Introduction

The PIC32MX Microcontroller Unit (MCU) is a complex system-on-a-chip (SOC) that is based on a M4K™ core from MIPS® Technologies. M4K™ is a state-of-the-art 32-bit, low-power, RISC processor core with the enhanced MIPS32® Release 2 Instruction Set Architecture. This section provides an overview of the CPU features and system architecture of the PIC32MX family[1] of microcontrollers.

Key features:

- Up to 1.5 DMIPS/MHz of performance
- Programmable prefetch cache memory to enhance execution from Flash memory
- 16-bit Instruction mode (MIPS16e) for compact code
- Vectored interrupt controller with 63 priority levels
- Programmable User and Kernel modes of operation
- Atomic bit manipulations on peripheral registers (Single cycle)
- Multiply-Divide unit with a maximum issue rate of one 32x16 multiply per clock
- High speed Microchip ICD port with hardware-based non-intrusive data monitoring and application data streaming functions
- EJTAG debug port allows extensive third party debug, programming and test tools support
- Instruction controlled power management modes
- Five stage piplined instruction execution
- Internal Code protection to help protect intellectual property

PIC32MX Architecture Overview

As mentioned earlier, the PIC32MX family processors are complex SOC that contain many features. Included in all processors of the PIC32MX family is a high-performance RISC CPU, which can be programmed in 32-bit and 16-bit modes, and even mixed modes. The PIC32MX MCU contains a high-performance interrupt controller, DMA controller, USB controller, in-circuit debugger, high performance switching matrix for high-speed data accesses to the peripherals, on-chip data RAM memory that holds data and programs. The unique prefetch cache and prefetch buffer for the Flash memory, which hides the latency of the flash, gives zero Wait state equivalent performance.

There are two internal buses in the chip to connect all the peripherals. The main peripheral bus connects most of the peripheral units to the bus matrix through a peripheral bridge. There is also a high-speed peripheral bridge that connects the interrupt controller DMA controller, in-circuit debugger, and USB peripherals. The heart of the PIC32MX MCU is the M4K CPU core. The CPU performs operations under program

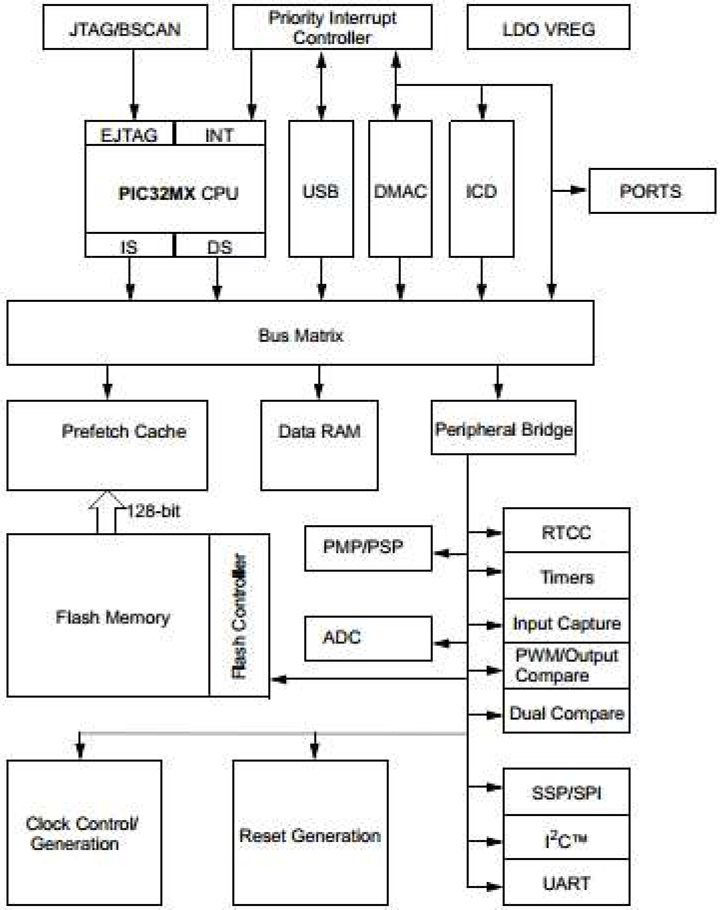

Figure 1: PIC32MX MCU Block Diagram.

control. Instructions are fetched by the CPU, decoded and executed synchronously. Instructions exist in either the Program Flash memory or Data RAM memory. Figure 1 shows the PIC32MX Block Diagram.

The PIC32MX CPU is based on a load/store architecture and performs most operations on a set of internal registers. Specific load and store instructions are used to move data between these internal registers and the outside world.

Cerebot MX7cK Overview

In this lab, we will use the PIC32MX795F512L which is a member of the 32-bit PIC32 microcontroller family. The Cerebot MX7cK is a microcontroller development board based on the Microchip PIC32MX795F512L. It is compatible with Digilent's line of Pmod™ peripheral modules, and is suitable for use with the Microchip MPLAB IDE tools. The Cerebot MX7cK is also compatible for use with the chipKIT™ MPIDE development environment. ChipKIT and MPIDE is a PIC32 based system compatible with many existing Arduino™ code examples, reference materials and other resources.

The Cerebot MX7cK is designed to be easy to use and suitable for use by anyone from beginners to advanced users for experimenting with embedded control and network communications application. A built in programming/debugging circuit compatible with the Microchip MPLAB IDE is provided, so no additional hardware is required for use with MPLAB. The kit contains everything needed to start developing embedded applications using either the MPLAB® IDE or the MPIDE.

The Cerebot MX7cK provides 52 I/O pins that support a number of peripheral functions, such as UART,

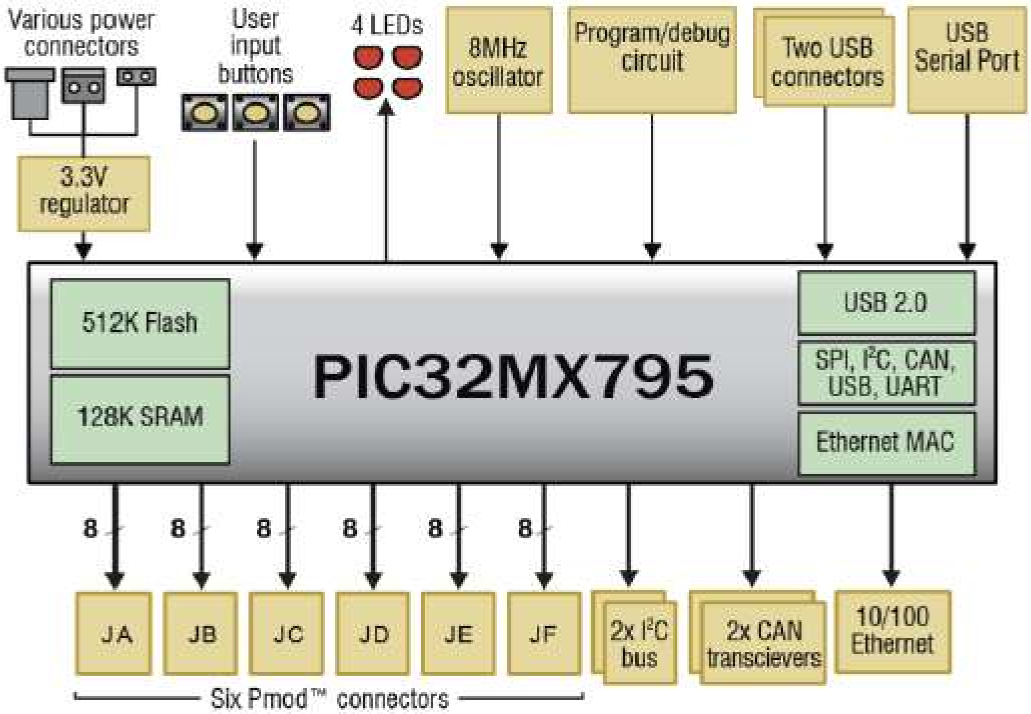

Figure 2: Cerebot MX7cK Circuit Diagram.

SPI and I2C™ ports as well as five pulse width modulated outputs and five external interrupt inputs. Its network and communications features also include a 10/100 Ethernet interface, Full Speed USB 2.0 OTG interface, and dual CAN network interfaces. Ten of the I/O pins can be used as analog inputs in addition to their use as digital inputs and outputs. Figure 2 shows the Cerebot MX7cK Circuit Diagram.

The Cerebot MX7cK can be powered in various ways via USB, or using an external AC-DC power adapter.

Functional Description

The Cerebot MX7cK is designed for embedded control and network communications applications as well as for general microprocessor experimentation. Firmware suitable for many applications can be downloaded to the Cerebot MX7cK's programmable PIC32 microcontroller.

Features of the Cerebot MX7cK include:

- a PIC32MX795F512L microcontroller
- Support for programming and debugging within the Microchip MPLAB development environment
- Support for programming within the chipKIT MPIDE development environment
- Six Pmod connectors for Digilent peripheral module boards
- 10/100 Ethernet
- USB 2.0 compatible Device, Host, and OTG support
- Two CAN network interfaces
- Three push buttons

- Four LEDs
- Multiple power supply options, including USB powered
- ESD protection and short circuit protection for all I/O pins

Features of the PIC32MX795F512L include:

- 512KB internal program flash memory
- 128KB internal SRAM memory
- USB 2.0 compliant full-speed On-The-Go (OTG) controller with dedicated DMA channel
- 10/100 Ethernet controller
- Two CAN network controllers
- Up to four serial peripheral interfaces (SPI)
- Up to six UART serial interfaces
- Up to four I^2C serial interfaces
- Five 16-bit timer/counters
- Five timer capture inputs
- Five compare/PWM outputs
- Sixteen 10-bit analog inputs
- Two analog comparators

The Cerebot MX7cK has a number of input/output connection options, and is designed to work with the Digilent line of Pmod peripheral modules that provide various input and output functions. In addition to the Pmod connectors, the board provides three push buttons and four LEDs for user I/O, as well as providing connections for two I2C busses. A serial EEPROM is provided on one of the I2C buses.

The Cerebot MX7cK features a flexible power supply system with a number of options for powering the board as well as powering peripheral devices connected to the board. It can be USB powered via the debug USB port, the USB UART serial port, or the USB device port. It can also be powered from an external 5V power supply.

Programming Tools

The Cerebot MX7cK can be used with either the Microchip MPLAB® development environment or the chipKIT MPIDE development environment. When used with the MPLAB® IDE, in-system-programming and debugging of firmware running on the PIC32MX795 microcontroller is supported using an on-board programming/debugging circuit licensed from Microchip.

Board Hardware Description

The following describes the various hardware features of the Cerebot MX7cK board and the PIC32MX795F512L microcontroller.

Board Power Supply

There is a **power switch SW1** in the lower left corner of the board. It is possible to place this switch in the ON position to turn the board power on and in the OFF position to turn it off. The Cerebot MX7cK may be USB powered via either the USB debug port, the USB UART port, or the USB device port. Alternatively, the board may be powered via dedicated, "external", power supply connectors.

The **jumper block J3** selects the power source used to provide power to the board. This jumper block provides the following four positions:

- USB – power is supplied by USB device connector J19. This is used when the Cerebot MX7cK is being used to implement a USB bus powered device.
- EXT – Power is supplied by one of the external power connectors.
- DBG – Power is supplied by DEBUG USB connector J15.
- UART – Power is supplied by UART USB connector J2.

Place the shorting block in the appropriate position on J3 for the desired power source for the board.

The Cerebot MX7cK is rated for external power from 3.6 to 5.5 volts DC. Using a voltage outside this range will damage the board and connected devices. For most purposes, when using external power, a regulated 5V supply should be used. If the board is operated from an external supply with a voltage less than 5V, some features won't work correctly.

The PIC32 microcontroller operates at 3.3V and the I/O pins provide 3.3V logic levels. It is possible, in some circumstances, to use the Cerebot MX7cK to operate with 5V logic devices. However, there are two issues to consider when dealing with 5V compatibility for 3.3V logic. The first is protection of 3.3V inputs from damage caused by 5V signals. The second is whether the 3.3V output is high enough to be recognized as a logic high value by a 5V input.

The digital only I/O pins on the PIC32 microcontroller are 5V tolerant. It is safe to apply 5V logic signals directly to these pins without risk of damage to the microcontroller.

The analog capable I/O pins on the PIC32 are not 5V tolerant. The absolute maximum voltage rating for the analog pins is 3.6V. Generally, the analog pins are the pins on I/O port B, however, there are other non-5V tolerant pins on the device.

Refer to the PIC32MX5XX/6XX/7XX Family Data Sheet[2] for more information about which pins on the device are 5V tolerant before applying input signals higher than 3.3V to any pin on the Cerebot MX7cK board.

Pmod™ Connectors

The Cerebot MX7cK has six connectors for connecting Digilent Pmod peripheral modules. The Pmod connectors, labeled JA–JF, are 2x6 pin, right-angle, female pin header connectors. Each connector has an associated power select jumper block labeled JPA–JPF.

Digilent Pmods are a line of small peripheral modules that provide various kinds of I/O interfaces. The Pmod product line includes such things as button, switch and LED modules, connector modules, LCD displays, high current output drivers, various kinds of RF interfaces, and many others.

There are two styles of Pmod connector: six-pin and twelve-pin. Both connectors use standard pin headers with 100mil spaced pins. The six-pin connectors have the pins in a 1x6 configuration, while the twelve-pin connectors use a 2x6 configuration. All of the Pmod connectors on the Cerebot MX7cK are twelve pin connectors.

Six-pin Pmod connectors provide four I/O signals, ground and a switchable power connection. The twelve-pin connectors provide eight I/O signals, two power and two ground pins. The twelve-pin connectors have the signals arranged so that one twelve-pin connector is equivalent to two of the six-pin connectors. Pins 1–4 and 7–10 are the signal pins, pins 5 and 11 are the ground pins and pins 6 and 12 are the power supply pins.

The upper row of pins are numbered 1–6, left to right (when viewed from the top of the board), and the lower row of pins are numbered 7–12, left to right. This is in keeping with the convention that the upper and lower rows of pins can be considered to be two six-pin connectors stacked. When viewed from the end of the connector, pin 1 is the upper right pin and pin 7 is immediately below it.

Each Pmod connector has an associated power select jumper. These are used to select the power supply voltage supplied to the power supply pins on the Pmod connector. They are switchable between either the unregulated power supply, VCC 5V0 or the 3.3V main board supply, VCC3V3. Place the shorting block in the 3V3 position for regulated 3.3V and in the 5V0 position to use the unregulated supply.

Digital Inputs and Outputs

The Cerebot MX7cK board provides access to 48 of the I/O pins from the PIC32MX795 microcontroller via the Pmod connectors. Four additional I/O pins can be accessed via the I^2C connectors, J7 and J8. Any of the pins on the Pmod or I^2C connectors can be individually accessed for digital input or output. Note that when the I^2C signals on J7 or J8 are being used for I^2C communications, they are not available for general purpose I/O.

On PIC32 microcontrollers, the input/output pins are grouped into I/O Ports and are accessed via peripheral registers in the microcontroller. There are seven I/O Ports numbered A–G and each is 16 bits wide. Depending on the particular PIC32 microcontroller, some of the I/O Ports are not present, and not all 16 bits are present in all I/O Ports.

Each I/O Port has four associated registers: **TRIS**, **LAT**, **PORT**, and **ODC**. The registers for I/O Port A are named TRISA, LATA, PORTA and ODCA. The registers for the other I/O Ports are named similarly.

Pmod connector JF, pins 8, 9, and 10 are connected to the signals TCK/RA1, TDI/RA4, and TDO/RA5 respectively. These microcontroller pins are shared between general purpose I/O functions and use by the JTAG controller. The JTAG controller is enabled on reset, so these pins are not available for general purpose I/O until the JTAG controller is disabled. The following statement can be used to disable the JTAG controller:

```
DDPCONbits.JTAGEN = 0;
```

On the Cerebot MX7cK, pin numbers 0-47 are used to access the pins on the Pmod connectors and pin numbers 55-58 are used for the signal pins on the I^2C connectors, J7 and J8. The pin numbers are assigned so that connector JA pin 1 (JA-01) is digital pin 0, JA pin 2 (JA-02) is digital pin 1, and so on. Pins 0-7 are on connector JA, pins 8-15 on JB, pins 16-23 on JC and so on.

Push Buttons and LEDs

Cerebot MX7cK board provides three push button switches for user input and four LEDs for output. The buttons, BTN1 and BTN2 are connected to I/O Port G, bits 6 and 7 respectively. BTN3 is connected to I/O Port A, bit 0. To read the buttons, pins 6 and 7 of I/O Port G and pin 0 of I/O Port A must be configured as inputs by setting the corresponding bits in the TRISG and TRISA registers. The button state is then obtained by reading the PORTG or PORTA registers. When a button is pressed, the corresponding bit will be high ('1'). The pins used by the buttons are dedicated to this use and do not appear on any connector.

Button BTN3 is connected to the signal TMS/RA0 on the PIC32 microcontroller. This microcontroller pin is shared between general purpose I/O functions and use by the JTAG controller. The JTAG controller is enabled on reset, and so BTN3 is not useable as a button input until the JTAG controller is disabled.

The four LEDs are connected to bits 12-15 of I/O Port G. LED 1 is connected to bit 12, LED 2 is connected to bit 13, and so on. These four pins are dedicated to use with the LEDs and do not appear on any connector pin. To use the LEDs, configure the desired bits as outputs by clearing the corresponding bits in the TRISG register. The state of an LED is set by writing values to the LATG register. Setting a bit to 1 will illuminate the LED and setting the bit to 0 will turn it off.

A **reset button** is at the upper right corner of the board. Pressing this button will reset the PIC32 microcontroller.

CPU Clock Source

The PIC32 microcontroller supports numerous clock source options for the main processor operating clock. The Cerebot MX7cK board is designed to operate with either a silicon resonator from Discera, I^2C , for use with the EC oscillator option, or an external crystal, X1, for use with the XT oscillator option. Standard production boards will have an 8Mhz Discera silicon resonator loaded and the EC oscillator option should be used. If I^2C is not loaded, an 8Mhz crystal will be loaded for X1 (on the bottom of the board) and the XT oscillator option should be used. Oscillator options are selected via the configuration settings specified using the #pragma config statement. Use #pragma config POSCMOD=EC to select the EC option and #pragma config POSCMOD=XT to select the XT option.

Using the internal system clock phase-locked loop (PLL), it is possible to select numerous multiples or divisions of the 8Mhz oscillator to produce CPU operating frequencies up to 80Mhz. As shown in Figure 3, the clock circuit PLL provides an input divider, multiplier, and output divider. The external clock frequency (8Mhz) is first divided by the input divider value selected. This is multiplied by the selected multiplier value and then finally divided by the selected output divider. The result is the system clock, SYSCLK, frequency. The SYSCLK frequency is used by the CPU, DMA controller, interrupt controller and pre-fetch cache.

The operating frequency is selected using the PIC32MX795 configuration variables. These are set using the #pragma config statement. Use #pragma config FPLLIDIV to set the input divider, #pragma config FPLLMUL to set the multiplication factor and #pragma config FPLLODIV to set the output divider.

In addition to configuring the SYSCLK frequency, the peripheral bus clock, PBCLK, frequency is also configurable. The peripheral bus clock is used for most peripheral devices, and in particular is the clock used by the timers, and serial controllers (UART, SPI, I2C). The PBLCK frequency is a division of the SYSCLK frequency selected using #pragma config FPBDIV. The PBCLK divider can be set to divide by 1, 2, 4, or 8.

The following example will set up the Cerebot MX7cK for operation with a SYSCLK frequency of 80MHz and a PBCLK frequency of 10MHz:

```
#pragma config FNOSC    = PRIPLL
#pragma config POSCMOD  = EC
#pragma config FPLLIDIV = DIV_2
#pragma config FPLLMUL  = MUL_20
#pragma config FPLLODIV = DIV_1
#pragma config FPBDIV   = DIV_8
```

Documentation for the PIC32 configuration variables can be found in the PIC32MX Configuration Settings guide. This is found using the "Help.Topics..." command in the MPLAB IDE. Also, refer to Appendix B for an example of setting the configuration variables.

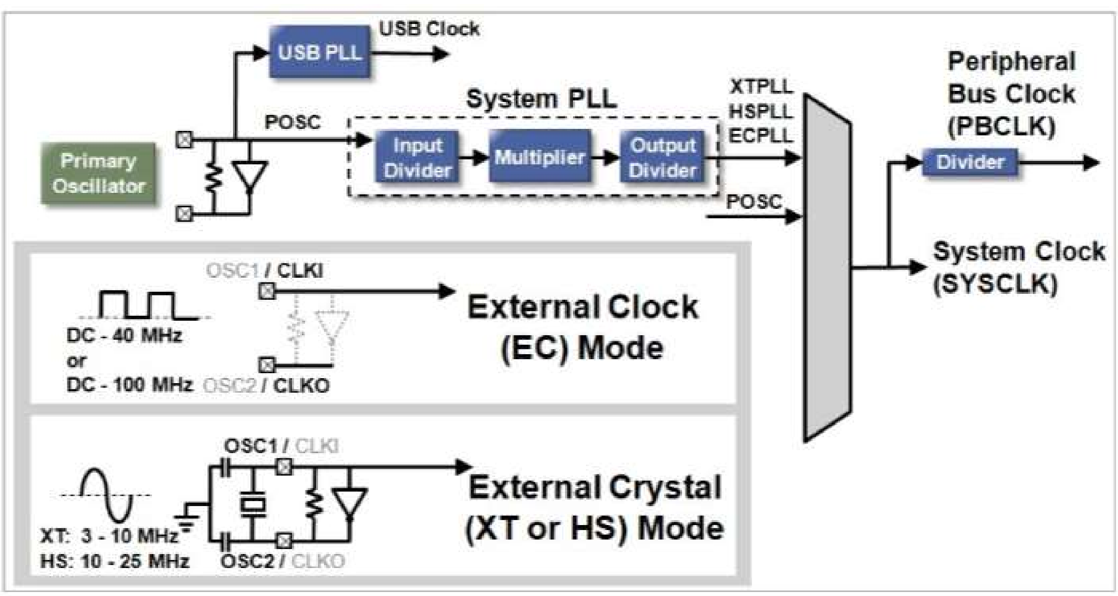

Figure 3: CPU clock source.

Analog Inputs

The PIC32MX795 microcontroller provides a 10-bit analog to digital (A/D) converter that provides up to sixteen analog inputs. The Cerebot MX7cK board provides access to 10 of these inputs via the Pmod connectors. The converted values produced by the A/D converter will be in the range 0–1023.

The following gives the Pmod connector position, digital pin number, and microcontroller I/O port and bit number for the analog inputs:

- A0 – JA-01, digital pin 0, RB02
- A1 – JA-02, digital pin 1, RB03
- A2 – JA-03, digital pin 2, RB04
- A3 – JA-04, digital pin 3, RB06
- A4 – JA-07, digital pin 4, RB07
- A5 – JA-08, digital pin 5, RB08
- A6 – JA-09, digital pin 6, RB09
- A7 – JA-10, digital pin 7, RB10
- A8 – JC-07, digital pin 20, RB15
- A9 – JC-10, digital pin 23, RB14

A/D Converter Voltage Reference

The PIC32 microcontroller provides two voltage reference inputs to the analog to digital converter. Vref- is used set the lower reference level and Vref+ is used to set the upper reference level. These references can be connected to internal references or to external references using two of the analog input pins.

When the internal references are being used, Vref- is connected to VSS and Vref+ is connected to VDD. This means that the voltage input range at the analog input pins is 0V– 3.3V. In this case, an input voltage of 0V will convert to ˜0, an input voltage of 1.65V will convert to ˜511, and an input voltage of 3.3V will convert to ˜1023.

Either one, or both, of the references can be connected to external reference pins. When this is done, the references can be set to voltages other than 0V and 3.3V.

If, for example, both references were selected to use external references, with 1V applied to Vref- and 2V applied to Vref+, the input voltage range at the analog input pins would be from 1V to 2V. An applied voltage of 1V would have a converted value of ˜0, 1.5V would have a converted value of ˜511, and 2V would have a converted value of ˜1023. When both external references are being used, Vref+ must have a higher voltage applied to in than Vref-.

The analog reference input pins appear on Pmod connector JE, pins 9 and 10. Vref- is on pin JE-09, and Vref+ is on pin JE-10. These pins are not available to be used for digital I/O when being used as an external reference.