

# Section 33. Charge Time Measurement Unit (CTMU)

# HIGHLIGHTS

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Note: This family reference manual section is meant to serve as a complement to device data sheets. Depending on the device variant, this manual section may not apply to all dsPIC33E/PIC24E devices.

Please consult the note at the beginning of the "Charge Time Measurement Unit (CTMU)" chapter in the current device data sheet to check whether this document supports the device you are using.

Device data sheets and family reference manual sections are available for download from the Microchip Worldwide Web site at: http://www.microchip.com

# 33.1 INTRODUCTION

The Charge Time Measurement Unit (CTMU) is a flexible analog module that provides accurate differential time measurement between pulse sources and asynchronous pulse generation. By working with other on-chip analog modules, the CTMU can be used to precisely measure time, capacitance, relative changes in capacitance or generate output pulses with a specific time delay. The CTMU is ideal for interfacing with capacitive-based sensors.

The CTMU module includes the following key features:

- Up to 16 channels available for capacitive or time measurement input
- On-chip precision current source
- Four-edge input trigger sources
- Polarity control for each edge source
- Control of edge sequence
- · Control of response to edges
- High precision time measurement
- Time delay of external or internal signal asynchronous to system clock

The CTMU module works in conjunction with the Analog-to-Digital Converter (ADC) module to provide input channels for time or charge measurement. When configured for time delay, and depending on the device variant, the CTMU is connected to one of the analog comparators. The level-sensitive input edge sources can be selected from the following sources: two external inputs, Timers, Output Compare, Input Capture, and Comparator modules. For device-specific information on available input sources, refer to the specific device data sheet.

A block diagram of the CTMU is illustrated in Figure 33-1.





- Note 1: Refer to the specific device data sheet to determine the inputs that are available on your device.
  - **2:** Refer to the specific device data sheet to determine the number of available edge trigger inputs for your device.

Charge Time Measurement Unit (CTMU)

### 33.2 REGISTERS

Depending on the device variant, there are up to three control registers available for the CTMU: CMTUCON1, CTMUCON2, and CTMUICON.

The CTMUCON1 and CTMUCON2 registers (Register 33-1 and Register 33-2) contain control bits for configuring the CTMU module edge source selection, edge source polarity selection, edge sequencing, analog-to-digital trigger, analog circuit capacitor discharge and enables. The CTMUICON register (Register 33-3) has bits for selecting the current source range and current source trim.

Register 33-1:	CTMUCON1: CTMU Control Register 1 <sup>(1)</sup>
----------------	--

R/W-0	U-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0		
CTMUEN —		CTMUSIDL	CTMUSIDL TGEN		EDGSEQEN	IDISSEN	CTTRIG		
bit 15 bit 8									

U-0	U-0	U-0	U-0	U-0	U-0	U-0	U-0
—	—	—	—	—	—		_
bit 7							bit 0

Legend:						
R = Readable bit	R = Readable bit W = Writable bit U = Unimplemented bit, read as '0'					
-n = Value at POR	'1' = Bit is set	'0' = Bit is cleared	x = Bit is unknown			

bit 15	CTMUEN: CTMU Enable bit
	1 = Module is enabled
	0 = Module is disabled
bit 14	Unimplemented: Read as '0'
bit 13	CTMUSIDL: Stop in Idle Mode bit
	1 = Discontinue module operation when device enters Idle mode
	0 = Continue module operation in Idle mode
bit 12	TGEN: Time Generation Enable bit
	1 = Enables edge delay generation
	0 = Disables edge delay generation
bit 10	EDGEN: Edge Enable bit
	1 = Edges are not blocked
	0 = Edges are blocked
bit 10	EDGSEQEN: Edge Sequence Enable bit
	1 = Edge 1 event must occur before Edge 2 event can occur
	0 = No edge sequence is needed
bit 9	IDISSEN: Analog Current Source Control bit
	1 = Analog current source output is grounded
	0 = Analog current source output is not grounded
bit 8	CTTRIG: Trigger Control bit
	1 = Trigger output is enabled
	0 = Trigger output is disabled
bit 7-0	Unimplemented: Read as '0'

**Note 1:** Refer to the specific device data sheet to determine whether this register is available on your particular device.

				-			
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	U-0
EDG1MOD	EDG1POL		EDG1S	EL<3:0> <sup>(1)</sup>		EDG2STAT	EDG1STAT
bit 15							bit 8
<b>D</b> 444 o	<b>D</b> 444 0	D MM O	<b>D</b> 444 o	<b>D</b> 444 o	<b>D</b> 444 o		
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	0-0	0-0
EDG2MOD	EDG2POL		EDG2S	EL<3:0>(1)			—
bit 7							bit 0
Legend:							
R = Readable	bit	W = Writable b	it	U = Unimpler	nented bit. rea	ad as '0'	
-n = Value at	POR	'1' = Bit is set		'0' = Bit is cle	ared	x = Bit is unkr	nown
bit 15	<b>EDG1MOD:</b> I 1 = Input is ed 0 = Input is le	nput mode seleo dge-sensitive evel-sensitive	ction bit				
bit 14	EDG1POL: E	dge 1 Polarity S	elect bit				
	1 = Edge 1 p 0 = Edge 1 p	rogrammed for a	a positive lev a negative le	vel response vel response			
bit 13-10	EDG1SEL<3	: <b>0&gt;:</b> Edge 1 Sou	rce Select b	its <sup>(1)</sup>			
	1111 = Edge 1110 = Edge 1101 = Edge 1010 = Edge 1010 = Edge 1000 = Edge 0111 = Edge 0111 = Edge 0110 = Edge 0101 = Edge 0100 = Edge 0011 = Edge 0010 = Edge 0010 = Edge	1 Source 15 se 1 Source 14 se 1 Source 13 se 1 Source 12 se 1 Source 12 se 1 Source 10 se 1 Source 9 sele 1 Source 8 sele 1 Source 6 sele 1 Source 5 sele 1 Source 3 sele 1 Source 2 sele 1 Source 2 sele 1 Source 1 sele 1 Source 0 sele	lected le				
bit 9	<b>EDG2STAT:</b> E 1 = Edge 2 e 0 = Edge 2 e	Edge 2 Status bi event has occurre event has not occ	t ed curred				
bit 8	<b>EDG1STAT:</b> E 1 = Edge 1 e 0 = Edge 1 e	Edge 1 Status bi event has occurre event has not occ	t ed curred				
bit 7	<b>EDG2MOD:</b> I 1 = Input is ed 0 = Input is le	nput Mode Sele dge-sensitive vel-sensitive	ction bit				
bit 6	EDG2POL: E	dge 2 Polarity S	elect bit				
	1 = Edge 2 p 0 = Edge 2 p	orogrammed for a programmed for a	a positive lev a negative le	vel response			

### Register 33-2: CTMUCON2: CTMU Control Register 2

Note 1: Refer to the specific device data sheet for edge source types and assignments.

Register 33-2: CTMUCON2: CTMU Control Register (Continued)2

- EDG2SEL<3:0>: Edge 2 Source Select bits(1) bit 5-2 1111 = Edge 2 Source 15 selected 1110 = Edge 2 Source 14 selected 1101 = Edge 2 Source 13 selected 1100 = Edge 2 Source 12 selected 1011 = Edge 2 Source 11 selected 1010 = Edge 2 Source 10 selected 1001 = Edge 2 Source 9 selected 1000 = Edge 2 Source 8 selected 0111 = Edge 2 Source 7 selected 0110 = Edge 2 Source 6 selected 0101 = Edge 2 Source 5 selected 0100 = Edge 2 Source 4 selected 0011 = Edge 2 Source 3 selected 0010 = Edge 2 Source 2 selected 0001 = Edge 2 Source 1 selected 0000 = Edge 2 Source 0 selected bit 1-0 Unimplemented: Read as '0'
- Note 1: Refer to the specific device data sheet for edge source types and assignments.

R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0						
		ITRIM	<5:0>			IRNG<1:0> <sup>(1)</sup>							
bit 15							bit 8						
0-0	0-0	0-0	0-0	0-0	0-0	0-0	U-0						
	_	—		—	_	—	—						
Dit 7							bit U						
l egend:													
R = Readat	ole bit	W = Writable b	oit	U = Unimplen	nented bit, rea	ad as '0'							
-n = Value a	at POR	'1' = Bit is set		'0' = Bit is clea	ared	x = Bit is unknown							
	• 000001 = Minimum positive change from nominal current 000000 = Nominal current output specified by IRNG<1:0> 111111 = Minimum negative change from nominal current •												
	•												
	100001 = M	100001 = Maximum negative change from nominal current											
dit 9-8	IRNG<1:0>: 11 = 100 × I 10 = 10 × ba 01 = Base c 00 = Reserv	Current Source base current ase current urrent level (0.55 red	κange Select μΑ nominal)	t dits'''									
bit 7-0	Unimpleme	nted: Read as '0	,										

### Register 33-3: CTMUICON: CTMU Current Control Register

Note 1: Refer to the specific device data sheet to determine which setting is available on your particular device.

## 33.3 CTMU OPERATION

The CTMU works by using a fixed current source to charge a circuit. The type of circuit depends on the type of measurement is made. In the case of charge measurement, the current and the amount of time the current is applied to the circuit is fixed. The amount of voltage read by the ADC is then a measurement of the capacitance of the circuit. In the case of time measurement, the current and the capacitance of the circuit is fixed. In this case, the voltage read by the ADC is then representative of the amount of time elapsed from the time the current source starts and stops charging the circuit.

If the CTMU is used as a time delay, both capacitance and current source are fixed, and the voltage supplied to the comparator circuit also fixed. The delay of a signal is determined by the amount of time it takes the voltage to charge to the comparator threshold voltage.

### 33.3.1 Theory of Operation

The operation of the CTMU is based on the equation for charge, as shown in Equation 33-1.

### Equation 33-1:

$$I = C \cdot \frac{dV}{dT}$$

The amount of charge measured in coulombs in a circuit is defined as current in amperes (I) multiplied by the amount of time in seconds that the current flows (t). Charge is also defined as the capacitance in farads (C) multiplied by the voltage of the circuit (V), as shown in Equation 33-2.

#### Equation 33-2:

$$I \cdot t = C \cdot V$$

The CTMU module provides a constant current source. The ADC is used to measure (V) in the equation, leaving two unknowns: capacitance (C) and time (t). Equation 33-2 can be used to calculate capacitance or time either using the known fixed capacitance of the circuit, as shown in Equation 33-3, or using a fixed time that the current source is applied to the circuit, as shown in Equation 33-4.

#### Equation 33-3:

$$= \frac{(C \cdot V)}{I}$$

t

Equation 33-4:

$$C = \frac{(I \cdot t)}{V}$$

### 33.3.2 Current Source

At the core of the CTMU is a precision current source, designed to provide a constant reference for measurements. The level of current is user-selectable across three ranges or a total of two orders of magnitude, with the ability to trim the output in  $\pm 2\%$  increments (nominal). The current range is selected by the IRNG<1:0> bits (CTMUICON<9:8>), with a value of '00' representing the lowest range.

Current trim is provided by the ITRIM<5:0> bits (CTMUICON<15:10>). These six bits allow trimming of the current source in steps of approximately 2% per step. One half of the range adjusts the current source positively and the other half reduces the current source. A value of '000000' is the neutral position (no change). A value of '100000' is the maximum negative adjustment (approximately -62%), and '011111' is the maximum positive adjustment (approximately +62%).

## 33.3.3 Edge Selection and Control

CTMU measurements are controlled by edge events occurring on the module's input channels. Each channel, referred to as Edge 1 and Edge 2, can be configured to receive input pulses from one of the edge input pins (CTEDx), and from some peripherals such as Timers, Output Compare Module, Input Capture, and Comparators. Refer to the specific device data sheet to determine which setting is available on each particular device. The input channels are level-sensitive, responding to the instantaneous level on the channel rather than a transition between levels. The inputs are selected using the EDG1SEL and EDG2SEL bit pairs (CTMUCON2<5:2> and CTMUCON2<13:9>).

In addition to source, each channel can be configured for event polarity using the EDGE2POL and EDGE1POL bits (CTMUCON2<14:6>). The input channels can also be filtered for an edge event sequence (Edge 1 occurring before Edge 2) by setting the EDGSEQEN bit (CTMUCON1<10>).

### 33.3.4 Edge Status

The CTMUCON register also contains two status bits, EDG2STAT and EDG1STAT (CTMUCON2<9:8>). Their primary function is to show if an edge response has occurred on the corresponding channel. The CTMU automatically sets a bit when an edge response is detected on its channel. The level-sensitive nature of the input channels also means that the status bits become set immediately if the channel's configuration is changed and the input channels remain at their current state.

The module uses the edge status bits to control the current source output to external analog modules like ADC. Current is supplied to external modules only when one (but not both) of the status bits is set, and shuts current off when both the bits are either set or cleared. This allows the CTMU to measure current only during the interval between edges. After both status bits are set, it is necessary to clear them before another measurement is taken. If possible, both the bits should be cleared simultaneously to avoid re-enabling the CTMU current source.

In addition to being set by the CTMU hardware, the edge status bits can also be set by software. This is also the user's application to manually enable or disable the current source. Setting either one (but not both) of the bits enables the current source. Setting or clearing both bits at once disables the source.

### 33.3.5 Interrupts

The CTMU sets its interrupt flag, CTMUIF (IFS4<13>), whenever the current source is enabled and disabled. An interrupt is generated only if the corresponding interrupt enable bit, CTMUIE (IEC4<13>), is also set. If edge sequencing is not enabled (that is Edge 1 must occur before Edge 2), it is necessary to monitor the edge status bits and determine which edge occurred last and caused the interrupt.

# 33.4 CTMU MODULE INITIALIZATION

The following sequence is a general guideline that can be used to initialize the CTMU module:

- 1. Select the current source range using the IRNG<1:0> bits (CTMUICON<9:8>).
- 2. Adjust the current source trim using the ITRIM<5:0> bits (CTMUICON<15:10>).
- 3. Configure the edge input sources for Edge 1 and Edge 2 by setting the EDG1SEL and EDG2SEL bits (CTMUCON2<13:10> and CTMUCON2<5:2>).
- Configure the input polarities for the edge inputs using the EDG1POL and EDG2POL bits (CTMUCON2<14:6>). The default configuration is for negative edge polarity (high-to-low transitions).
- 5. Enable edge sequencing using the EDGSEQEN bit (CTMUCON1<10>). By default, edge sequencing is disabled.
- 6. Select the operating mode (Measurement or Time Delay) with the TGEN bit (CTMUCON1<12>). The default mode is Time/Capacitance Measurement.
- Configure the module to automatically trigger an analog-to-digital conversion when the second edge event has occurred using the CTTRIG bit (CTMUCON1<8>). The conversion trigger is disabled by default.
- 8. Discharge the connected circuit by setting the IDISSEN bit (CTMUCON1<9>); after waiting a sufficient time for the circuit to discharge, clear IDISSEN.
- 9. Disable the module by clearing the CTMUEN bit (CTMUCON1<15>).
- 10. Clear the Edge Status bits, EDG2STAT and EDG1STAT (CTMUCON2<9:8>).
- 11. Enable both edge inputs by setting the EDGEN bit (CTMUCON1<11>).
- 12. Enable the module by setting the CTMUEN bit (CTMUCON1<15>).

Depending on the type of measurement or pulse generation being performed, one or more additional modules may also need to be initialized and configured with the CTMU module:

- Edge Source Generation: In addition to the external edge input pins, other peripherals such as Timers, Output Compare, Input Capture, and Comparators can be used as edge sources for the CTMU
- Capacitance or Time Measurement: The CTMU module uses the ADC to measure the voltage across a capacitor that is connected to one of the analog input channels.
- Pulse Generation: When generating system clock independent output pulses, the CTMU module uses one analog Comparator module and the associated comparator voltage reference

For specific information on initializing these modules, refer to the applicable chapter of the *"dsPIC33E/PIC24E Family Reference Manual"* for the appropriate module.

# 33.5 CALIBRATING THE CTMU MODULE

The CTMU requires calibration for precise measurements of capacitance and time, and also for accurate time delay. If the application only requires measurement of a relative change in capacitance or time, calibration is usually not necessary. An example of this type of application would include a capacitive touch switch, in which the touch circuit has a baseline capacitance, and the added capacitance of the human body changes the overall capacitance of a circuit.

If actual capacitance or time measurement is required, two hardware calibrations must take place: the current source needs calibration to set it to a precise current, and the circuit being measured needs calibration to measure and/or nullify all other capacitance other than that to be measured.

### 33.5.1 Current Source Calibration

The current source onboard the CTMU module has a range of  $\pm 62\%$  nominal for each of three current ranges. Therefore, for precise measurements, it is possible to measure and adjust this current source by placing a high precision resistor, RCAL, on the analog channel ANx. An example circuit is illustrated in Figure 33-2. The current source measurement is performed using the following steps:

- 1. Initialize the ADC.
- 2. Initialize the CTMU by configuring the module for Pulse Generation mode (TGEN = 1).
- 3. Enable the current source by setting EDG1STAT (CTMUCON1<8>).
- 4. Issue settling time delay.
- 5. Perform analog-to-digital conversion.
- 6. Calculate the current source current using I = V/RCAL, where RCAL is a high precision resistance and V is measured by performing an analog-to-digital conversion.

The CTMU current source may be trimmed with the trim bits in CTMUICON using an iterative process to get an exact desired current. Alternatively, the nominal value without adjustment may be used and it may be stored by the software for use in all subsequent capacitive or time measurements.

When the module is configured for pulse generation delay by setting the TGEN bit (CTMUCON1<12>), the internal current source is connected to one of the inputs of a Comparator module. Figure 33-2 illustrates the external connections for current source calibration and the relationship of the different analog modules required.

To calculate the value for *RCAL*, the nominal current must be chosen, and then the resistance can be calculated. For example, if the ADC reference voltage is 3.3V, use 70% of full scale, or 2.31V as the desired approximate voltage to be read by the ADC. If the range of the CTMU current source is selected to be 0.55  $\mu$ A, the resistor value needed is calculated as *RCAL* = 2.31V/0.55  $\mu$ A, for a value of 4.2 MΩ. Similarly, if the current source is chosen to be 5.5  $\mu$ A, *RCAL* will be 420,000Ω, and 42,000Ω if the current source is set to 55  $\mu$ A.

### Figure 33-2: CTMU Current Source Calibration Circuit



A value of 70% full-scale voltage is chosen to ensure that the ADC was in a range that is well above the noise floor. If an exact current is chosen that is to incorporate the trimming bits from CTMUICON, the resistor value of RCAL may need to be adjusted accordingly. RCAL may be adjusted to allow for available resistor values. RCAL should be of the highest precision available, the amount of precision required for the circuit that the CTMU will be used to measure. A recommended minimum precision will be 0.1% tolerance.

The following examples show a typical method for performing a CTMU current calibration. Example 33-1 shows how to initialize the ADC and the CTMU; this routine is typical for the applications using both the modules. Example 33-2 shows one method for the actual calibration routine. This method manually triggers the ADC and it is performed to demonstrate the entire stepwise process. It is also possible to automatically trigger the conversion by setting the CTTRIG bit (CTMUCON1<8>).

# Example 33-1: Setup for CTMU Calibration Routines for Devices with CTMUCON1 and CTMUCON2 Registers

<pre>#include "p33Exxxx.h"</pre>								
/*****	******							
/ Set up CTMU ************************************								
/ * * * * * * * * * * * * * * * * * * *	***************************************							
	S							
void setup(void)								
{ //CTMUCON - CTMU Control regis	ster							
$CTMUCON1 = 0 \times 1000;$	//make sure CTMU is disabled							
$CTMUCON2 = 0 \times C0C0;$								
//CTMU continues to run wh	nen emulator is stopped, CTMU continues							
//to run in idle mode, Time	e Generation mode enabled, Edges are							
//blocked. No edge sequence	e order, Analog current source not							
//grounded, trigger output	disabled, Edge 2 polarity = positive level,							
//Edge 2 source = source 0	, Edge 1 polarity = positive level,							
<pre>//Edge 1 source = source 0</pre>	, Set Edge status bits to zero							
//CTMUICON - CTMU Current Cont	trol Register							
$CTMUICON = 0 \times 0100;$	// 0.55uA, Nominal - No Adjustment							
	*****							
/ Set up Analog-to-Digital Conver								
$m_{\rm D} r_{\rm O} p_{\rm i} + a m_{\rm D} r_{\rm O} p_{\rm i} = 1$	//Cot abannol 2 ag an innut							
$\frac{1}{10000000000000000000000000000000000$	//Set channel z as an input							
AD1CHS0 = 0x002	//							
AD1CSSL = 0x0000;	// Server the analog chamicr(2)							
$AD1CON1 = 0 \times 8000;$	//Turn On ADC, continue in Idle mode,							
	//unsigned fractional format, Clear SAMP							
	//bit to start conversion, Sample when							
	//SAMP bit is set, sampling on hold							
$AD1CON2 = 0 \times 0000;$	//VR+ = AVDD, V- = AVSS, Don't scan,							
	//always use MUX A inputs							
AD1CON3 = $0 \times 0000;$	//ADC uses system clock,							
$\checkmark$	//conversion clock = 1xTcy							
}								



# Example 33-2: Current Calibration Routine for Devices with CTMUCON1 and CTMUCON2 Registers

### 33.5.2 Capacitance Calibration

A small amount of capacitance from the internal ADC sample capacitor and stray capacitance from the circuit board traces and pads that affect the precision of capacitance measurements. A measurement of the stray capacitance can be taken to ensure the desired capacitance to be measured is removed. The measurement is then performed using the following steps:

- 1. Initialize the ADC and the CTMU.
- 2. Set EDG1STAT (= 1).
- 3. Wait for a fixed delay of time *t*.
- 4. Clear EDG1STAT.
- 5. Perform an analog-to-digital conversion.
- 6. Calculate the stray and analog-to-digital sample capacitances using Equation 33-5.

Equation 33-5:

$$C_{OFFSET} = C_{STRAY} + C_{AD} = \frac{(I \cdot t)}{V}$$

where I is known from the current source measurement step, t is a fixed delay and V is measured by performing an analog-to-digital conversion.

This measured value is then stored and used for calculations of time measurement, or subtracted for capacitance measurement. For calibration, it is expected that the capacitance of CSTRAY + CAD is approximately known. *CAD* is approximately 4 pF.

An iterative process must be used to adjust the time t, that the circuit is charged to obtain a reasonable voltage reading from the ADC. The value of t may be determined by setting *COFFSET* to a theoretical value, then solving for t. For example, if *CSTRAY* is theoretically calculated to be 11 pF, and V is expected to be 70% of VDD, or 2.31V, t would be equal to Equation 33-6 or 63  $\mu$ s.

#### Equation 33-6: :

$$(4 \ pF + 11 \ pF) \bullet \frac{2.31V}{0.55\mu A}$$

A typical routine for CTMU capacitance calibration is shown in Example 33-3.



```
#include "p33Exxxx.h"
                                      //@ 7.37 MHz INTFRC = 62.5 us.
#define COUNT 28
#define ETIME (COUNT+2)/7.37*2
                                    //time in uS
#define DELAY asm("repeat #228");Nop(); //(228+2)/(7.37/2) = 62.5us
                                         //the repeat count and the COUNT
                                         //define must be identical
#define ADSCALE 1023
                                      //for unsigned conversion 10 sig bits
#define ADREF 3.3
                                      //Vdd connected to ADC Vr+
int main(void)
{
   int i;
   int j = 0;
                                      //index for loop
   unsigned int Vread = 0;
   float CTMUISrc, CTMUCap, Vavg, VTot, Vcal;
   //Initialize the ADC and CTMU module. See Example
   setup();
                                               the CTMU
   CTMUCON1bits.CTMUEN = 1;
                                      //Enable
   for(j=0;j<10;j++)</pre>
   {
       AD1CON1bits.SAMP = 1;
                                       /Manual sampling start
       CTMUCON1bits.IDISSEN= 1;
                                      //drain any charge on the circuit
       DELAY;
                                      //wait 62.5 us
       CTMUCON1bits.IDISSEN = 0;
                                      //end drain of circuit
       CTMUCON2bits.EDG1STAT =
                                      //Begin charging the circuit
                               1;
                                      //using the CTMU current source
       DELAY;
                                      //wait for 62.5 us for circuit
                                      //to charge
       CTMUCON2bits.EDG1STAT = 0;
                                      //Stop charging circuit and begin
                                      //Analog-to-Digital conversion
       AD1CON1bits.SAMP = 0;
       while(!IFSObits.AD1IF);
                                      //Wait for conversion to complete
       Vread = ADC1BUF0;
                                      //Get the value from the ADC
       IFSObits.AD1IF = 0;
                                      //Clear AD1IF
       VTot += Vread;
                                      //Add the reading to the total
   Vavg = (VTot/10); //Average of 10 readings
   Vcal = (Vavg/ADSCALE*ADREF);
   CTMUISrc = 5.5;
                                      //CTMUISrc is in 1/100ths of uA
                                      //use the nominal value or the value
                                      //calculated in Example 33-2
   CTMUCap = (CTMUISrc*ETIME/Vcal)/100; //time is in us
                                          //CTMUCap is in pF
```

## 33.6 MEASURING CAPACITANCE WITH THE CTMU

The two methods of measuring capacitance with the CTMU are:

- · Absolute Capacitance Measurement: The actual capacitance value is required
- Relative Charge Measurement: The actual capacitance value is not required instead an indication of change in capacitance is required.

### 33.6.1 Absolute Capacitance Measurement

For absolute capacitance measurements, both the current and capacitance calibration steps found in **33.5** "Calibrating the CTMU Module" should be followed. Capacitance measurements are then performed using the following steps:

- 1. Initialize the ADC.
- 2. Initialize the CTMU.
- 3. Set EDG1STAT.
- 4. Wait for a fixed delay, *T*.
- 5. Clear EDG1STAT.
- 6. Perform an analog-to-digital conversion.
- 7. Calculate the total capacitance, CTOTAL = (I \* T)/V, where *I* is known from the current source measurement step (33.5.1 "Current Source Calibration"), *T* is a fixed delay and *V* is measured by performing an analog-to-digital conversion
- 8. Subtract the stray and analog-to-digital capacitance (*COFFSET* from 33.5.2 "Capacitance Calibration") from *CTOTAL* to determine the measured capacitance.

### 33.6.2 Relative Charge Measurement

An application may not require precise capacitance measurements. For example, when detecting a valid press of a capacitance-based switch, detecting a relative change of capacitance is of interest. In this application, when the switch is open (or not touched), the total capacitance is the capacitance of the combination of the board traces, the ADC, etc. A larger voltage will be measured by the ADC. When the switch is closed (or is touched), the total capacitance is larger due to the addition of the capacitance of the human body to the above listed capacitances, and a smaller voltage will be measured by the ADC.

Detecting capacitance changes can be done with the CTMU using these steps:

- 1. Initialize the ADC and the CTMU.
- 2. Set EDG1STAT.
- 3. Wait for a fixed delay.
- 4. Clear EDG1STAT.
- 5. Perform an analog-to-digital conversion.

The voltage measured by performing the analog-to-digital conversion is an indication of the relative capacitance. In this case, no calibration of the current source or circuit capacitance measurement is required. A sample software routine for a capacitive touch switch is shown in Example 33-4.

#### #include "p33Exxxx.h" #define COUNT //@ 7.37 MHz = 125uS. 459 #define DELAY asm("repeat #459");Nop(); //(459+2)/(7.37/2) = 125us //the repeat count and the COUNT //define must be identical #define OPENSW 1000 //Unpressed switch value #define TRIP 300 //Difference between pressed //and unpressed switch #define HYST 65 //amount to change //from pressed to unpressed #define PRESSED 1 #define UNPRESSED 0 int main(void) { unsigned int Vread; //storage for reading unsigned int switchState; int i; //Initialize the ADC and CTMU module. See Example 33-1. setup(); CTMUCON1bits.CTMUEN = 1; //Enable the CTMU AD1CON1bits.SAMP = 1; //Manual sampling start CTMUCON1bits.IDISSEN = 1; //drain charge on the circuit DELAY; //wait 125us CTMUCON1bits.IDISSEN = 0; \/end drain of circuit CTMUCON2bits.EDG1STAT = 1; //Begin charging the circuit //using CTMU current source DELAY; //wait for 125us CTMUCON2bits.EDG1STAT = 0; //Stop charging circuit IFSObits.AD1IF = 0; //make sure ADC Interrupt is not set AD1CON1bits.SAMP = 0; //and begin Analog-to-Digital conversion while(!IFS0bits.AD1IF); //Wait for conversion to complete AD1CON1bits.DONE = 0; Vread = ADC1BUF0; //Get the value from the ADC if(Vread < OPENSW - TRIP) switchState = PRESSED; } else if(Vread > OPENSW - TRIP + HYST) { switchState = UNPRESSED; }

# Example 33-4: Routine for Capacitive Touch Switch for Devices with CTMUCON1 and CTMUCON2 Registers

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### 33.7 MEASURING TIME WITH THE CTMU MODULE

Time can be precisely measured after the ratio (C/I) is measured from the current and capacitance calibration step by following these steps:

- 1. Initialize the ADC and the CTMU.
- 2. Set EDG1STAT.
- 3. Set EDG2STAT.
- 4. Perform an analog-to-digital conversion.
- 5. Calculate the time between edges as T = (C/I) \* V, where *I* is calculated in the current calibration step (33.5.1 "Current Source Calibration"), *C* is calculated in the capacitance calibration step (33.5.2 "Capacitance Calibration") and *V* is measured by performing the analog-to-digital conversion.

It is assumed that the time measured is small enough that the capacitance *CoFFSET* provides a valid voltage to the ADC. For the smallest time measurement, set the ADC Channel Select register (AD1CHS0) to an unused ADC channel; the corresponding pin for which is not connected to any circuit board trace. This minimizes added stray capacitance by keeping the total circuit capacitance close to the ADC (4-5 pF). To measure longer time intervals, an external capacitor may be connected to an ADC channel, and this channel is selected when making a time measurement.

# 33.8 CREATING A DELAY WITH THE CTMU MODULE

A unique feature of the CTMU module is to generate system clock independent output pulses based on an external capacitor value. This is accomplished using the internal comparator voltage reference module, the Comparator module input pin, and an external capacitor. The pulse is output onto the CTPLS pin. To enable this mode, you need to set the TGEN bit (CTMUCON1<12>).

An example circuit is illustrated in Figure 33-3. *CPULSE* is chosen by the user to determine the output pulse width on CTPLS. The pulse width is calculated by T = (CPULSE/I)\*V, where *I* is known from the current source measurement step (33.5.1 "Current Source Calibration") and *V* is the internal reference voltage (CVREF).

An example use of this feature is for interfacing with variable capacitive-based sensors like a humidity sensor. As the humidity varies, the pulse-width output on CTPLS will vary. The CTPLS output pin can be connected to an input capture pin and the varying pulse width is measured to determine the humidity in the application.

Follow these steps to use this feature:

- 1. Initialize the Comparator module.
- 2. Initialize the comparator voltage reference.
- 3. Initialize the CTMU and enable time delay generation by setting the TGEN bit.
- 4. Set EDG1STAT.
- 5. When *CPULSE* charges to the value of the voltage reference trip point, an output pulse is generated on CTPLS.

# Figure 33-3: Typical Connections and Internal Configuration for Pulse Delay Generation



## 33.9 MEASURING ON-CHIP TEMPERATURE WITH THE CTMU

The CTMU module can be used to measure the internal temperature of the device through an internal diode that is available for such purposes. When EDGE 1 is not equal to EDGE 2 and TGEN = 0, the current is steered into the temperature sensing diode. The voltage across the diode is available as an input to the ADC module. Refer to the specific device data sheet for information on the analog channel on which the diode is connected.

Figure 33-4 illustrates how this module can be used for temperature measurement. As the temperature rises, the voltage across the diode will drop by about 300 mV over a 150°C range. Selecting a higher current drive strength will raise the voltage value by a few 100 mV.

Figure 33-4: CTMU Temperature Measurement Circuit



At 25°C, the forward voltage of the temperature diode is 0.83V. The rate of change between the forward voltage of the diode and its temperature is 1.87 mV per degree Celsius. The formula shown in Equation 33-7 can be used to calculate the forward voltage.

### Equation 33-7: Voltage versus Temperature

$$Vf(\text{in mV}) = 783.24mV + 1.87mV \cdot T$$

Where:

Vf = Forward voltage of temperature diode

T = Temperature in degrees Celsius

# 33.10 OPERATION DURING SLEEP OR IDLE MODE

### 33.10.1 Sleep Mode

When the device enters Sleep mode, the CTMU module current source is always disabled. If the CTMU is performing an operation that depends on the current source when Sleep mode is invoked, the operation may not terminate correctly. Capacitance and time measurements may return erroneous values.

### 33.10.2 Idle Mode

The behavior of the CTMU in Idle mode is determined by the CTMUSIDL bit (CTMUCON1<13>). If CTMUSIDL is cleared, the module will continue to operate in Idle mode. If CTMUSIDL is set, the CTMU module's current source is disabled when the device enters Idle mode. If the CTMU module is performing an operation when Idle mode is invoked, the results will be similar to those with Sleep mode.

# 33.11 EFFECTS OF A RESET ON CTMU

Upon Reset, all registers of the CTMU are cleared. This leaves the CTMU module disabled, its current source is turned off and all configuration options return to their default settings. The module needs to be reinitialized following any Reset.

If the CTMU is in the process of taking a measurement at the time of Reset, the measurement will be lost. A partial charge may exist on the circuit that was being measured, and should be properly discharged before the CTMU makes subsequent attempts to make a measurement. The circuit is discharged by setting and then clearing the IDISSEN bit (CTMUCON1<9>) while the ADC is connected to the appropriate channel.

# 33.12 REGISTER MAPS

A summary of the registers associated with the dsPIC33E/PIC24E CTMU is given in Table 33-1.

### Table 33-1: CTMU Register Map

File Name	Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	All Resets
CTMUCON1	1) CTMUEN	—	CTMUSIDL	TGEN	EDGEN	EDGSEQEN	IDISSEN	CTTRIG	_	_	-	—	_		_	—	0000
CTMUCON2	1) EDG1MOD	EDG1POL		EDG18	SEL<3:0>		EDG2STAT	EDG1STAT	EDG2MOD	EDG2POL		EDG2S	EL<3:0>			_	0000
CTMUICON			ITRIM<	<5:0>			IRNG	<1:0>	_	_	_	_	_	_	_	_	0000

Legend: — = unimplemented, read as '0'. Reset values are shown in hexadecimal.

Note 1: Refer to the specific device data sheet to determine whether this register is available on your particular device.

# 33.13 RELATED APPLICATION NOTES

This section lists application notes that are related to this section of the manual. These application notes may not be written specifically for the dsPIC33E/PIC24E device family, but the concepts are pertinent and could be used with modification and possible limitations. The current application notes related to the Charge Time Measurement Unit (CTMU) module are:

Title	Application Note #
Microchip CTMU for Capacitive Touch Applications	AN1250
Water-Resistant Capacitive Sensing	AN1286
mTouch <sup>™</sup> Conducted Noise Immunity Techniques for the CTMU	AN1317
Techniques for Robust Touch Sensing Design	AN1334

**Note:** Visit the Microchip web site (www.microchip.com) for additional application notes and code examples for the dsPIC33E/PIC24E family of devices.

# 33.14 REVISION HISTORY

# Revision A (May 2011)

This is the initial released version of this document.

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

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