected demo command

CC1310 performs the following tasks:

- Waits for commands from TM4C129 through the UART
- Interacts with other Sub-1 GHz nodes depending on the requested command
- Responds back to TM4C129 with the data read from the slave TM4C123 Sub-1 GHz node
- Encrypts and decrypts data sent and received

2.2 Slave Sub-1 GHz Node

CC1310 performs the following tasks:

- Waits for the command from the Sub-1 GHz master.
- Sends user command to TM4C123 device through UART and waits for response.
- Responds back to Sub-1 GHz master.
- Encrypts and decrypts data sent and received

TM4C123 performs the following tasks:

- Receives commands from CC1310 through UART.
- Performs the task associated with the command
- Responds with the appropriate data or acknowledgment to the CC1310 through UART

3 Getting Started Hardware

For the master node, the EK-TM4C129XL connected LaunchPad and the CC1310 EMK board are used. For the slave Sub-1 GHz node EK-TM4C123GXL LaunchPad and the CC1310 EMK boards are used. The EK-TM4C129XL connected LaunchPad board is connected to the SimpleLink™ CC1310 BoosterPack™ board through the BoosterPack connector 1 and a CC BOOST interface board. The communication channel is UART in 2-pin standard mode. Table 1 lists the required signal mapping for the demo.

Table 1. Signal Mapping

BoosterPack Connector	TM4C1294 LaunchPad	CC1310EMK	EM Adapter BoosterPack
A1-1	3.3 V	3.3 V	VDD_LP
A1-2	PE4	Unused	PE4
A1-3	PC4_U7RX	IOID_2	LP1-3
A1-4	PC5_U7TX	IOID_3	LP1-4
A1-5	PC6	Unused	Unused
A1-6	PE5	Unused	Unused
A1-7	PD3_SSI2CLK	Unused	Unused
A1-8	PC7	Unused	Unused
A1-9	PB2	Unused	Unused
A1-10	PB3	Unused	Unused
D1-1	GND	GND	GND
D1-2	PM3	Unused	Unused
D1-3	PH2	Unused	Unused
D1-4	PH3	Unused	Unused
D1-5	RESET	Unused	Unused
D1-6	PD1_I2C7SDA	Unused	Unused
D1-7	PD0_I2C7SCL	Unused	Unused
D1-8	PN2	Unused	Unused
D1-9	PN3	Unused	Unused
D1-10	PP2	Unused	Unused

The EK-TM4C123GXL LaunchPad board is connected to the SimpleLink CC1310 BoosterPack board through the BoosterPack connector 1 and a CC BOOST interface board. The communication channel is UART in 2-pin standard mode, the signal mapping for the demo is illustrated in Table 2:

Table 2. Signal Mapping

BoosterPack Connector	TM4C123 LaunchPad	CC1310EMK	EM Adapter BoosterPack
A1-1	3.3 V	3.3 V	VDD_LP
A1-2	PB5	Unused	PE4
A1-3	PB0_U1RX	IOID_2	LP1-3
A1-4	PB1_U1TX	IOID_3	LP1-4
A1-5	PE4	Unused	Unused
A1-6	PE5	Unused	Unused
A1-7	PB4	Unused	Unused
A1-8	PA5	Unused	Unused
A1-9	PA6	Unused	Unused
A1-10	PA7	Unused	Unused
D1-1	GND	GND	GND
D1-2	PB2	Unused	Unused
D1-3	PE0	Unused	Unused
D1-4	PF0	Unused	Unused
D1-5	RESET	Unused	Unused
D1-6	PB7	Unused	Unused
D1-7	PB6	Unused	Unused
D1-8	PA4	Unused	Unused
D1-9	PA3	Unused	Unused
D1-10	PA2	Unused	Unused

4 Getting Started Software

4.1 Software Architecture -–TM4C Sub-1 GHz Master

Figure 7 shows the architecture of the TM4C129 Sub-1 GHz master node.

TM4C129 software blocks

- TivaWare C—Used for TM4C hardware register access and UART communication
- LWIP Ethernet stack for web server
- Demo packet handler
  – Converts http request to UART demo commands

CC1310 software blocks

- TI RTOS—Used for general scheduling
  – Task for demo command and response over UART
  – Task for performing RF operations
- CC13xxWare—Used for CC1310 hardware access and UART operation
- EasyLink API—Abstraction layer on top of the CC13xx RF driver

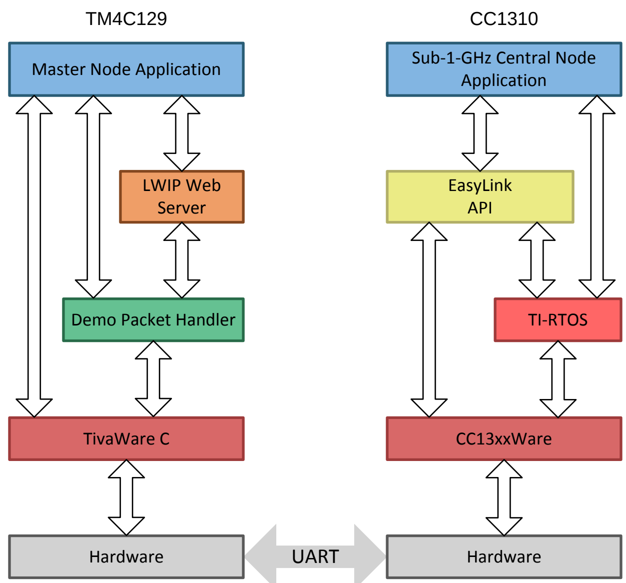

Figure 7. TM4C Sub-1 GHz Master Architecture Block Diagram

4.2 Software Architecture – TM4C Sub-1 GHz Slave

Figure 8 shows the architecture of the TM4C123 Sub-1 GHz slave node.

CC1310 software blocks

- TI RTOS—Used for general scheduling
  - Task for demo command and response over UART
  - Task for performing RF operations
- CC13xxWare—Used for CC1310 hardware access and UART operation
- EasyLink API—Abstraction layer on top of the CC13xx RF driver

TM4C123 Software Blocks

- TI RTOS—Used for general scheduling
  - Task for demo command and response over UART
  - Task for performing demo application that performs LED control, temperature, button counts, and so forth
- TivaWare C—Used for TM4C hardware register access and UART communication
- Demo packet handler
  - Decodes UART-based demo commands to demo tasks

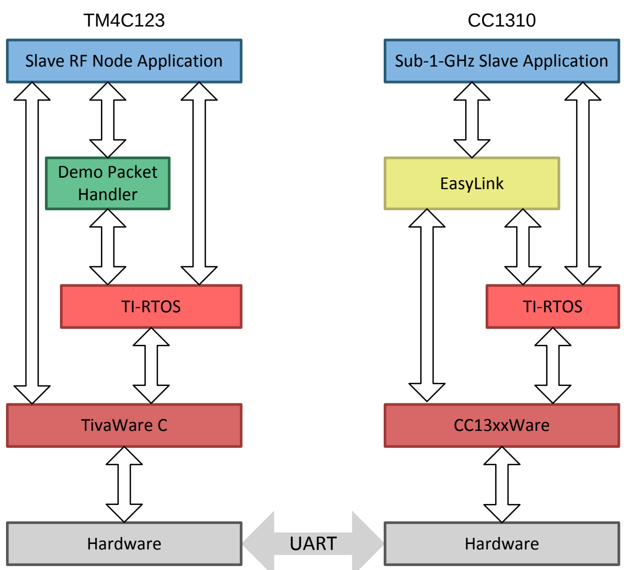

Figure 8. TM4C Sub-1 GHz Slave Architecture Block Diagram

The following TI-RTOS functions are statically configured in the TI-RTOS configuration file:

TM4C

- ledAnimationClock: Function controls LED animation.
- updateTempClock: Function updates the temperature value every second.
- updateButtonCountclock: Function updates button press status every 10 ms
- cmdReceived_sem: Semaphore waits until the demo command is received.
- cmdResponse_sem: Semaphore waits until the demo response is ready.
- Task_ uartCommand: Function transmits UART command receive and response.
- Task_ demoRFnode: Function performs demo applications like LED control, temperature, update button counts, and so forth.

5 Software Setup

These tools and software packages are required to build and work on the demo:

- CCS
- TivaWare_C v2.1.1.71
- TI RTOS for CC21310 v2_14_03_28 (CC13xxWare is included.)
- TI RTOS for Tiva v2.14.0.10

NOTE: The software versions listed above were used in the development of this design and tested for proper operation. TI does not recommend using any other software version in the building of this design package because it can cause incompatibilities.

TI recommends installing these packages in the default location under C:\ti to avoid making any changes in the CCS project. When the previous tools are installed, follow these steps:

1. Unzip the software release zip file.
2. Place the extracted CC13xx_Master, CC13xx_Slave, TM4C_Sub1GHz_Master, and TM4C_Sub1GHz_Node directories in your workspace (see Figure 9).

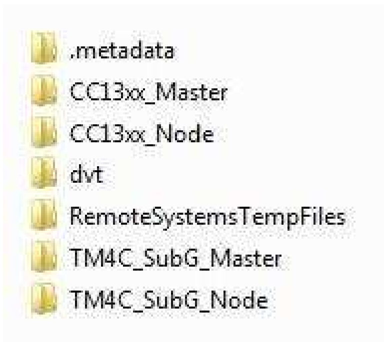

Figure 9. CCS Workspace

3. Import all projects into CCS (see Figure 10).

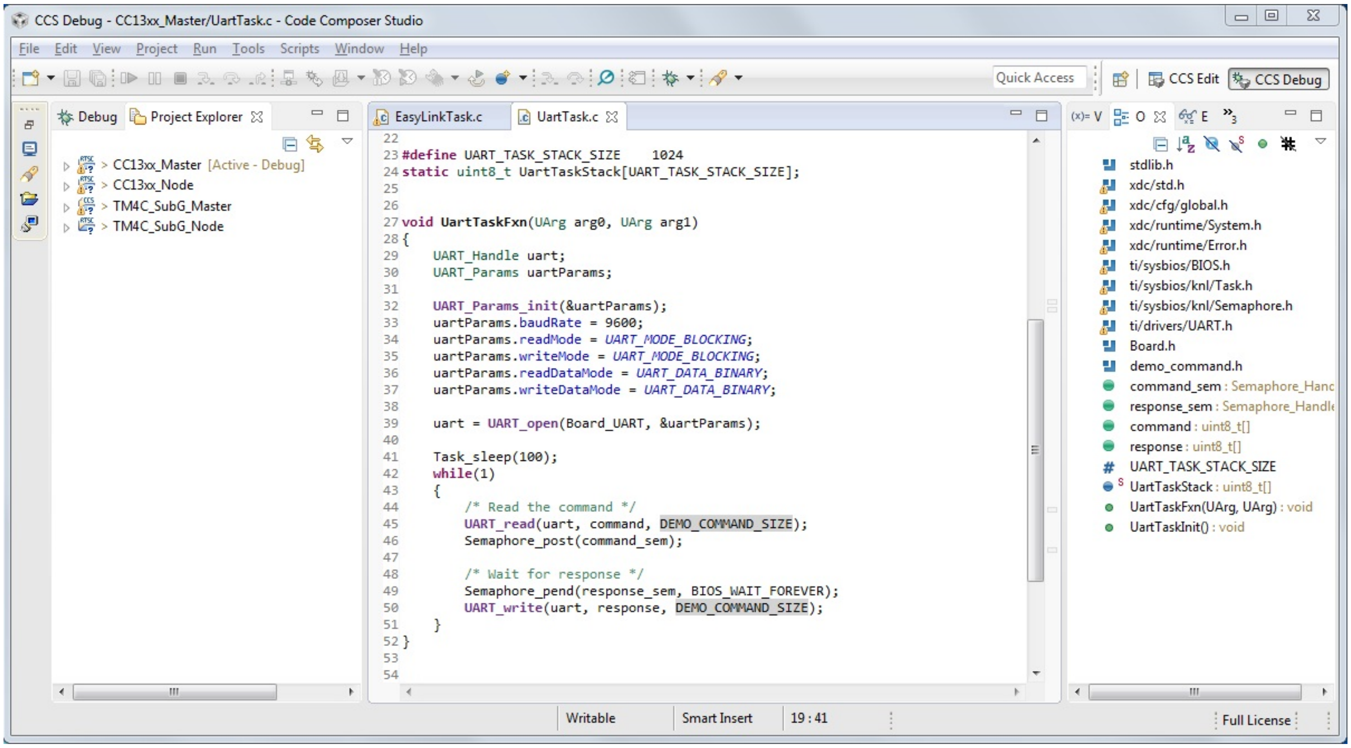

Figure 10. CCS Projects

4. Check the *Path Variables* in *Linked Resources* to confirm those correspond to the folders in the setup.

5. Check the TI-RTOS version and platform selection (see Figure 11 and Figure 12).

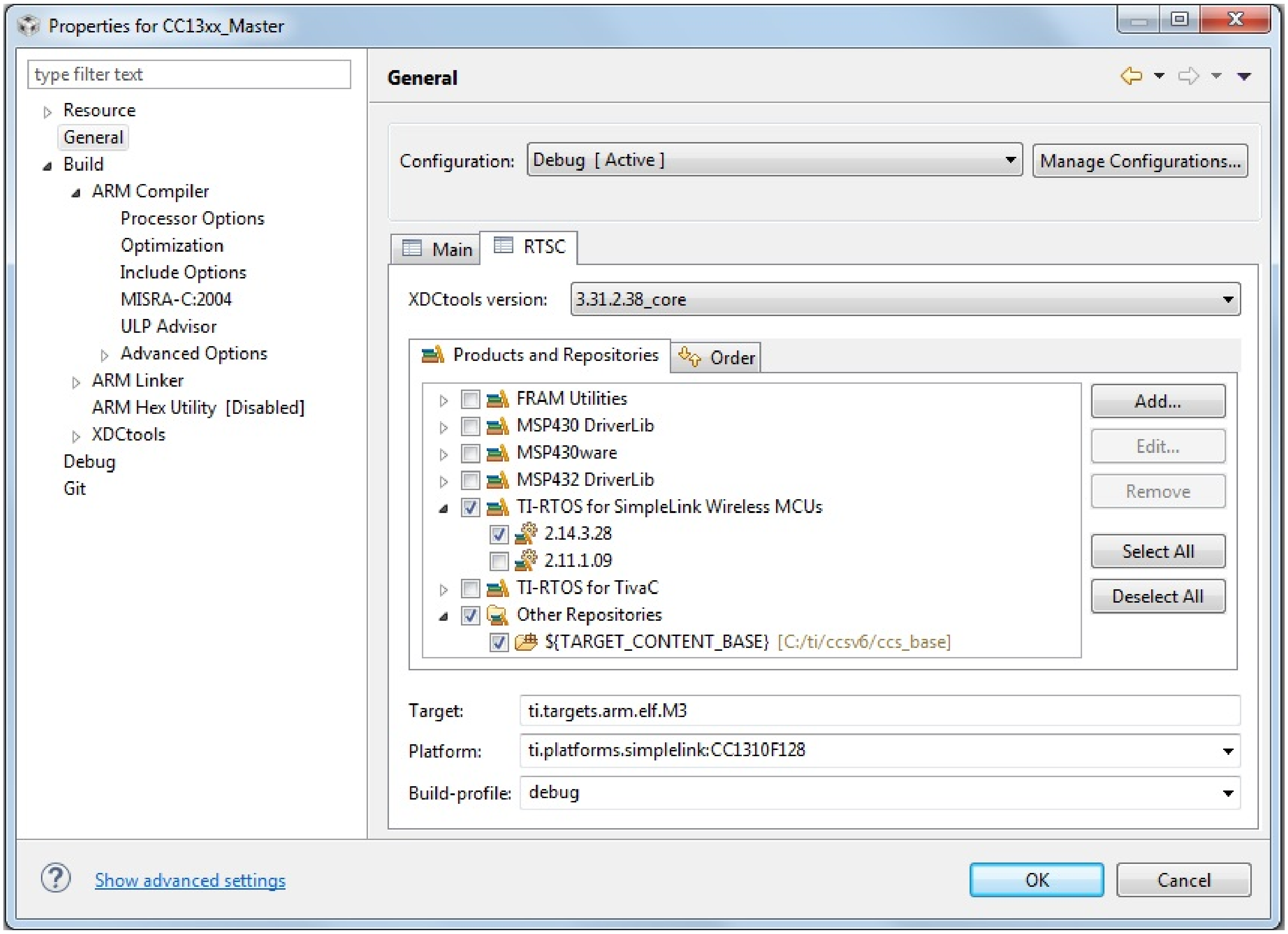

Figure 11. TI-RTOS Product Selection—CC2650

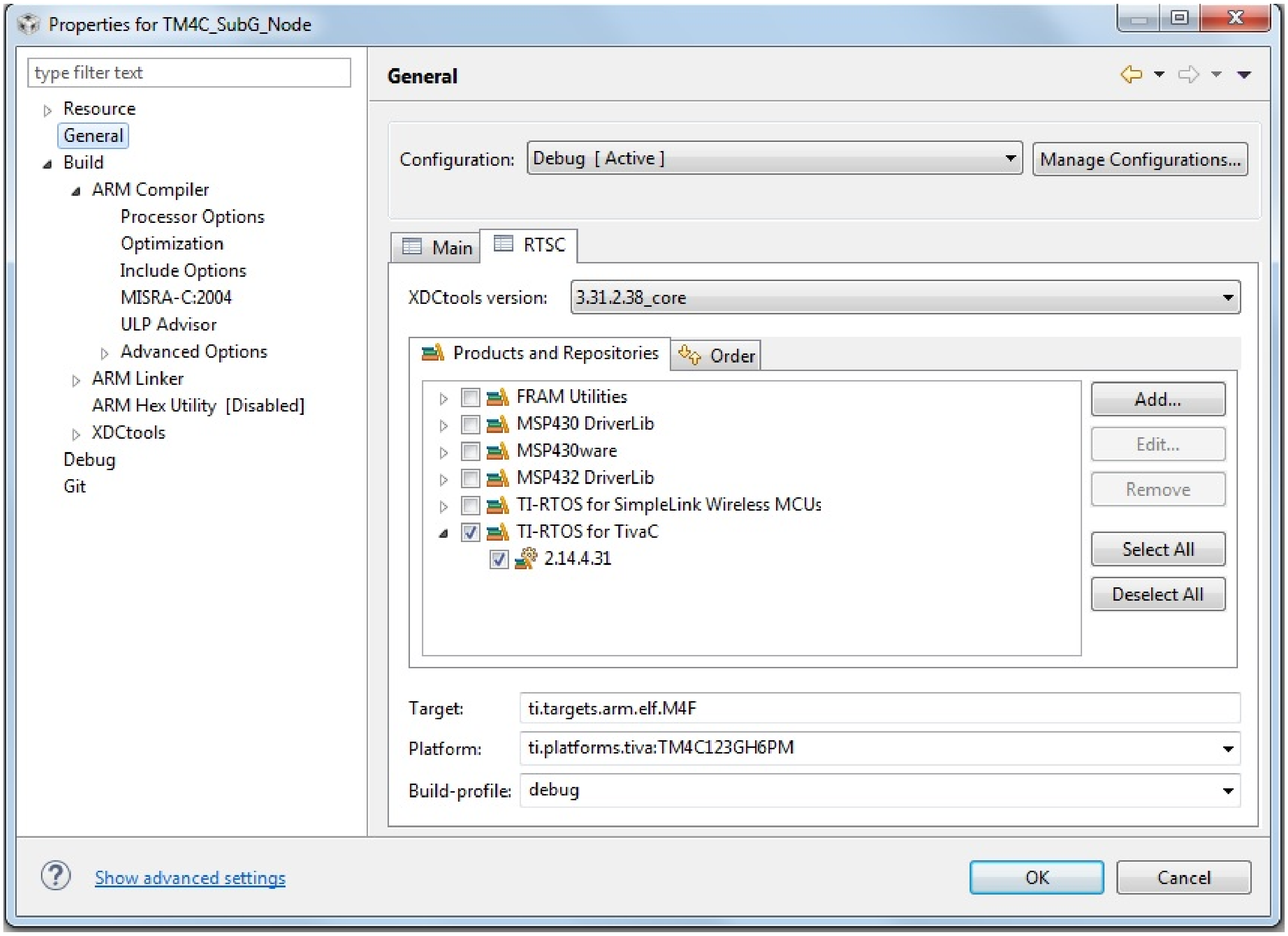

Figure 12. TI-RTOS Product Selection—TM4C Slave

6. Run the following demo files:
   - TM4C
     – Wired master – TM4C_SubG_Master.out
     – RF node slave – TM4C_SubG_Node.out
   - CC1310
     – Master – CC13xx_Master.out
     – Slave RF node – CC13xx_Slave.out

6 Demo Execution

6.1 Debug Port Setup for TM4C Wired Master Device

To debug the port setup, do as follows:

1. Open a terminal window (like HyperTerminal or TeraTerm).
2. Connect to the Stellaris virtual serial port COM port corresponding to the TM4C-wired master device.
3. Set the baud rate as 9600, data bits to 8, parity to none, stop bits to 1, and flow control to none.

   When the Ethernet cable is connected to the TM4C-wired master device, the IP address is acquired and displayed on the debug terminal (see Figure 13).

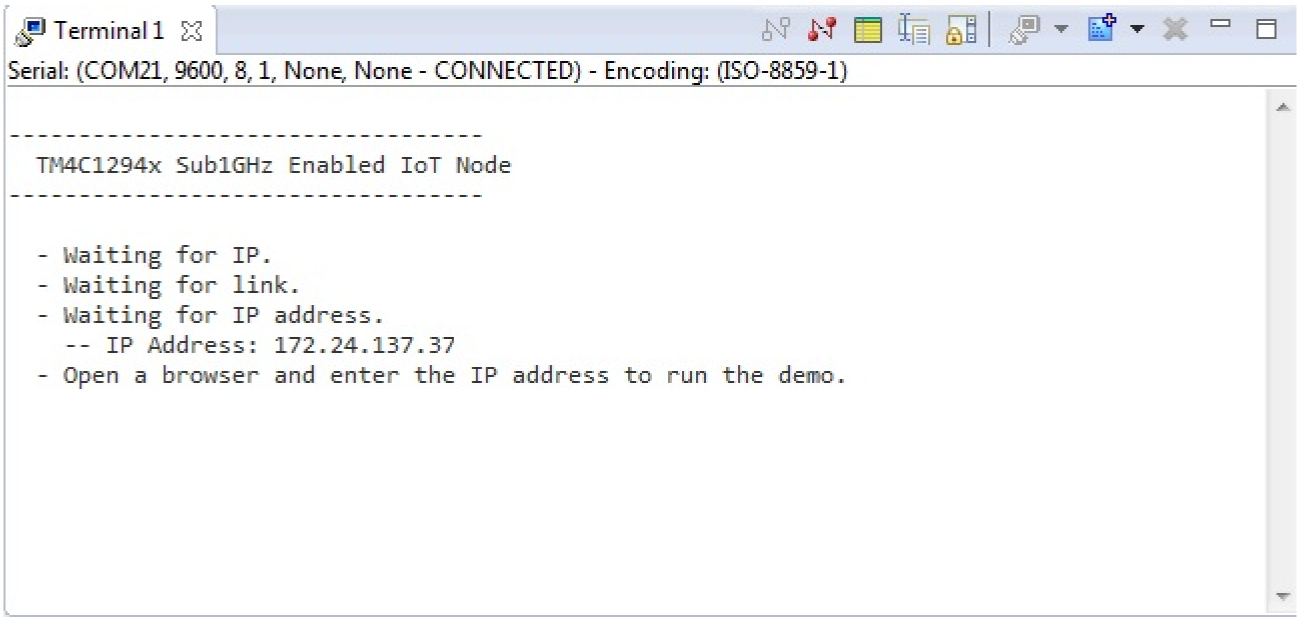

Figure 13. COM Port Snapshot for IP Address

The Ethernet cable can be connected directly to the PC or LAN. If connected directly to PC, the IP address is locally assigned by the TM4C, which can be used for the demo.

6.2 Running the Demo on the Web Page

To run the demo, on the web page, do as follows:

1. Power on the Slave node.
2. Open a web browser and enter the assigned IP address to open the web page from a PC connected to the same network as the master node.
3. Press Connect and wait until status displays as CONNECTED (this can take 8 seconds).
4. Run Demo 1: Toggle LED
   - Pressing Toggle LED toggles the LED1 on the slave TM4C-connected LaunchPad.
5. Run Demo 2: LED Animation
   - Controls the LED animation speed on the slave TM4C. 0% is 1 s and 100% is 20 ms.
6. Run Demo 3: Get and Clear Button Press Count
   - Get Button 1 Count displays press count of button SW1 on the slave TM4C board.
   - Clear Button 1 Count clears press count of button SW1 on the slave TM4C board.
   - Get Button 2 Count displays press count of button SW2 on the slave TM4C board.
   - Clear Button 2 Count clears press count of button SW2 on the slave TM4C board.

7. Run Demo 4: Get Temperature (see Figure 14).
   - Get Temperature gives the device junction temperature of the slave TM4C microcontroller.

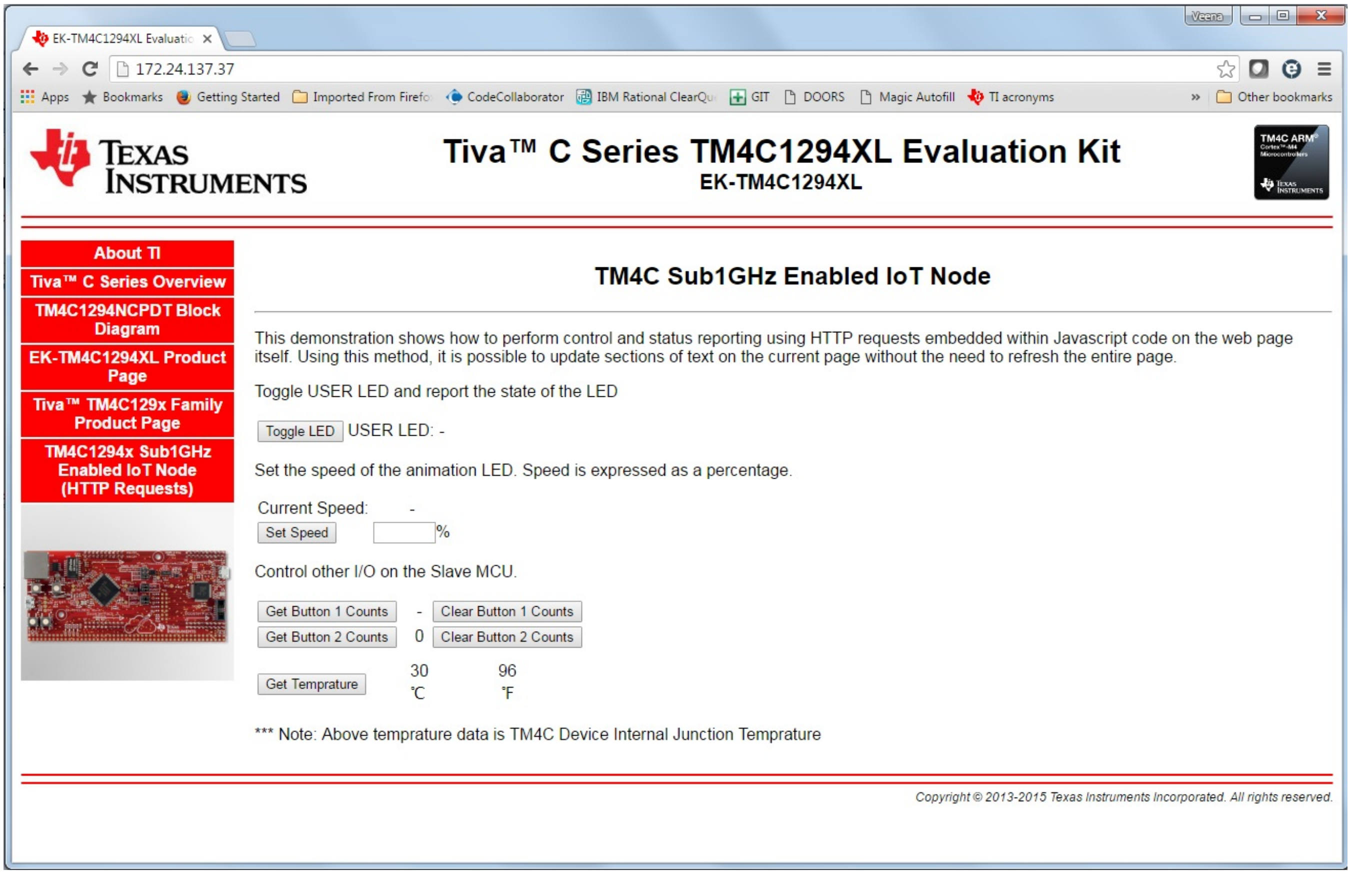

Figure 14. Demo Web Page Snapshot

Resources

To download the resource files like BOM, schematics, gerber files, design files, software for this reference design, see http://www.ti.com/tool/TIDM-TM4C123XSUB1GHZ.

7 References

- *TivaWare for C Series* tool page, http://www.ti.com/tool/SW-TM4C
- *Stellaris In-Circuit Debug Interface (ICDI) and Virtual COM Port Driver Installation Instructions* (SPMU287)
- *TI RTOS* tool page, http://www.ti.com/tool/ti-rtos
- *EK-TM4C1294XL LaunchPad* tool page, http://www.ti.com/tool/ek-tm4c1294xl
- *EK-TM4C123GXL LaunchPad* tool page, http://www.ti.com/tool/ek-tm4c123gxl
- *CC1310 Development Kit* tool page, http://www.ti.com/tool/cc1310dk
- *EM Adapter BoosterPack* tool page, http://www.ti.com/tool/boost-ccemadapter

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