

AN1921

Microchip TCP/IP Lite Stack

Authors: Janaki Kuruganti, Alin Stoicescu, Marius Cristea, Microchip Technology Inc.

INTRODUCTION

This application note describes the structure and the interface for the Microchip Transmission Control Protocol/Internet Protocol (TCP/IP) Lite Stack library, and includes some simple example applications using MPLAB[®] Code Configurator (MCC). The purpose of the implementation is to provide an optimized (low Flash and RAM footprint) TCP/IP stack for microcontrollers with ≥ 8 KB Flash (UDP only) and ≥ 16

KB Flash (TCP/IP), while still having a fully functional TCP/IPv4 stack. The stack will allow users to add wired communication and interoperability with other systems to their applications over Ethernet.

The Microchip TCP/IP Lite Stack is implemented in a configurable and modular way, allowing users to include only the intended features or functionalities to their application. The stack is written in C programming language and it is intended to be compiled with the MPLAB[®] XC8 compiler.

TCP/IP STACK ARCHITECTURE

The TCP/IP Lite library implementation is based on the TCP/IP communication model, as shown in Figure 1:



FIGURE 1: MULTILAYER TCP/IP COMMUNICATION MODEL

The TCP/IP stack is divided into multiple layers (Figure 1). Each layer in the Microchip TCP/IP Lite Stack can directly access one or more layers situated above or below it.

The TCP/IP stack needs a background task called periodically by the user, in order to handle asynchronous events like managing a timeout, checking the status for the Ethernet controller, and parsing the received buffers.

The code implementing each protocol resides in separate source files, while the services and the Application Programming Interfaces (APIs) are defined through header or include files.

Stack Configuration

TCP/IP Lite stack is scalable (i.e., the user can configure the protocols as per application requirements). MCC gives the user the flexibility to choose and to generate code only for the needed protocols. Apart from the protocol selection, users also have the option of configuring the stack parameters using MCC. These stack parameters reside in the tcpip_config.h file as part of MCC code generation.

Some important configurations include:

1. dhcpName:

Used by the DHCP server to assign a human readable name to a MAC address. The default value is the device name ETHERNET, for example: "PIC16F18346 ETHERNET".

2. ARP_MAP_SIZE:

This refers to the maximum size of the Address Resolution Protocol (ARP) table. The default value is 8.

- 3. IP address, Subnet Mask, Default Gateway, Preferred and Alternate DNS Server addresses, in case of static IP address
- 4. For ICMP, there is an option to generate Echo Response and Port Unreachable messages.

TCP/IP STACK BUFFER MANAGEMENT

Overview

The TCP/IP stack uses by default the least possible memory, so that users have the maximum possible memory available to be allocated for their applications. In order to achieve this, users are responsible for providing all the buffers required for each TCP/IP protocol/connection, as described further on.

The Ethernet controller receives and stores multiple packets until the TCP/IP stack can process them. The buffer for each received packet is managed by the Ethernet controller automatically and a buffer descriptor is available for the user. The Ethernet controller starts dropping the received packets if it does not have enough memory left to store the incoming packets.

Ethernet packets to be transmitted are also built and kept in the Ethernet controller's memory.

Buffers Used by the UDP Protocol

The stack allows the user to directly store the payload in the Ethernet controller's RAM. The user will call the API to start a UDP packet, transfer the payload and send the packet.

When receiving data over the UDP protocol, the Ethernet controller manages the received packet buffer. If the packet was received successfully and there is a user callback registered for the incoming port, the stack calls the registered function (callback) and gives the user the opportunity to access the payload directly from the Ethernet controller. This avoids copying the payload multiple times and saves time and memory.

Buffers Used by the TCP Protocol

In case of TCP, the user needs to allocate some memory for each TCP connection. There are a few types of buffers needed by the TCP:

- The Socket Memory
 - Memory allocation for each socket is the user's responsibility. This can be done by calling an API, especially designed for this purpose. This is where all the internal information about the TCP connection is kept.
- The Rx and Tx Buffers
 - The receive (Rx) and the transmit (Tx) buffers for each TCP connection are to be created by the user and passed to the stack via the stack API. Each socket can have only one Rx and one Tx buffer at a time. The stack always needs one Rx buffer available to receive data from the remote host. The stack functions only for a short period of time without the Rx buffer, before asking for packet retransmission.

TCP/IP Stack Features and Limitations

The TCP/IP stack has some limitations based on the limited memory, for both RAM and Flash, available to run on constrained devices like 8-bit microcontrollers. To find information about the current features and limitations of the stack, refer to MCC's TCP/IP Lite library release notes.

RUNNING THE TCP/IP STACK DEMOS

Required Hardware and Software to Run the Demo

- 1. Curiosity Development Board (DM164137)
- 2. PIC16F18346 MCU
- 3. USB Power Supply
- 4. MPLAB[®] X v3.45 or later
- 5. XC8 v1.41 C compiler or later
- 6. Computer with Windows, Linux or MAC OS
- 7. TCP/IP Demo Application
- 8. Ethernet ENC28J60 Click Board (ETH Click)
- 9. Packet Sender Application (to send and receive UDP/TCP packets). Download the application at https://packetsender.com/.
- DHCP Server (without it the board cannot retrieve an IP address and the UDP demo will not work). The TCP Demo works with static IP address configuration.
- 11. Ethernet cables:
 - Straight-through if the board will be connected to a router/switch
 - Crossover if the board will be connected to the computer directly

Setting up the Hardware

- 1. Connect the ETH click board to the Curiosity Development board (connector J35).
- Connect the ENC28J60 to an Ethernet network using an Ethernet cable (it can be connected directly to the Ethernet port of a PC). The board must be able to connect to a running DHCP server for the UDP demo.
- 3. Connect the USB power supply to the Curiosity Development board using the J2 connector.
- 4. For each application the user should follow the steps presented in the setup chapter related to each demo.

SETUP THE SOFTWARE FOR TCP CLIENT/SERVER DEMO USING MCC

In order to create an application using TCP the user should configure the TCP/IP Lite module, available through MCC, as shown below:

- 1. Start MPLAB X and create a new project for the PIC16F18346 device. (This demo uses PIC16F18346, but any 8-bit MCU can be utilized instead.)
- 2. Open MCC.
- From <u>Device Resources → Libraries</u>, double click on the TCP/IP Lite module, as shown in Figure 2:





- 4. A TCP Application requires some changes to the TCP/IP module, as illustrated in Figure 3:
 - UDP not checked
 - DHCP not checked. The user must provide its own static IP configuration
 - TCP checked

FIGURE 3: STACK CONFIGURATION

ર@3 Easy Setup 🛛 🔼 N	otifications : 3		
Microchip Lightweight	TCPIP Stack		
	P IPV4 TCP V ICMP V ARE	TFTP NTP	DNS
▼ TCP			
Nothing to Configu	re		
▼ ICMP			
The center Response			
▼ IPV4 IP Address	192.168.0.1		
IPV4 IP Address Subnet Mask	192.168.0.1 255.255.255.0		
IPV4 IP Address Subnet Mask Default Gateway	192.168.0.1 255.255.255.0 192.168.0.0		-
IPV4 IP Address Subnet Mask Default Gateway Preferred DNS Server	192.168.0.1 255.255.255.0 192.168.0.0		
IPV4 IP Address Subnet Mask Default Gateway Preferred DNS Server Alternate DNS Server	192.168.0.1 255.255.255.0 192.168.0.0 ###,###,###,### ###,###,###,###		
IPV4 IP Address Subnet Mask Default Gateway Preferred DNS Server Alternate DNS Server ARP	192.168.0.1 255.255.255.0 192.168.0.0 ###,###,###,### ###,###,###.###		

- 5. The **Notifications** tab shows different types of messages (Figure 4).
 - "WARNING" messages are required to be addressed to generate an error free code
 - "HINT" messages help the user follow the code generation
 - "INFO" messages allow the user to give information about the loaded modules

The **Notifications** tab shows all the dependencies of the TCP/IP stack.

FIGURE 4: NOTIFICATIONS TAB

TCP/IP Lite								
(응) Easy Setup 🔥 Notifications : 3								
Category	Module Name	Туре	Description					
1	TCP/IP Lite	HINT	Add Network_Manage() in the main while loop					
1	TCP/IP Lite	WARNING	Configure MAC under Ethernet Library for TCP/IP Lite					
1	TCP/IP Lite	WARNING	Configure Timer1 to serve as RTCC for TCP/IP Lite					

- 6. TCP/IP Lite module requires the Ethernet MAC library and Timer1 module, as indicated in Figure 5.
 - From <u>Device Resources</u> → <u>Libraries</u> → <u>Ethernet</u>, double click on MAC
 From <u>Device Resources</u> → <u>Peripherals</u> → <u>Timer</u>, double click on TMR1

FIGURE 5:	STACK DEPENDENCIES
	SELECTION



- The device needs to be configured with a 1s tick of system clock. The user shall configure the Timer1 as shown in Figure 6 below:
 - Timer Period 250 ms
 - Enable Timer Interrupt Checked
 - Callback Function Rate 4

FIGURE 6: TIMER CONFIGURATION

		5:0				
dware Settings						
Enable Timer						
mer Clock			Timer Period			
lock Source	FOSC/4	•	Timer Period 4 us ≤	250 ms	≤ 262.144 ms	
ternal Frequency	32.768 k	Hz	Period count 0x0 ≤	0xBDC	≤ 0xFFFF	
rescaler	1:1	-	Calculated Period	250 ms		
/ Enable Synchronizatio	n		Enable Gate			
Enable Oscillator Circu	lit		Enable Gate Toggle	Gate Signal Source	TIG	*
			Enable Gate Single-Pulse mode	Gate Polarity	low	*
Enable Timer Interrupt]					
Enable Timer Gate Interr	rupt					
ware Settings						

- 8. Below are the steps required to configure the Ethernet MAC module (Figure 7):
 - In the Easy Setup window, the user should select the ENC28J60 controller from the drop down selection box. The ENC28J60 controller is based on the Serial Peripheral Interface. The Curiosity Development board (DM164137) supports the MSSP1 – SPI module interface on the J35 connector.

FIGURE 7: MAC LIBRARY CONFIGURATION

Media Access Co	ontroller	
ENC28J60	-	
02:00:00:00:00:	01	

- 9. The user shall add the MSSP1 module, as shown in Figure 8:
 - From <u>Device Resources → Peripherals →</u> <u>MSSP</u>, double click on MSSP1

FIGURE 8: MAC LIBRARY DEPENDENCY SELECTION



- 10. Steps required to configure MSSP1 module are shown in Figure 9:
 - Mode SPI Master
 - Input Data Sampled at End
 - Clock Edge Active to Idle

FIGURE 9: SPI CONFIGURATION

lware Settings				
de SPI Master	•			
Enable MSSP				
ut Data Sampled at	End 💌			
PI Mode		1]	
Clock Polarity Idle:L	ow, Active:High	•		
Clock Edge Activ	e to Idie	-	8	
PI Mode 0				
PI Clock			-	
Clock Source	FOSC/4		*	
Clock Divider 0x00 ≤	0x0			≤ 0xFF
FI Clock	250.0 kHz			

- 11. The user shall use the ADC module to send the potentiometer data over TCP, as shown in Figure 10.
 - From <u>Device Resources → Peripherals →</u> <u>ADC</u>, double click on ADC

FIGURE 10: ADC MODULE SELECTION



- 12. The ADC module should be configured (Figure 11) with:
 - Clock Source Fosc/4Result Alignment Right

	gisters 🛛 🔔 Notification			
dware Settings				
Enable ADC				
DC Clock		Result Alignment	right	-
lock Source	FOSC/4 👻	Positive Reference	VDD	-
		Negative Reference	VSS	-
TAD	4.0 us	2004075002000000000000000000000000000000		
TAD ampling Frequency conversion Time	4.0 us 21.7391 kHz = 11.5 * TAD = 46.0	Auto-conversion Trigger	no_auto_trigger	-
TAD ampling Frequency Conversion Time Enable ADC Interru elected Channels	4.0 us 21.7391 kHz = 11.5 * TAD = 46.0 pt	Auto-conversion Trigger	no_auto_trigger	•
TAD ampling Frequency conversion Time Enable ADC Interru elected Channels Pin	4.0 us 21.7391 kHz = 11.5 * TAD = 46.0 pt Channel	Auto-conversion Trigger	no_auto_trigger	•
TAD ampling Frequency conversion Time Enable ADC Interru elected Channels Pin Internal Channel	4.0 us 21.7391 kHz = 11.5 * TAD = 46.0 pt Channel Temp	Auto-conversion Trigger	no_auto_trigger	•
TAD ampling Frequency conversion Time Enable ADC Interru elected Channels Pin Internal Channel Internal Channel	4.0 us 21.7391 kHz = 11.5 * TAD = 46.0 pt Channel Temp FVR	Auto-conversion Trigger Cu channel_Temp channel_FVR	no_auto_trigger	•
TAD ampling Frequency onversion Time Enable ADC Interru elected Channels Pin Internal Channel Internal Channel Internal Channel	4.0 us 21.7391 kHz = 11.5 * TAD = 46.0 pt Channel Temp FVR DAC1	Auto-conversion Trigger Cu channel_Temp channel_FVR channel_DAC1	no_auto_trigger	•

- Steps required to configure the Pin Manager (Figure 12):
- MSSP1 module Pin configuration:
 - SCK1 output Port RB6
 - SDI1 input Port RB4
- SDO1 output Port RC7
- MAC module Pin configuration
 - ETH_CS for the ENC28J60 controller output Port RC6
- ADC module Pin configuration:
 - ANx input Port RC0
 - From <u>Project Resources → System → Pin</u> <u>Module</u>, the user can provide a custom name to the AN0 channel ex: Pot

Pin Module	ii.																										0	
👸 Easy Setup	Reg	isters	A Notifications	: 6																								
Selected Package	: UQFN20		50																									
Pin Name 🔺	Mo	dule	Function		Cust	om I	Vame	2	Sta	rt Hig	gh		Ana	alog			Out	put		1	WPU	10 10		(DD		IO	C
RA5	Pin Mod	lule	GPIO		Тод	gle_L	ed		[V	/			\checkmark]									none	•
RB4	MSSP1		SDI1						[]									none	*
RB6	MSSP1		SCK1						[\checkmark]									none	*
RC0	ADC		ANC0	ſ	Pot								V	7]									none	-
RC6	MAC		ETH_CS						[-				-				1					-	Ē	7	_	none	+
			C-Str.	_				-		_			-					1	_				-		_			
RC7	MSSP1		SDO1										V	4			\checkmark										none	*
Output Sear	ch Result	ts P	'in Manager: Gri	d [MC	C] 8	8																						
Package:	UQFN20	-	Pin No:	16	15	14	1	20	19	10	9	8	7	13	12	11	4	3	2	5	6							
					-	Por	t A 🔻				Port	в					Por	t C 🔻		-	-							
Module	Fu	nction	Direction	0	1	2	3	4	5	4	5	6	7	0	1	2	3	4	5	6	7							
	ANx		input	10	6	6		6	ì	î.	ì a	1	Ъ	â	Ъ	6	î.	î.	î.	6	ĵ,							
ADC 🔻	VREF+		input		î.							(1															
	VREF-	1	input			Ъ						1																
MAC	ETH_C	s	output	1	î.	î.	3.	6	î	î	1	1	î.	6	î.	î.	î	î	î.	â	n.							
	SCK1		in/out	6	ì	ì		6	î	î	î.	â	î.	6	î	î.	ì	î	î.	ì	î.							
MSSP1 🔻	SDI1		input	1	î.	6	3	6	î	â	î.	6	ĵ.	6	î.	î.	î	î	î.	î.	î.							
	SDO1		output	1	î.	î.		1	î	ì	6	ì	î.	6	î.	6	î.	î	î.	6	â							
	CLKIN		input						Ъ													ľ						
	CLKOU	л	output	(1				ĺ.								Ĩ.	1							
	OSC1	1	input		1				î.			ſ								1	1							
OSC V	OSC2		input	1				1																				
	SOSCI		input	1					ì			0								1								
	sosco)	output					î.																				
	GPIO		input	1	1	6	ીસ	Ъ	1	1	6	1	1	6	1	1	î.	1	6	6	1							
Pin Module V	GPIO		output	1	6	2	3	2	ô	12	2	1	1	2	2	2	6	2	2	2	6	1						
RESET	MCLR		input				â		-	1																		
	T1CKI		input	1	ì	6	30	1	1	1	1	1	1	6	1	6	ì	1	6	6	1							
TMR1 V	T1G		input	2	2	2	3-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1						

FIGURE 12: PIN FUNCTIONS AND NAMES

14. All the required configurations were made and the user can click the **Generate** button.

- Configure Pin Manager for LED on Curiosity board
 - Pin module output Port RA5
 - From <u>Project Resources → System → Pin</u> <u>Module</u>, the user can provide a custom name to the RA5 Pin ex: Toggle_Led

SIMPLE TCP CLIENT DEMO IMPLEMENTATION

Overview

This is a simple TCP client implementation that will connect to a server that runs on a computer on port 60. The user needs to modify the server IP address in the firmware. Once the connection is established, the client will send status packets to the server every 2 seconds. The packets sent by the client contain potentiometer value and LED status. From the server, the user can also turn the LED on or off on the board, using the GUI push buttons. In this demo any button will trigger the same LED.

For this demo there is only one active connection implemented, but the TCP/IP stack supports multiple TCP connections on the same board. For each new connection the user needs to create a new socket, an Rx buffer, and try to connect to the server. This demo has been set up to run on the Curiosity board.

The TCP Client demo will try to connect to the server every two seconds. This was implemented so the user can easily watch and analyze the packets using Wireshark protocol analyzer.

Setting up the Software for the TCP Client Demo

- 1. The user should find the IP address of the computer where the TCP/IP server Java demo application runs on.
- 2. Use the TCP/IP Lite library from the previously created project.
- 3. Add the tcp_client_demo.c and tcp_client_demo.h files to the project.
- 4. In main(), the user should call TCP_Client_Initialize() to add the server IP address and port number. The IP address is the one from step 1, as shown in Example 1.

EXAMPLE 1: SETTING SERVER LOCATION

remoteSocket.addr.s_addr	=	MAKE_IPV4_AD-
DRESS(192,168,0,3);		
remoteSocket.port = 60;		

- 5. In main(), the user shall enable the Global and Peripheral Interrupts.
- 6. In while(1) loop, the Network_Manage() command must be called. It is an API which polls the Ethernet controller for new packets and processes them.
- In while(1) loop, the DEMO_TCP_Client() command must be called to handle the socket states of the Client connected to the server.
- 8. The project must be compiled using XC8.

- 9. Using MPLAB X, the user can program the firmware on the PIC16F18346 on the Curiosity Development board.
- 10. If the IP address configured in MCC and the IP address of the computer where the TCP/IP server runs on are both unique, valid and in the same network, they must be able to exchange packets. The user can test this by sending ICMP messages (using the ping command).
- 11. Start the TCP/IP demo Java application on the computer, as shown in Figure 13.
- 12. Go to the TCP Server Demo tab.
- 13. Go to the Server → Local Port and change the port number to 60.
- 14. Push the **Listen** button (The status will be changed to "Listen..." and the button should be replaced by one with a Disconnect option).
- 15. When the Curiosity board will connect to the computer, a message in the Sent/Received Data windows will be printed, as shown in Example 2.

EXAMPLE 2: CONNECTION STATUS

192.168.0.21: Connected

- 16. In the Send field, the user can type a message to be sent to the board. The message will be sent when the **Enter** or **Send** button is pressed. Both sent data and received data will be printed in different colors in the Sent/Received Data window.
- 17. Messages that came from the board will be automatically printed in Sent/Received Data and contain the LED state and the raw value of the on-board potentiometer. Values are in hexadecimal format.
- 18. Pushing the LED 0 LED 7 button will initiate the sending of a command to the board. In this demo, all buttons will trigger the same LED on the board (will be turned on or off). The implementation supports only one LED turning on or off at a time.
- 19. Pushing the **Disconnect** button will close the Server connection and print a "Server closed" message followed by a "Client disconnected" message. This message will be printed for each "Client connected" message.
- 20. Repeat steps 13 to 18 to test the connection.

FIGURE 13: MICROCHIP TCP CLIENT DEMO IN JAVA APPLICATION

Alicrochip TCP/IP Demo GUI	
UDP TCP Client Demo TCP Server Demo About TCP/IP Demo	
Server	
Local Port 60 Listen	
STATUS	
Listen 192.168.0.2 : Connected Server closed Client disconnected	
Sent/Received Data	
->: led 0 on ->: led 0 off	
Send ADD: <u>C</u> R LF	Gand
	send
LED Control	
Led0 Led2 Led4 Led6 Led1 Led3 Led5 Led7	

TCP Client Demo Firmware – Buffer Creation

Before starting the Client, the user needs to create the socket and also, at least, the Rx buffer, as shown in Example 3. The Tx buffer will be created by the user and passed to the TCP stack when it is ready to be sent.

EXAMPLE 3: SOCKET CREATION

// create the socket for the TCP Client
tcpTCB_t port60TCB;
// create the TX and RX buffers
uint8_t rxdataPort60[50];
uint8_t txdataPort60[80];

TCP Client Implementation

The steps required to start and implement the TCP Client are as follows:

 Initialize the TCP stack. The function should be called before any other TCP function is called. It is done automatically through Network_Init() by the MCC's SYSTEM_Initialize() function.

TCP_Init();

 Set the IP address and port number. The user needs to provide the port number to connect to (this is the port number where the server listens on) and the IP address of the computer where the TCP/IP server Java demo application runs on. This function should be called before the while(1) loop.

TCP_Client_Initialize();

 Check the status of the socket. This function checks if the pointer provided as parameter is registered internally to the TCP/IP stack as a socket. If the pointer is a valid socket, the function will return the state of that socket. The possible states of the socket are defined in the tcpv4.h file.

socket_state = TCP_SocketPoll(&port7TCB);

4. Insert and initialize the socket in order to create the connection. All the necessary information for the TCP connection is kept here.

TCP_SocketInit(&port60TCB);

5. Set the local port for the client. This step is not mandatory, as the TCP stack will use the next available port number as a local port. The user needs to use TCP_Bind() to make sure that a certain port number will be used when the connection is initiated. This is useful when the server accepts connections only from a certain port number.

TCP_Bind(&port60TCB, 1024);

6. Add the Rx buffer to the socket. The function will insert the buffer into the socket. It will be used for saving the received data.

TCP_InsertRxBuffer(&port60TCB, rxdat aPort60, sizeof(rxdataPort60));

7. Start the Client by calling the TCP_Connect() function that will initiate the TCP connect procedure for connecting to the server. If the TCP handshake is successful, the user can exchange data with the remote server over the TCP connection.

TCP_Connect(&port60TCB, &remoteSocket);

8. Close a TCP connection. If the connection failed, the Client should abort the connection and close the socket. The user should initiate a new TCP connect procedure every two seconds. This function will close the TCP connection. The user needs to check the socket state periodically, until the socket is in closed state. When the socket is in closed state, the Rx and Tx buffers can be safely reused.

TCP_Close(&port60TCB);

9. Check if the Tx buffer was sent correctly. This function needs to be called before trying to send anything, because the socket can handle only one buffer at a time.

TCP_SendDone(&port60TCB);

10. Read available bytes in Rx buffer and make the buffer user ready. The function below will return the number of bytes available in the buffer. After calling this function, the user can access the buffer in a safe way. Once the function is called, the stack will not save further received data into this Rx buffer. The user should provide, as quickly as possible, another Rx buffer to the stack (in order to avoid packet retransmission).

rxLen = TCP_GetReceivedData(&port60TCB);

11. Send the buffer to the remote machine. The API will allow the user to send data over an active TCP connection. The data cannot be sent if the connection is not established between the local and remote host.

TCP_Send(&port60TCB, txdataPort60, txLen);

12. Remove the socket. When the socket is closed, if the user wants to remove the socket from the internal socket list, the following API will remove the pointer.

TCP_SocketRemove(&port60TCB);

 Background task. The function below needs to be called periodically by the application, in order to handle the timeouts from the TCP stack. The TCP background task is called once per second to handle the TCP stack timeouts.

TCP_Update(); // handle timeouts

Source Code for the TCP Client Implementation

The TCP Client demo code in Example 4 (source code and prebuilt hex file) is available as download on www.microchip.com.

Software License Agreement

The software supplied herewith by Microchip Technology Incorporated (the "Company") is intended and supplied to you, the Company's customer, for use solely and exclusively with products manufactured by the Company.

The software is owned by the Company and/or its supplier, and is protected under applicable copyright laws. All rights are reserved. Any use in violation of the foregoing restrictions may subject the user to criminal sanctions under applicable laws, as well as to civil liability for the breach of the terms and conditions of this license.

THIS SOFTWARE IS PROVIDED IN AN "AS IS" CONDITION. NO WARRANTIES, WHETHER EXPRESS, IMPLIED OR STATU-TORY, INCLUDING, BUT NOT LIMITED TO, IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICU-LAR PURPOSE APPLY TO THIS SOFTWARE. THE COMPANY SHALL NOT, IN ANY CIRCUMSTANCES, BE LIABLE FOR SPECIAL, INCIDENTAL OR CONSEQUENTIAL DAMAGES, FOR ANY REASON WHATSOEVER.

```
EXAMPLE 4: TCP CLIENT DEMO SOURCE CODE
```

```
void DEMO_TCP_Client(void)
{
         // create the socket for the TCP Client
         static tcpTCB_t port60TCB;
         // create the TX and RX Client's buffers
         static uint8_t rxdataPort60[50];
         static uint8_t txdataPort60[80];
         static time_t t_client = 0;
         static time_t socketTimeout = 0;
         uint16_t rx_len;
         sockaddr_in_t remoteSocket;
         socketState_t socketState;
         rx_len = 0;
         socketState = TCP_SocketPoll(&port60TCB);
         time(&t_client);
         switch(socketState)
         {
                 case NOT_A_SOCKET:
                           // Inserting and initializing the socket
                           TCP_SocketInit(&port60TCB);
                           break;
                  case SOCKET_CLOSED:
                           \ensuremath{{\prime\prime}}\xspace if the socket is closed we will try to connect again
                           // try to connect once at 2 seconds
                           socketTimeout = t_client + 2;
                           TCP_InsertRxBuffer(&port60TCB,rxdataPort60, sizeof(rxdataPort60));
                           TCP_Connect(&port60TCB, &remoteSocket);
                           break;
                  case SOCKET_IN_PROGRESS:
                           // close the socket
                           if(t_client >= socketTimeout)
                           {
                                    TCP_Close(&port60TCB);
                           }
                           break;
```

AN1921

```
TCP CLIENT DEMO SOURCE CODE (CONTINUED)
EXAMPLE 4:
                     case SOCKET_CONNECTED:
                            // implement an echo client over TCP
                            // check if the previous buffer was sent
                            if (TCP_SendDone(&port60TCB))
                            {
                                rx_len = TCP_GetReceivedData(&port60TCB);
                                // handle the incoming data
                                if(rx_len > 0)
                                {
                                        /*
                                        LED Command parsing and LCD updates was removed from this example.
                                        The full code is available in the source code.
                                        */
                                        // reuse the RX buffer
                                        TCP_InsertRxBuffer(&port60TCB, rxdataPort60, sizeof(rxdataPort60));
                                  }
                                  if(t_client >= socketTimeout)
                                  {
                                        // send board status message only once at 2 seconds
                                        socketTimeout = t_client + 2;
                                        /*
                                        Composing the TX message in the TX buffer was removed from this example.
                                        The full code is available in the source code.
                                                                     .....
                                        */
                                        //send data back to the source
                                        TCP_Send(&port60TCB, txdataPort60, strlen(txdataPort60));
                                   }
                            }
                            break;
                      case SOCKET_CLOSING:
                            //remove the used socket form the list
                            TCP_SocketRemove(&port60TCB);
                           break;
                      default:
                           break;
        }
```

SIMPLE TCP SERVER DEMO IMPLEMENTATION

Overview

This is a simple TCP echo server implementation, listening on port 7. The Server is started on the Curiosity board and it will wait for any incoming connection. The Server will echo back all the received data once the connection with a client is established. Only one active connection will be created for this demo, but the TCP/IP stack supports multiple TCP connections on the same board. The user needs to create a new Server (create buffers, initialize and start listening) for each new connection.

Setting up the Software for the TCP Server Demo

- The user should create a project as it was shown in Section "Setup the Software for TCP Client/Server Demo Using MCC", this time excluding steps 11 and 12. The Server does not need an ADC module or LEDs to be toggled.
- 2. Add the tcp_server_demo.c and tcp_server_demo.h files to the project.
- 3. In the main() function, the user will enable the Global and Peripheral Interrupts.
- In while(1) loop, the Network_Manage() function must be called. It is an API which polls the Ethernet controller for new packets and processes them.
- 5. In while(1) loop, the DEMO_TCP_EchoServer() function must be called to open the socket and listen for incoming clients.
- 6. The project must be compiled using XC8.
- 7. Using MPLAB X, the user can program the firmware to the PIC16F18346 on the Curiosity Development board.
- 8. Start the TCP/IP demo Java application on the computer (see Figure 14).
- 9. Go to the TCP Client Demo tab.
- 10. Go to the "Server IP Address" and set the IP address and the port number to 7. The IP address is static and it was configured using MCC.
- 11. Click on the **Connect** button.
- When the computer is connected to the Curiosity board, a message in the Sent/ Received Data windows will be printed, as shown in Example 5.

EXAMPLE 5: INITIAL LOG MESSAGE

Connected to 192.168.0.21 Port: 7

13. The user can type in the Send window and press

Enter from keyboard or push the **Send** button to send the string. Both sent and received data will be printed with different colors in the Sent/ Received Data window.

- Pushing the **Disconnect** button will close the TCP connection. A "Connection closed" message will be printed.
- 15. Repeat steps 9 to 13 to test the connection using different strings length.
- 16. To generate TCP traffic to the board the ECHO back received message button should be enabled. The Send text box should be filled with the desired message to be sent to the board. Pushing the Send button will initiate the data exchange. To stop the TCP traffic the Echo Back received message button should be pushed again. In this case, in the Sent/Received Data window, only the received messages will be printed.

FIGURE 14: MICROCHIP TCP CLIENT DEMO FOR JAVA APPLICATION

SUI		
TCP Server Demo	About TCP/IP Demo	
Port		
7	CONN	ECT
	Print	HEX
A	DD: <u>C</u> R <u>L</u> F	
A	DD: <u>C</u> R <u>L</u> F	Send
A	DD: <u>C</u> R <u>L</u> F	Send
	UI TCP Server Demo Port 7	UI TCP Server Demo About TCP/IP Demo Port 7 CONN Print

TCP Server Demo Firmware – Buffer Creation

Before starting the Server, the user needs to create the socket and also, at least, the Rx buffer. The Tx buffer will be created by the user and passed to the TCP stack when it is ready to be sent.

EXAMPLE 6: SOCKET CREATION

// create the socket for the TCP Server tcpTCB_t port7TCB; // create the TX and RX buffers uint8_t rxdataPort7[20]; uint8_t txdataPort7[20];

TCP Server Implementation

These are the steps required to implement the TCP Server:

 Initialize the TCP stack. The function should be called before any other TCP function. It is done automatically through Network_Init() by the MCC's SYSTEM_Initialize() function.

TCP_Init();

 Check the status of the socket: This function checks if the pointer provided as parameter is registered internally to the TCP/IP stack as a socket. If the pointer is a valid socket, the function will return the state of that socket. The possible states of the socket are defined in the tcpv4.h file.

socket_state = TCP_SocketPoll(&port7TCB);

3. Insert and initialize the socket in order to create the connection. All the necessary information for the TCP connection is kept here.

TCP_SocketInit(&port7TCB);

4. Assign the local port for the Server. The function will assign a port for the socket to listen on. The Server will listen on this port for any incoming connections. The TCP stack will automatically allocate a port number to listen on if a port number is not supplied by the user.

TCP_Bind(&port7TCB, 7);

5. Add the receive buffer to a socket. The function will insert the buffer into the socket for storing the received data.

TCP_InsertRxBuffer(&port7TCB,

```
rxdataPort7, sizeof(rxdataPort7));
```

6. Start the TCP Server. The function will set the TCP stack to listen to a port for a connection request. If the TCP handshake completes successfully, the user can exchange data with the remote over the TCP connection. Only one connection request is accepted at a time. The TCP stack can handle multiple connections for a particular port number. But for each new connection the user needs to create a new socket, an Rx buffer, and start a new instance of the Server for the same port.

TCP_Listen(&port7TCB);

7. Check the status of the socket. This function checks if the pointer provided as parameter is already registered to the TCP/IP stack as a socket. If the pointer is a valid socket, the function will return the state of that socket. The possible states of the socket are defined in the tcpv4.h file.

socket_state = TCP_SocketPoll(&port7TCB);

8. Check if the Tx buffer was sent correctly (this means that the remote acknowledged all the received bytes). This function needs to be called before trying to send anything, because the socket can handle only one buffer at a time.

TCP_SendDone(&port7TCB);

9. Check if there is any data received in the socket. The function will return the number of bytes available in the Rx buffer.

rxLen = TCP_GetRxLength(&port7TCB);

10. Read how many bytes are available in the Rx buffer and make the buffer ready to use. The function will return the number of bytes available in the buffer. After calling this function, the user can access the buffer in a safe way. Once the function is called, the stack will not save any further data received into this Rx buffer. The user should provide, as fast as possible, another Rx buffer to the stack, in order to avoid packet retransmission.

```
rxLen = TCP_GetReceivedData
(&port7TCB);
```

11. Send the buffer to the remote machine. The API will allow the user to send data over an active TCP connection. The data cannot be sent if the connection is not established between the local and the remote host.

TCP_Send(&port7TCB, txdataPort7, txLen);

12. Close the TCP connection. Socket connection closing will happen after the TCP connection handshake is done (the connection closing is not done right away). The user needs to check the socket state periodically, until the socket is in Closed state. When the socket is in Closed state, the Rx and the Tx buffers can be safely reused.

TCP_Close(&port7TCB)

13. Remove the socket. If the user wants to remove the socket from the internal socket list when the socket is closed, the following API will remove the pointer.

TCP_SocketRemove(&port7TCB)

14. Background task. This function needs to be called periodically by the application, in order to handle the timeouts from the TCP stack. The TCP background task is called once per second to handle the TCP stack timeouts.

TCP_Update();// handle timeouts

Source Code for the TCP Server Implementation

The TCP Client demo code in Example 7 (source code and prebuilt hex file) is available as download on www.microchip.com.

```
void DEMO_TCP_echo_server(void)
      // create the socket for the TCP Server
      static tcpTCB_t port7TCB;
      // create the TX and RX buffers
      static uint8_t rxdataPort7[20];
      static uint8_t txdataPort7[20];
      uint16_t rxLen, txLen, i;
      socket_state_t socket_state;
      rxLen = 0;
      // checking the status of the socket
      socket_state = TCP_SocketPoll(&port7TCB);
      switch(socket_state)
      {
              case NOT_A_SOCKET:
                   //Inserting and initializing the socket
                   TCP_SocketInit(&port7TCB);
              case SOCKET_CLOSED:
                   //configure the local port
                   TCP_Bind(&port7TCB, 7);
                   // add receive buffer
                   TCP_InsertRxBuffer(&port7TCB,rxdataPort7, sizeof(rxdataPort7));
                  // start the server
                  TCP_Listen(&port7TCB);
                  break;
```

TCP ECHO SERVER IMPLEMENTATION EXAMPLE 7:

```
EXAMPLE 7: TCP ECHO SERVER IMPLEMENTATION (CONTINUED)
```

```
case SOCKET_CONNECTED:
               // check if the buffer was sent, if yes we can reuse the //buffer
               if(TCP_SendDone(&port7TCB))
               {
                      // check to see if there are any received data
                     rxLen = TCP_GetRxLength(&port7TCB);
                     if(rxLen > 0)
                     {
                          //make sure it safe to use the receive buffer
                          rxLen = TCP_GetReceivedData(&port7TCB);
                          //simulate some buffer processing copy from //the RX buffer to the TX buffer
                          for(i = 0; i < rxLen; i++)
                          {
                             txdataPort7[i] = rxdataPort7[i];
                          }
                          // reuse the rx buffer
                          TCP_InsertRxBuffer(&port7TCB,rxdataPort7, sizeof(rxdataPort7));
                          txLen = rxLen;
                          //send data back to the source
                          TCP_Send(&port7TCB, txdataPort7, txLen);
                     }
               }
               break;
        case SOCKET_CLOSING:
               TCP_SocketRemove(&port60TCB);
               break;
        default:
               // we should not end up here
               break;
}
```

UDP DEMO

Overview

This is a UDP Client and Server implementation. It consists of UDP Send (UDP Client) and UDP Receive (UDP Server) implementations. As UDP Send, the Curiosity Development board sends potentiometer readings as UDP packets. As UDP Receive, the Curiosity Development board starts listening to any incoming UDP packets such as toggle LEDs on port 65531. The port numbers can be anything between in 0 to 65535, but some of them are reserved or already registered. Therefore, it is recommended to choose a port between 49152 to 65535, since all of them are free.

Setting up the Software for UDP Send/ Receive (Client/Server) Demo

- 1. Start MPLAB X and create a new project for the device PIC16F18346.
- 2. Load the MCC module.
- 3. Go to Device Resources, and under Libraries select TCP/IP Lite module.
- 4. Load the TCP/IP Lite module.
- 5. The **Notifications** tab shows different types of messages:
 - "WARNING" messages are required to be implemented to generate an error free code
 - "HINT" messages help the user follow the code generation
 - "INFO" messages allow the user to give information about the modules loaded
- 6. Go to Device Resources, under Libraries select <u>Ethernet \rightarrow MAC module</u>.
- 7. Load the MAC module.
- 8. In the Easy Setup, select the ENC28J60 controller from the drop down selection box.
- The ENC28J60 controller is based on Serial Peripheral Interface. So, as per the Curiosity Development board schematics, the "MSSP1 – SPI module" interface is supported on the connector J35.
- 10. Go to Device Resources, under Peripherals select MSSP1 module.
- 11. Load MSSP1 module and configure to SPI Master mode and select the Clock Edge to Active to Idle mode, and set Input Data Sampled at "End".
- 12. Go to Device Resources, and under Peripherals select TMR1 module.
- 13. Update the Timer Period to 250 ms. Enable the Timer Interrupt and update the Callback Function Rate to 4 to generate a 1s period. This feature is required to configure the device with a 1s tick of system clock.

- 14. Configure the ADC module to send the potentiometer data over UDP. Go to Device Resources, under Peripherals select ADC module. Load the ADC module.
- 15. In the ADC module, configure Clock Source to Fosc/4, and Result Alignment to right.
- 16. Configure the Pin Manager:
- MSSP1 module Pin Configuration
 - SCK1 output Port RB6
 - SDI1 input Port RB4
 - SDO1 output Port RC7
- MAC module Pin Configuration
- ETH_CS (for the ENC28J60 controller) output Port RC6
- ADC module Pin Configuration
 - ANx input PORT RC0
 - From <u>Project Resource → System → Pin</u> <u>Module</u>, the user can provide a custom name to the AN0 channel, for example: Pot
- Configure the Pin Manager for LEDs on Curiosity board:
 - Pin module output Port RA5
 - From <u>Project Resource → System → Pin</u> <u>Module</u>, the user can provide a custom name to the RA5 Pin, for example: Toggle_Led
- 17. Click on Generate button to generate the code.
- 18. Add the udp_demo.c and udp_demo.h files to the project.
- 19. In the main() function, the user should enable the Global and Peripheral interrupts.
- 20. In main(), call the POT_UDP_Initialize() API in the udp_demo.c file to initialize the potentiometer and UDP server packet i.e., UDP server (destination) Port Number – 65531, UDP Server Address – computer IP address (Destination address), and UDP Client (Source) Port Number – 65533.
- 21. In while(1) loop, call the Network_Mange() API which polls the Ethernet controller for new packets and processes them.
- 22. The project must be compiled using XC8 and program the firmware to the PIC16F18346 on the Curiosity Development board.
- 23. Start the Packet Sender application (Figure 15) on the computer.

	FIGURE 15:	PACKET SENDER INTERFACE
--	------------	-------------------------

Packet Send	er							^
File Tools I	lelp							
Name Packet ASCII ASCII HEX HEX re	Name representation presentation							
Address Inva	lid Port 1 to 6.	Resend Dela	iy 0	💼 UD	P 🔻	Send	Save	
Search Saved F	ackets				Delete Sa	aved Packet	Persistent	ГСР
Send Name	Resend (sec)	To Address	To Port	Method	ASCII	I	Hex	
Clear Log		🔽 Log Tra	affic Sa	ave Log	Save Tr	affic Packet	Copy to Clipbo	ard
Time From	P From Port	To IP To Port	Method	Error	ASCII	H	Hex	

- 24. Go to <u>File →Settings →Network</u>, enable the UDP Server and update the port to 65531.
- 25. Turn the knob on the Curiosity Development board. The board sends UDP packets to display the potentiometer reading in volts.
- 26. In the Packet Sender application, send a UDP packet to turn the LEDs on the Curiosity Development board to toggle.
- Name UDP Led1 Send
- ASCII L1
- Address board's IP address. This can be accessed from the D-Discover O-Offer R-Request A-Acknowledgment process using the Wireshark analyzer tool.
- Port 65531
- Select the UDP protocol
- Click on Save to save this packet

Name UDP Led	1 Send				
ASCII L1					
HEX 4c 31 Address 192.10	68.0.144 Port 65531	Resend Delay	.0/bla 🖆 UDP	▼ Send	Save
Search Saved Pa	ckets		D	elete Saved Packet	Persistent TCP
Send	Name F	Resend (sec) To	Address To Port	Method	ASCII
1 🖾 Send	UDP Led1 Send 0	192.	168.0.144 65531	UDP L1	
•		III			4
Clear Log		Log Traffic	Save Log	Save Traffic Packet	Copy to Clipboard
Time From IP	From Port To IP	To Port Method	Error ASCII	He	x

27. In Packet Sender, click on the **Send** button of the saved UDP packets to toggle the LED on the Curiosity board.

28. Repeat steps 25 and 27 to verify the UDP send and UDP receive packets on port 65531.

UDP Send Implementation

In order to start the UDP packet, the following steps are required:

1. Start the UDP Packet

The function will start the UDPv4 Packet, which starts the IPv4 packet and writes the UDP Header. The UDP Header fields – checksum and Data length – are initially set to '0'.

- UDP_Start(uint32_t destIP, uint16_t srcPort, uint16_t destPort); 2. Write the UDP Packet

There are six methods of writing a UDP packet, depending on the size and order of data written.

- UDP_WriteBlock(uint8_t* data, uint16_t length) - Writes a block of data
- UDP_Write8(uint8_t data) Writes 1 byte of data
- UDP_Write16(uint16_t data); -Writes 2 bytes of data in Host Order
- UDP_Write24(uint32_t data); -Writes 3 bytes of data in Host Order
- UDP_Write32(uint32_t data); Writes 4 bytes of data in Host Order
- UDP_String(const char *string)-Writes String in Network Order
- 3. Send the UDP Packet

The function will insert the total payload length into the UDP header, compute the checksum of the UDP packet and send the packet on the wire.

- UDP_Send();

UDP Receive Implementation

In order to receive the UDP packet, the following steps are required:

1. Port Handling

In the <code>udpv4_port_handler_table.c</code> file, the <code>UDP_CallBackTable[]</code> function needs to be updated with the receiving port number and its callback function.

EXAMPLE 8: PORT HANDLING

```
typedef struct
{
    uint16_t portNumber;
    ip_receive_function_ptr callBack;
}udp_handler_t;
const udp_handler_t UDP_CallBackTable [] = \
    {
        {
            {portNumber, &callback}
        };
```

2. Receive the UDP Packet

At first, check for the valid checksum. Any UDP packets with invalid checksums are discarded. If the checksum is correct, the function will check for the port number to be matched in UDP_CallBackTable[]. If the port number and the corresponding function handler (callback) are valid in the table, the length of UDP payload is passed as parameter to the callback. Any UDP packet with invalid port number will respond with an "ICMP PORT UNREACHABLE" message, if "ICMP Port Unreachable" option is selected in the MCC while configuring the stack; else the UDP packet is discarded.

- UDP_Receive(uint16_t udpcksm);
- 3. Read the UDP Packet

There are five methods of reading a UDP packet, depending on the size and order of data.

- UDP_ReadBlock(uint8_t* data, uint16_t length) - Reads a block of data
- UDP_Read8() Reads 1 byte of data
- UDP_Read16() Reads 2 bytes of data in Host Order
- UDP_Read24() Reads 3 bytes of data in Host Order
- UDP_Read32() Reads 4 bytes of data in Host Order

Source Code for the UDP Client/Server Implementation

The UDP demo code (source code and prebuilt hex file) is available as download on www.microchip.com.

EXAMPLE 9: UDP CLIENT IMPLEMENTATION

```
void UDP_DEMO_Send (void)
{
     error_msg ret = ERROR;
     potCurrResult = (ADCC_GetSingleConversion(Pot)/10);
     if(...)
     {
            . . .
            ret
                        =
                                   UDP_Start(udpPacket.destinationAddress,
                                                                                   udpPacket.sourcePortNumber,
udpPacket.destinationPortNumber);
            if(ret = SUCCESS)
            {
                  UDP_Write16(potCurrResult);
                  UDP_Send();
            }
     }
}
```

EXAMPLE 10: UDP SERVER IMPLEMENTATION

CONCLUSION

This application note presents some very simple software solutions for implementing a TCP Server, a TCP Client and exchange data over UDP based on the Microchip lightweight TCP/IP stack. The TCP/IP stack provides space efficiency and modular implementation allowing to add network connectivity to embedded systems with limited resources.

APPENDIX A: REFERENCES

- 1. User Datagram Protocol, RFC 768
- 2. Internet Protocol, DARPA Internet Program Protocol Specification, RFC 791
- Internet Control Message Protocol, DARPA Internet Program Protocol Specification, RFC 792
- 4. Transmission Control Protocol, DARPA Internet Program Protocol Specification, RFC 793
- 5. Requirements for Internet Hosts, Communication Layers, RFC 1122
- 6. An Ethernet Address Resolution Protocol or Converting Network Protocol Addresses to 48 bit Ethernet Address for Transmission on Ethernet Hardware, RFC 826
- 7. Domain Names Implementation and Specification, RFC 1035
- 8. Clarifications to the DNS Specification, RFC 2181
- 9. Service Name and Transport Protocol Port Number Registry (www.iana.org)

APPENDIX B: FLOWCHART FOR TCP CLIENT DEMO

Since the demo containing the TCP/IP stack is very large, the software flowchart shown in Figure B-1 is only for the main application with a focus on the TCP Client routine found in the main.c file.





AN1921



FIGURE B-2: FLOWCHART FOR TCP SERVER DEMO

AN1921



FIGURE B-3: FLOWCHART FOR UDP DATA EXCHANGE DEMO

Note the following details of the code protection feature on Microchip devices:

- Microchip products meet the specification contained in their particular Microchip Data Sheet.
- Microchip believes that its family of products is one of the most secure families of its kind on the market today, when used in the intended manner and under normal conditions.
- There are dishonest and possibly illegal methods used to breach the code protection feature. All of these methods, to our knowledge, require using the Microchip products in a manner outside the operating specifications contained in Microchip's Data Sheets. Most likely, the person doing so is engaged in theft of intellectual property.
- Microchip is willing to work with the customer who is concerned about the integrity of their code.
- Neither Microchip nor any other semiconductor manufacturer can guarantee the security of their code. Code protection does not mean that we are guaranteeing the product as "unbreakable."

Code protection is constantly evolving. We at Microchip are committed to continuously improving the code protection features of our products. Attempts to break Microchip's code protection feature may be a violation of the Digital Millennium Copyright Act. If such acts allow unauthorized access to your software or other copyrighted work, you may have a right to sue for relief under that Act.

Information contained in this publication regarding device applications and the like is provided only for your convenience and may be superseded by updates. It is your responsibility to ensure that your application meets with your specifications. MICROCHIP MAKES NO REPRESENTATIONS OR WARRANTIES OF ANY KIND WHETHER EXPRESS OR IMPLIED, WRITTEN OR ORAL, STATUTORY OR OTHERWISE, RELATED TO THE INFORMATION, INCLUDING BUT NOT LIMITED TO ITS CONDITION, QUALITY, PERFORMANCE, MERCHANTABILITY OR FITNESS FOR PURPOSE. Microchip disclaims all liability arising from this information and its use. Use of Microchip devices in life support and/or safety applications is entirely at the buyer's risk, and the buyer agrees to defend, indemnify and hold harmless Microchip from any and all damages, claims, suits, or expenses resulting from such use. No licenses are conveyed, implicitly or otherwise, under any Microchip intellectual property rights unless otherwise stated.

Microchip received ISO/TS-16949:2009 certification for its worldwide headquarters, design and wafer fabrication facilities in Chandler and Tempe, Arizona; Gresham, Oregon and design centers in California and India. The Company's quality system processes and procedures are for its PIC® MCUs and dsPIC® DSCs, KEEL0Q® code hopping devices, Serial EEPROMs, microperipherals, nonvolatile memory and analog products. In addition, Microchip's quality system for the design and manufacture of development systems is ISO 9001:2000 certified.

QUALITY MANAGEMENT SYSTEM CERTIFIED BY DNV = ISO/TS 16949=

Trademarks

The Microchip name and logo, the Microchip logo, AnyRate, AVR, AVR logo, AVR Freaks, BeaconThings, BitCloud, chipKIT, chipKIT logo, CryptoMemory, CryptoRF, dsPIC, FlashFlex, flexPWR, Heldo, JukeBlox, KEELOQ, KEELOQ logo, Kleer, LANCheck, LINK MD, maXStylus, maXTouch, MediaLB, megaAVR, MOST, MOST logo, MPLAB, OptoLyzer, PIC, picoPower, PICSTART, PIC32 logo, Prochip Designer, QTouch, RightTouch, SAM-BA, SpyNIC, SST, SST Logo, SuperFlash, tinyAVR, UNI/O, and XMEGA are registered trademarks of Microchip Technology Incorporated in the U.S.A. and other countries.

ClockWorks, The Embedded Control Solutions Company, EtherSynch, Hyper Speed Control, HyperLight Load, IntelliMOS, mTouch, Precision Edge, and Quiet-Wire are registered trademarks of Microchip Technology Incorporated in the U.S.A.

Adjacent Key Suppression, AKS, Analog-for-the-Digital Age, Any Capacitor, AnyIn, AnyOut, BodyCom, CodeGuard, CryptoAuthentication, CryptoCompanion, CryptoController, dsPICDEM, dsPICDEM.net, Dynamic Average Matching, DAM, ECAN, EtherGREEN, In-Circuit Serial Programming, ICSP, Inter-Chip Connectivity, JitterBlocker, KleerNet, KleerNet logo, Mindi, MiWi, motorBench, MPASM, MPF, MPLAB Certified logo, MPLIB, MPLINK, MultiTRAK, NetDetach, Omniscient Code Generation, PICDEM, PICDEM.net, PICkit, PICtail, PureSilicon, QMatrix, RightTouch logo, REAL ICE, Ripple Blocker, SAM-ICE, Serial Quad I/O, SMART-I.S., SQI, SuperSwitcher, SuperSwitcher II, Total Endurance, TSHARC, USBCheck, VariSense, ViewSpan, WiperLock, Wireless DNA, and ZENA are trademarks of Microchip Technology Incorporated in the U.S.A. and other countries.

SQTP is a service mark of Microchip Technology Incorporated in the U.S.A.

Silicon Storage Technology is a registered trademark of Microchip Technology Inc. in other countries.

GestIC is a registered trademark of Microchip Technology Germany II GmbH & Co. KG, a subsidiary of Microchip Technology Inc., in other countries.

All other trademarks mentioned herein are property of their respective companies.

 $\textcircled{\mbox{\sc op}}$ 2015-2017, Microchip Technology Incorporated, All Rights Reserved.

ISBN: 978-1-5224-1727-9



Worldwide Sales and Service

AMERICAS

Corporate Office 2355 West Chandler Blvd. Chandler, AZ 85224-6199 Tel: 480-792-7200 Fax: 480-792-7277 Technical Support: http://www.microchip.com/ support

Web Address: www.microchip.com

Atlanta Duluth, GA Tel: 678-957-9614 Fax: 678-957-1455

Austin, TX Tel: 512-257-3370

Boston Westborough, MA Tel: 774-760-0087 Fax: 774-760-0088

Chicago Itasca, IL Tel: 630-285-0071 Fax: 630-285-0075

Dallas Addison, TX Tel: 972-818-7423 Fax: 972-818-2924

Detroit Novi, MI Tel: 248-848-4000

Houston, TX Tel: 281-894-5983

Indianapolis Noblesville, IN Tel: 317-773-8323 Fax: 317-773-5453 Tel: 317-536-2380

Los Angeles Mission Viejo, CA Tel: 949-462-9523 Fax: 949-462-9608 Tel: 951-273-7800

Raleigh, NC Tel: 919-844-7510

New York, NY Tel: 631-435-6000

San Jose, CA Tel: 408-735-9110 Tel: 408-436-4270

Canada - Toronto Tel: 905-695-1980 Fax: 905-695-2078

ASIA/PACIFIC

Asia Pacific Office Suites 3707-14, 37th Floor Tower 6, The Gateway

Harbour City, Kowloon Hong Kong Tel: 852-2943-5100 Fax: 852-2401-3431

Australia - Sydney Tel: 61-2-9868-6733 Fax: 61-2-9868-6755

China - Beijing Tel: 86-10-8569-7000 Fax: 86-10-8528-2104

China - Chengdu Tel: 86-28-8665-5511 Fax: 86-28-8665-7889

China - Chongqing Tel: 86-23-8980-9588 Fax: 86-23-8980-9500

China - Dongguan Tel: 86-769-8702-9880

China - Guangzhou Tel: 86-20-8755-8029

China - Hangzhou Tel: 86-571-8792-8115 Fax: 86-571-8792-8116

China - Hong Kong SAR Tel: 852-2943-5100

China - Nanjing Tel: 86-25-8473-2460 Fax: 86-25-8473-2470

Fax: 852-2401-3431

China - Qingdao Tel: 86-532-8502-7355 Fax: 86-532-8502-7205

China - Shanghai Tel: 86-21-3326-8000 Fax: 86-21-3326-8021

China - Shenyang Tel: 86-24-2334-2829 Fax: 86-24-2334-2393

China - Shenzhen Tel: 86-755-8864-2200 Fax: 86-755-8203-1760

China - Wuhan Tel: 86-27-5980-5300 Fax: 86-27-5980-5118

China - Xian Tel: 86-29-8833-7252 Fax: 86-29-8833-7256

ASIA/PACIFIC

China - Xiamen Tel: 86-592-2388138 Fax: 86-592-2388130

China - Zhuhai Tel: 86-756-3210040 Fax: 86-756-3210049

India - Bangalore Tel: 91-80-3090-4444 Fax: 91-80-3090-4123

India - New Delhi Tel: 91-11-4160-8631 Fax: 91-11-4160-8632

India - Pune Tel: 91-20-3019-1500

Japan - Osaka Tel: 81-6-6152-7160 Fax: 81-6-6152-9310

Japan - Tokyo Tel: 81-3-6880- 3770 Fax: 81-3-6880-3771

Korea - Daegu Tel: 82-53-744-4301 Fax: 82-53-744-4302

Korea - Seoul Tel: 82-2-554-7200 Fax: 82-2-558-5932 or 82-2-558-5934

Malaysia - Kuala Lumpur Tel: 60-3-6201-9857 Fax: 60-3-6201-9859

Malaysia - Penang Tel: 60-4-227-8870 Fax: 60-4-227-4068

Philippines - Manila Tel: 63-2-634-9065 Fax: 63-2-634-9069

Singapore Tel: 65-6334-8870 Fax: 65-6334-8850

Taiwan - Hsin Chu Tel: 886-3-5778-366 Fax: 886-3-5770-955

Taiwan - Kaohsiung Tel: 886-7-213-7830

Taiwan - Taipei Tel: 886-2-2508-8600 Fax: 886-2-2508-0102

Thailand - Bangkok Tel: 66-2-694-1351 Fax: 66-2-694-1350

EUROPE

Austria - Wels Tel: 43-7242-2244-39 Fax: 43-7242-2244-393

Denmark - Copenhagen Tel: 45-4450-2828 Fax: 45-4485-2829

Finland - Espoo Tel: 358-9-4520-820

France - Paris Tel: 33-1-69-53-63-20 Fax: 33-1-69-30-90-79

France - Saint Cloud Tel: 33-1-30-60-70-00

Germany - Garching Tel: 49-8931-9700 **Germany - Haan** Tel: 49-2129-3766400

Germany - Heilbronn Tel: 49-7131-67-3636

Germany - Karlsruhe Tel: 49-721-625370

Germany - Munich Tel: 49-89-627-144-0 Fax: 49-89-627-144-44

Germany - Rosenheim Tel: 49-8031-354-560

Israel - Ra'anana Tel: 972-9-744-7705

Italy - Milan Tel: 39-0331-742611 Fax: 39-0331-466781

Italy - Padova Tel: 39-049-7625286

Netherlands - Drunen Tel: 31-416-690399 Fax: 31-416-690340

Norway - Trondheim Tel: 47-7289-7561

Poland - Warsaw Tel: 48-22-3325737

Romania - Bucharest Tel: 40-21-407-87-50

Spain - Madrid Tel: 34-91-708-08-90 Fax: 34-91-708-08-91

Sweden - Gothenberg Tel: 46-31-704-60-40

Sweden - Stockholm Tel: 46-8-5090-4654

UK - Wokingham Tel: 44-118-921-5800 Fax: 44-118-921-5820