Overview of Charge Time Measurement Unit (CTMU)

Welcome to the "Overview of Charge Time Measurement Unit" Webinar. My name is Padmaraja Yedamale, I am an applications engineer working in Advanced Microcontroller and Architecture Division at Microchip Technology.

In this webinar I am going to explain the new peripheral on PIC microcontrollers called "Charge Time Measurement Unit"(CTMU). This peripheral is ideal for capacitive touch application and many other applications.

The agenda for this webinar is as follows..

Agenda

An Overview of Charge Time Measurement Unit

In this webinar are going to see the

Agenda

- **What is CTMU and Key Features**
  - **CTMU functional block diagram**

see the construction of CTMU, features of CTMU in detail by explaining the block diagram of CTMU.

Agenda

- **What is CTMU and Key Features**
  - **CTMU functional block diagram**
- **How CTMU is used for Capacitive Touch Sensing application**

An Overview of Charge Time Measurement Unit   Slide 4

Also I will explain how CTMU can be used for Capacitive touch application and few examples of capacitive touch applications.

Agenda

- **What is CTMU and Key Features**
  - **CTMU functional block diagram**
- **How CTMU is used for Capacitive Touch Sensing application**
- **Other applications using CTMU**

An Overview of Charge Time Measurement Unit Slide 5

CTMU can be used for other applications as well. I will describe how CTMU can be used for other applications.

Agenda

- **What is CTMU and Key Features**
  - **CTMU functional block diagram**
- **How CTMU is used for Capacitive Touch Sensing application**
- **Other applications using CTMU**
- **Resources available from Microchip**

An Overview of Charge Time Measurement Unit Slide 6

Finally I will explain the resources and collaterals available from Microchip to implement your application easy and fast.

Key features of CTMU

- **CTMU stand for**
  "Charge Time Measurement Unit"

An Overview of Charge Time Measurement Unit   Slide 7

Now let us see what CTMU is. As I mentioned earlier, CTMU stands for "Charge Time Measurement Unit".

Key features of CTMU

- **CTMU stand for**
  "Charge Time Measurement Unit"

- **Constant current source**
  - **Ranges: 0.55uA, 5.5uA and 55uA source**
  - **Trim-able up to +/- 62% on each range**

What are the features of CTMU?

• The heart of the CTMU is a constant current source, with choices of three ranges, with trim capability in each range. The three ranges in the current implementation are 0.55uA, 5.5uA and 55uA. Each of these current ranges can be trimmed up to plus or minus 62 percent giving a total range of 0.2uA to approximately 90uA of constant current source.

Key features of CTMU

- **CTMU stand for**
  "Charge Time Measurement Unit"

- **Constant current source**
  - **Ranges: 0.55uA, 5.5uA and 55uA source**
    - **Trim-able up to +/- 62% on each range**
- **Works in conjunction with ADC**

•The CTMU channels work in conjunction with Analog to Digital converters on the PIC microcontrollers.

Key features of CTMU

- **CTMU stand for**
  "Charge Time Measurement Unit"

- **Constant current source**
  - **Ranges: 0.55uA, 5.5uA and 55uA source**
  - **Trim-able up to +/- 62% on each range**
- **Works in conjunction with ADC**
- **High precision Time measurement asynchronous to the system clock**

•CTMU can be used for high precision time measurement, such as in flow meter and other metering applications

Key features of CTMU

- **CTMU stand for**
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  - **Trim-able up to +/- 62% on each range**
- **Works in conjunction with ADC**
- **High precision Time measurement asynchronous to the system clock**
- **Triggered by external or internal sources**
  - **Timer1, output compare, software trigger**
 - **Rising Edge, Falling edge combination of one or two external pins**

•There are many trigger sources for CTMU, as shown here, CTMU can be triggered using Timer1 or any output compare module or it can be triggered by software instructions. Also CTMU can be triggered using EDGE pins with rising edge or falling combinations.

Key features of CTMU

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  - **Timer1, output compare, software trigger**
  - **Rising Edge, Falling edge combination of one or two external pins**
- **Precise time delay output**

•CTMU can generate a precise time delay.

All these are explained using the following block diagram..
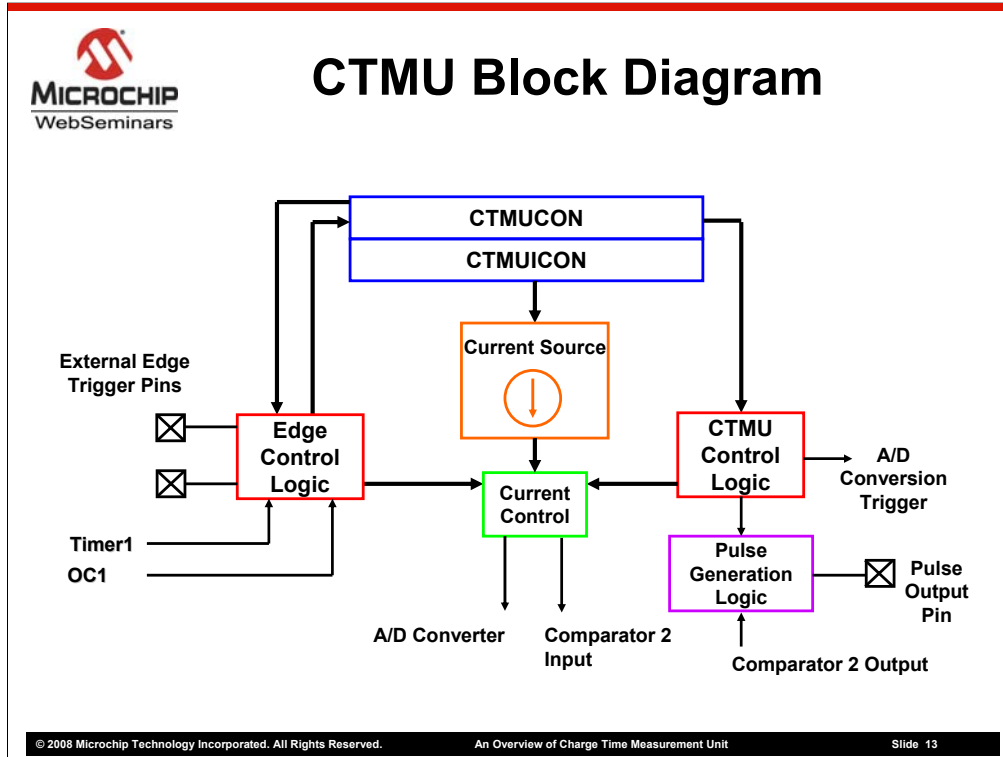
This slide shows a high level block diagram of the CTMU.

The On and off of the constant current source is controlled by the triggering sources discussed in the previous slide, such as external pins, Timer1 or Output Compare1. Alternatively, the current source can be turned on or off in the firmware using the CTMU control registers.
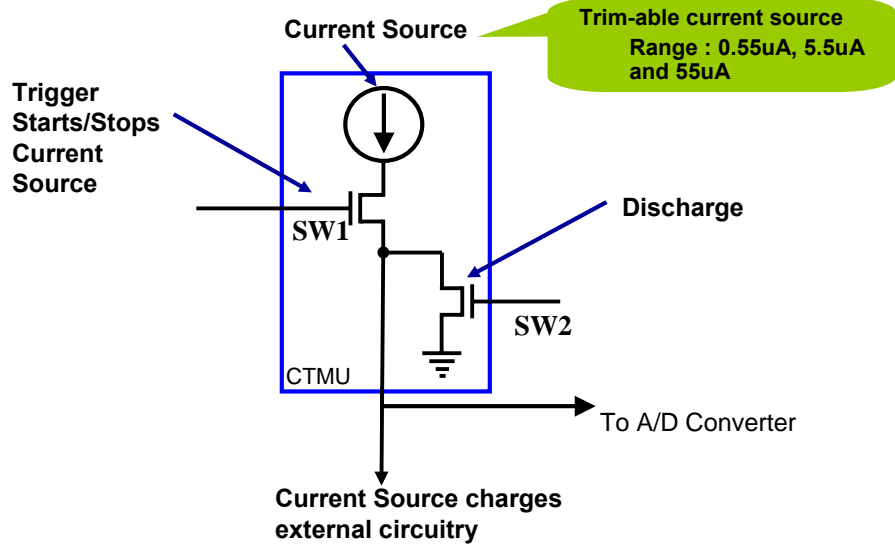
The special Function Registers (SFRs) CTMUCON and CTMUICON are used to setup the CTMU operation.

CTMU Block Diagram

Current Source

Current Control

A/D Converter
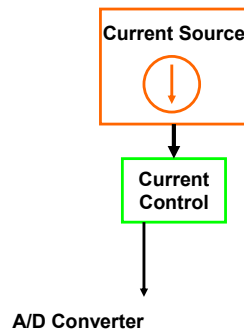
The following slide shows a closer look at the current source..

In simple words, by controlling the switch SW1, the current source can be turned ON and OFF. The SW2 makes sure that the external circuit is discharged before start charging.

CTMU Interface to ADC

PIC® MCU A/D with CTMU

ADC/CTMU Channels — Multiplexer — Current Source — CTMU — A/D Conversion Trigger — $C_{A/D}$ — A/D Converter
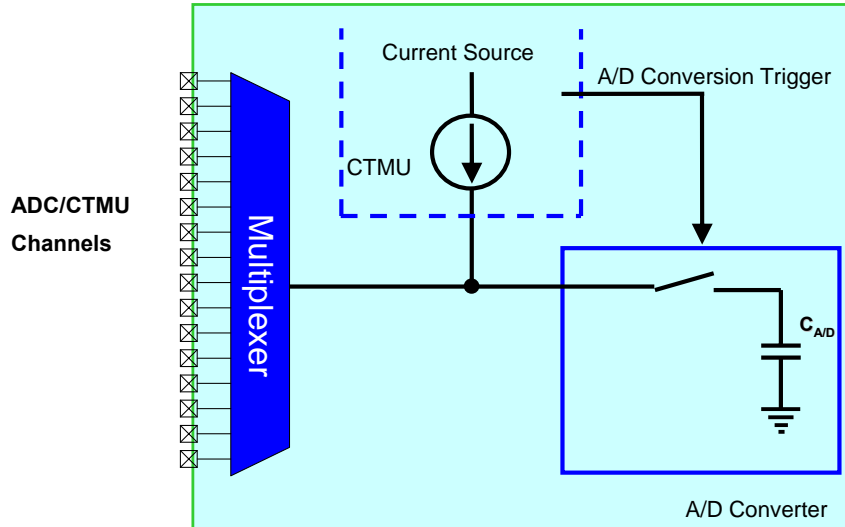
This diagram shows the interaction between the CTMU and the ADC. The CTMU module is add-on to the ADC module. When a channel is chosen, the multiplexer connects the CTMU to the external pin. When the application is ready to make a measurement on ADC, CTMU can trigger the ADC to start acquiring a sample and conversion there after. Because the CTMU and the ADC are interconnected, it is very easy to set up and use these peripherals in an application.

Now let us see how this current source in CTMU can be used for Capacitive Touch sensing Application.

16

CTMU for Cap Touch Application

EE101 basics:
- **Instantaneous Current in a capacitor**
  - **$i = C \cdot dV/dt$**

An Overview of Charge Time Measurement Unit Slide 17

Before going into the Capacitive sensing, let us see basics of capacitance by going back to Electrical Engineering 101 class.

The instantaneous current in a capacitor is equal to the Capacitance multiplied by change in voltage over time, $I = C \, dV/dt$.

CTMU for Cap Touch Application

EE101 basics:
- **Instantaneous Current in a capacitor**
  $$i = C \cdot dV/dt$$
- **If i = constant current, then**
  $$I = C \cdot V/t$$
  $$I \cdot t = C \cdot V$$

If the current is constant, the equation can be integrated on both sides. That gives, I = C V/t

If the equation is re arranged, 'Current' multiplied by 'time' is equal to the 'Capacitance' multiplied by 'Voltage'.

CTMU for Cap Touch Application

EE101 basics:

- **Instantaneous Current in a capacitor**

  $i = C \cdot dV/dt$

- **If i = constant current, then**

  $I = C \cdot V/t$

  $I \cdot t = C \cdot V$

- **If I and t are held constant,**

  as C increases, V must decrease

What this means is, if a Capacitor is charged with a constant current of 'I' for a fixed time 't', the capacitance varies inversely to the voltage.

Or in other words, as the C increases, V decreases.

This principle is used in a capacitive touch sensing application as following.

Capacitive Touch Theory

- **PCB pad is a sensor (C_P)**

C_P

An Overview of Charge Time Measurement Unit   Slide 20
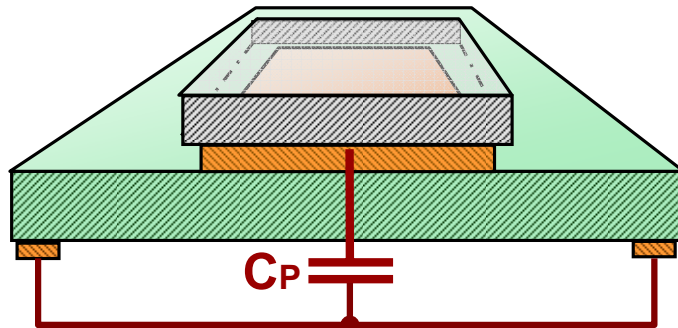
Let us see how a simple capacitive sensor can be built using a PCB and copper pad. PCB material such as FR-4 or epoxy acts as a delectric material. When a copper pad is placed on the PCB, it acts as one of the conductive plate of the capacitor and the ground plane or ground area acts like the second plate of the capacitor as shown in the diagram. The larger the pad, the better the sensitivity and a sensor touch will be more easily detected. The sensor capacitance is indicated by Cp in this slide.

Capacitive Touch Theory

- **PCB pad is a sensor (C_P)**
- **Introduction of finger produces a parallel capacitance (C_F)**
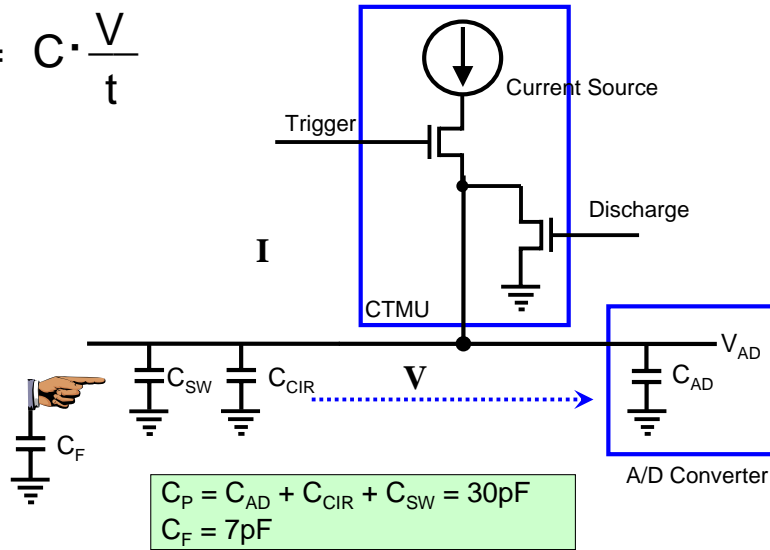
An Overview of Charge Time Measurement Unit   Slide 21
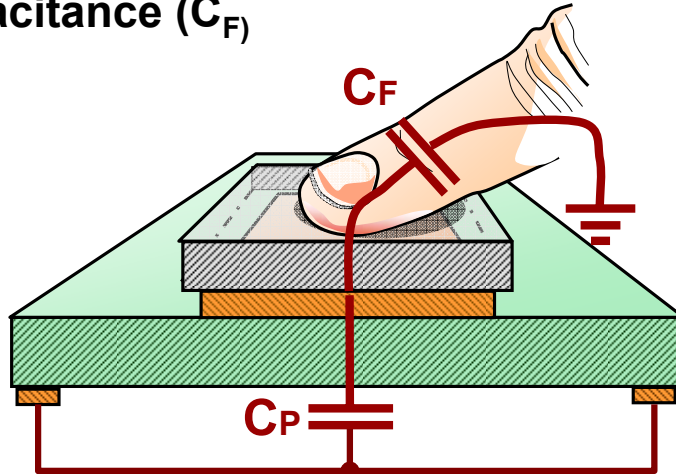
When a finger touch is introduced on the sensor pad, it adds a second capacitance, Cf, in parallel with the pad's capacitance.

So task of CTMU is to detect this change in capacitance when a human finger touches the PCB pad or capacitive switch.

Let us see how this is done using CTMU.
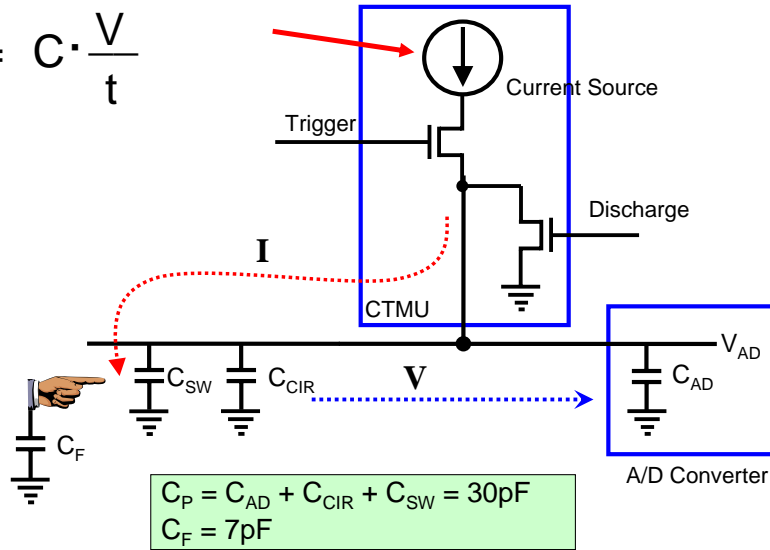
CTMU Touch Circuit Components

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

Trigger

Current Source

Discharge

CTMU

I

C_{SW} C_{CIR} **V**

C_F

V_{AD}

C_{AD}

A/D Converter

$C_P = C_{AD} + C_{CIR} + C_{SW} = 30pF$
$C_F = 7pF$

An Overview of Charge Time Measurement Unit   Slide 22

As shown here, all the elements of applying CTMU for capacitive touch sense application.
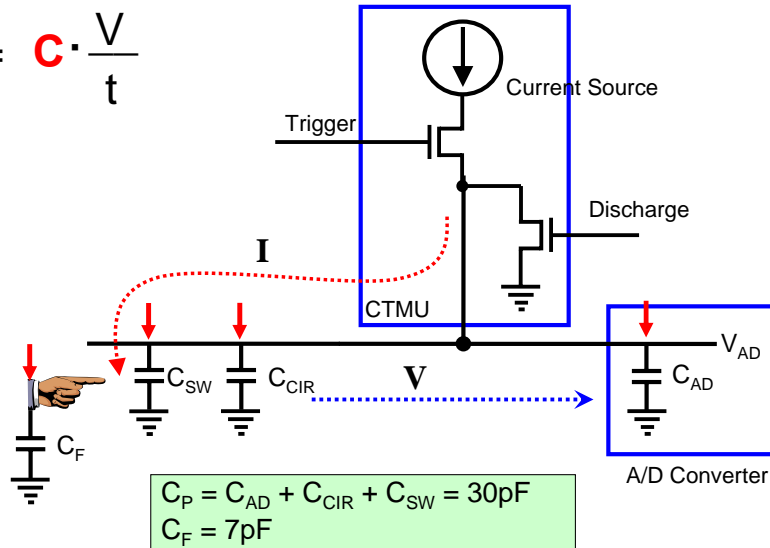
CTMU Touch Circuit Components

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

Current Source

Trigger

Discharge

I

CTMU

C_{SW} C_{CIR} V V_{AD}

C_{AD}

C_F

A/D Converter

$C_P = C_{AD} + C_{CIR} + C_{SW} = 30pF$
$C_F = 7pF$

The constant current source, I, from the CTMU charges the capacitive sensor for a fixed time. The charge time is controlled using the CTMU trigger inputs.
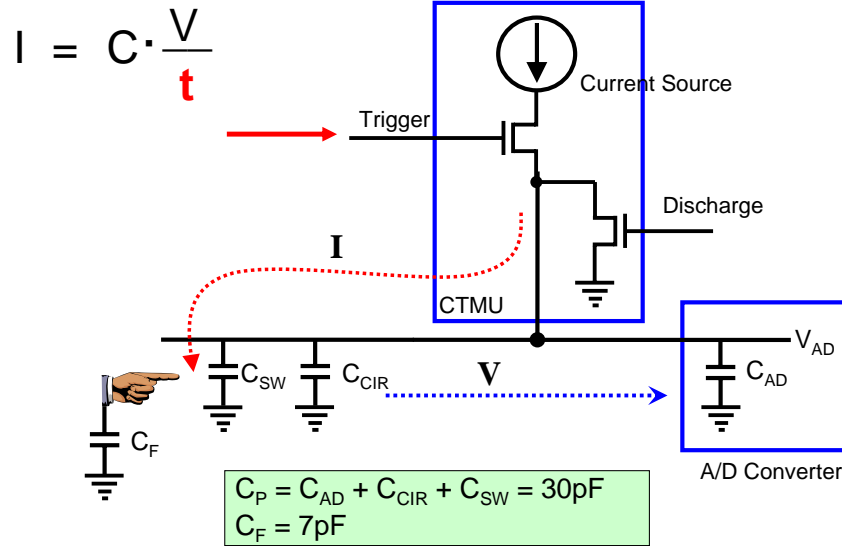
CTMU Touch Circuit Components

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

Current Source

Trigger

Discharge

I

CTMU

V_{AD}

C_{SW} C_{CIR} V C_{AD}

C_F

A/D Converter

$C_P = C_{AD} + C_{CIR} + C_{SW} = 30pF$
$C_F = 7pF$

An Overview of Charge Time Measurement Unit   Slide 24

The total capacitance of the sensor includes the sensor capacitance (CSW) the stray capacitance in the traces and circuit and capacitance due to ADC connection. Typically the value of the sensor CP is in the range of 30pF to 100pF.

Typically human body has about 7pF to 20pF of capacitance. When a finger is introduced, it is added in parallel to the sensor capacitance, thus making the total capacitance to 37pF in this example.
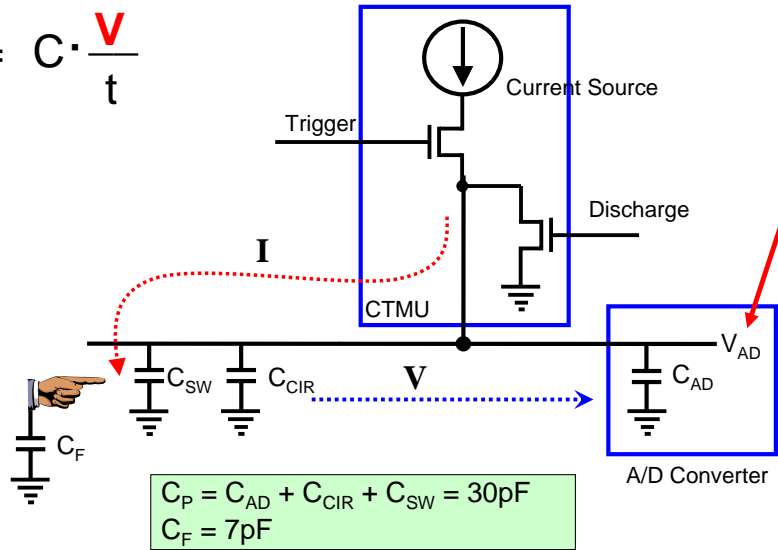
CTMU Touch Circuit Components

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

Current Source

Trigger

Discharge

CTMU

I

V_{AD}

C_{SW} C_{CIR} **V** C_{AD}

C_F

A/D Converter

$C_P = C_{AD} + C_{CIR} + C_{SW} = 30pF$
$C_F = 7pF$

An Overview of Charge Time Measurement Unit   Slide 25

Typical time used to charge the capacitance is about 4 to 5uSec.

CTMU Touch Circuit Components

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

$C_P = C_{AD} + C_{CIR} + C_{SW} = 30pF$
$C_F = 7pF$

ADC is used to measure the charge build-up , V, in the capacitance. In un touched condition, the charge up voltage is higher than when the sensor is touched. This is due to increase in total capacitance when the sensor is touched. Let us see a typical calculation to see the real voltage difference between touched and un touched conditions.

Let us take and example of 5.5uA current source on CTMU and charge the senor pad for 10uSec. With a typical value of 30pF of sensor capacitance, the charge build up is 1.833 Volts when the sensor is untouched.

When the sensor is touched, a 7pF of capacitor is added to the total capacitance, making the total charge build up to 1.486 Volts.

The ADC measure both of these voltages and the firmware determines when the switch is pressed.

CTMU Full Waveform

A/D Conversion

End Charge

Discharge

Begin Charge
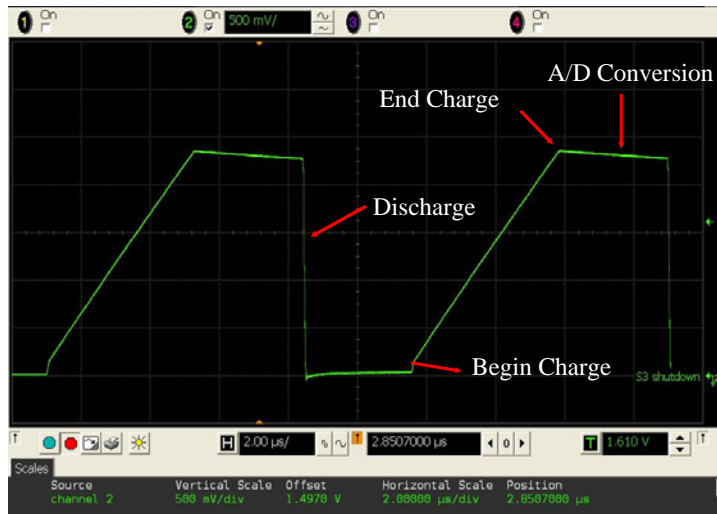
Fast scan rate, a CTMU channel can be scanned in 6uSec

An Overview of Charge Time Measurement Unit   Slide 29

This slide shows a scope plot of complete scanning cycle. First the channel is discharged, so that we can start from zero volts. Then the CTMU starts charging the sensor for a fixed time. Then the ADC converts the charge build up. Note that the voltage build up has a discharge slope due to high value of the oscilloscope probe leakage.

Typically CTMU can scan a channel in 6uSec. This enables to service a large number of capacitive touch buttons in an application.
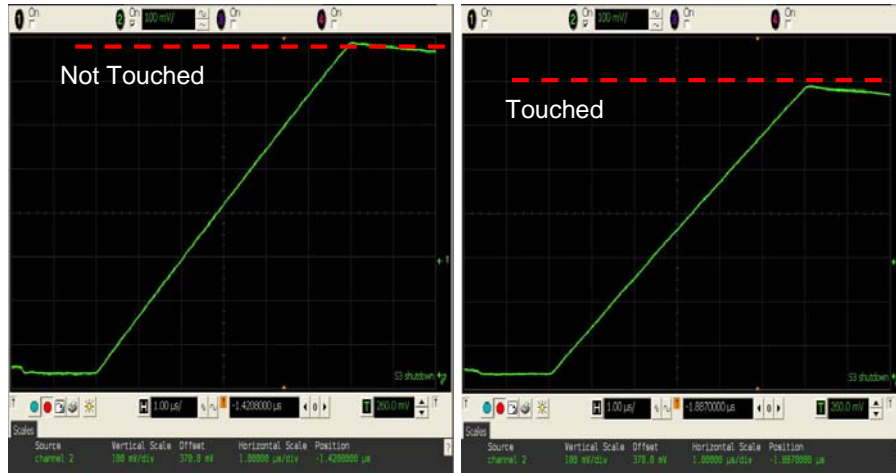
Also this allows bandwidth for other applications to run in conjunction with the Capacitive touch on the same PIC microcontroller.

Untouched & Touched

Not Touched

When the sensor is un touched the charge build up is higher than when the sensor is touched.

ADC measures the voltage and the firmware detects the sensor is been touched or pressed.

The same concept can be applied for proximity sensing. Basically the firmware differentiates a varying ADC value when a proximity is sensed.

Other Applications of CTMU

- **Time Domain Reflectometry (TDR)**
- **Temperature measurement**
- **Humidity measurement**
- **Precise Time measurement**
- **Absolute and relative capacitance measurement**
- **Digital to Analog Converter (DAC)**

There are many other applications the CTMU can be applied to. Some of them are listed here.

•Time domain reflloctometry uses the time measurement side of the CTMU

-Temperature measurement using a diode. We will see these two applications in the next section

- A humidity sensor is nothing but a varying capacitance and CTMU is perfect to measure the variance in capacitance.

-CTMU can be used to measure absolute capacitance and relative change in capacitance, as shown in capacitive touch sensing application

-Also it can be used as Digital to Analog converter (DAC)

We will see the TDR and temperature senor applications in detail in the coming sections.
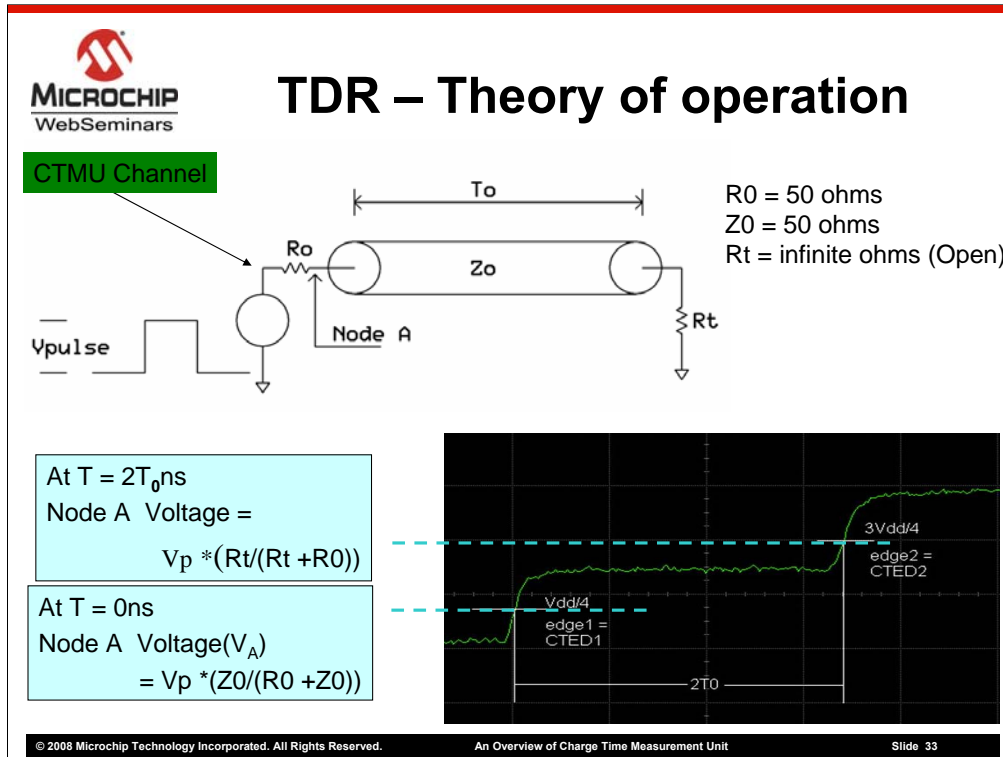
First, let us see what is the Time Domain Reflectometry or TDR. In layman terms, TDR is basically time taken by a pulse to propagate through a circuit and to reflect from the end of a circuit back to the source.

In example of a co axial cable that has 50 Ohms.

TDR has long been used to measure the electrical length of transmission lines, locate faults in transmission lines, and characterize transmission line impedance.

The figure shows a pulse generator with a resistor R0 connected to a transmission line with impedance Z0 and a termination resistance of RT.

If we use the occurrence of the rising edge of the pulse as a reference point in time (0nS), then at T = 0nS the voltage at node A is:

$$VA = VP * (Z0 / (R0 + Z0))$$
Eq. 1

Where VP is the amplitude of the pulse.

The transmission has an electrical length T0 where T0 is the time it takes the pulse to propagate down the transmission line.

The electrical length T0 of the transmission line can be calculated by taking 1/ (speed of light) or (1.017nS/ft) * (the length of the transmission line). The Voltage at node A at 2 times T0 will be:
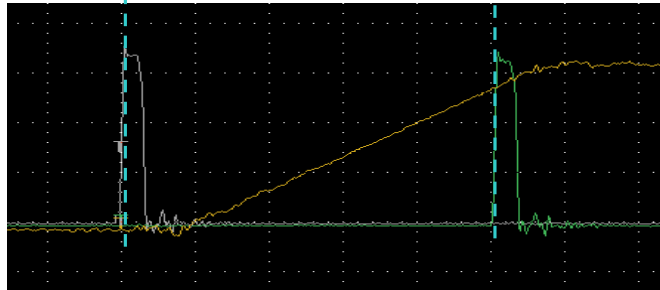
$$VA = VP * (RT / (RT + R0))$$

If the transmission line is un-terminated then VA = VP when T >= 2T0.

The scope plot here shows a pulse generator with a 50 ohm output impedance driving a 2V pulse into an un-terminated 50 ohm coaxial cable.

TDR Measurement

3Vdd/4
edge2 = CTED2

Vdd/4
edge1 = CTED1

2T0
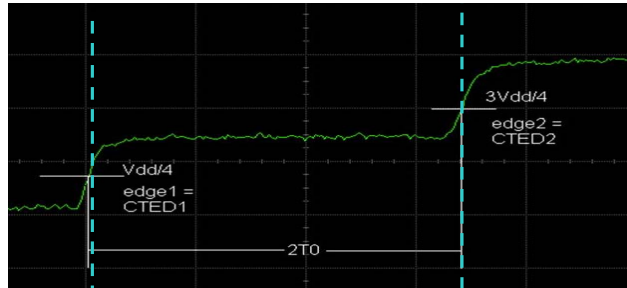
2T0 directly correlates to the length of the cable

The two step wave form of an un-terminated transmission line is shown in the scope plots here.

The initial voltage at T = 0nS, using equation at node A is 1V (VP/2).

At time 2T0 the reflected pulse from the un-terminated transmission line returns and using the second equation, the voltage at node A is 2V (VP). So Time Domain refers to the fact that we are looking at the wave form in the time domain, and Reflectometry refers to the fact that we are looking at the reflected impedance of the transmission line and the transmission line termination. The impedance is represented by the voltage.
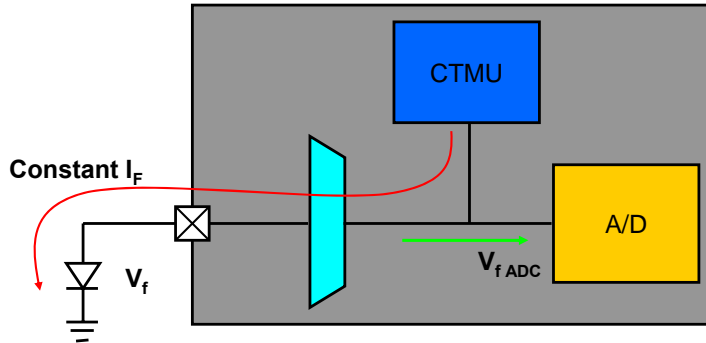
Temperature Measurement

- **The forward voltage of a diode varies with temperature**
- **Temperature can be measured with CTMU**
  - **Which is a constant current source over voltage and temperature**
  - **A diode**
  - **A/D converter**

An Overview of Charge Time Measurement Unit Slide 35

Next let us see how CTMU can be used to measure temperature using a diode.

An in expensive way of measuring temperature is using a diode. The forward voltage drop of a diode varies with the temperature.

With this theory, using a common diode and constant current source on CTMU and using ADC for measuring the forward voltage, temperature can be measured to accuracy of 1 degree C.

Temperature Sensing With CTMU and DIODE

CTMU

Constant I_F

A/D

V_f

$V_{f\ ADC}$

Basic DIODE Equation

Forward Current $I_F = I_S(e^{qVf/nkT} - 1)$

I_F is a constant then

$\ln(I_F/I_S + 1)nk$ is a constant

T α Vf

An Overview of Charge Time Measurement Unit   Slide 36

The equation shown here defines the forward current of a diode as factor of forward voltage and temperature. When forward current is constant, most other components are constant other than the temperature and the forward voltage. By measuring the forward voltage, temperature can be determined.

As shown in this block diagram, CTMU powers the diode with a constant current source and the ADC measures the forward voltage of the diode.

Temperature Measurement

CTMU Temp measurement - 914
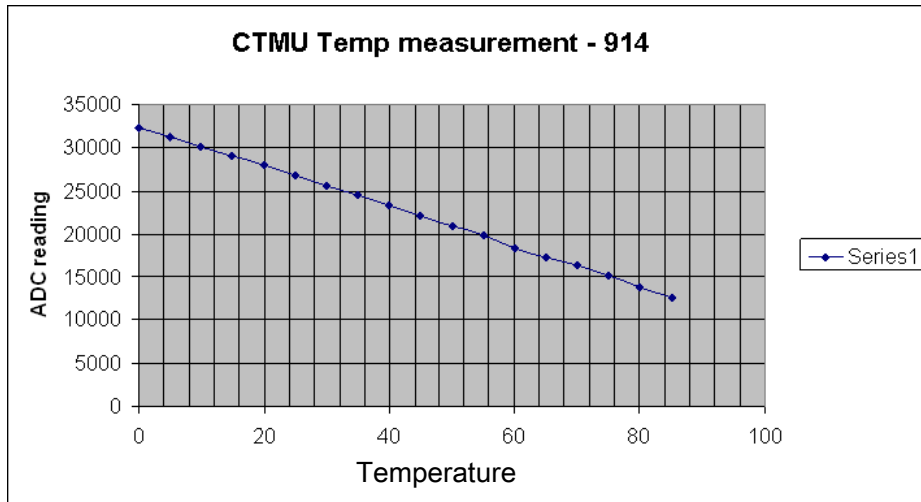
This graph shows the data for a commonly available rectifier diode 1N913.X axis is the temperature and Y axis shows ADC reading, with 64 samples accumulated. As you can see here, the ADC reading varies more or less linear to the temperature. This gives an in expensive way of measuring temperature using CTMU and a diode.

Resources

- **PIC24 Family Reference Manual – Section 11: CTMU (DS39724)**

- **PICDEM™ Touch Sense 2 board – DM164128**

- **Web page for all mTouch™ collateral**
  www.microchip.com/mtouch

To date, CTMU is in more than 20 parts and more to come

There are many resources available from Microchip for CTMU and capacitive touch sensing.
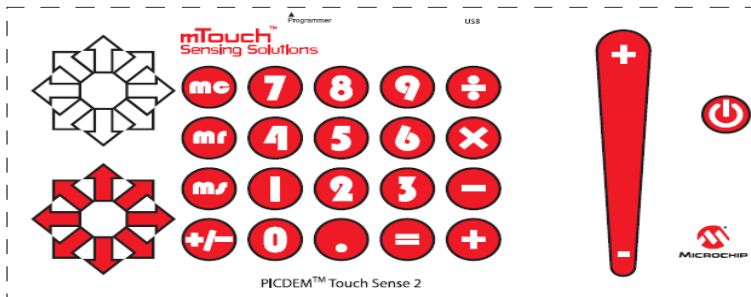
First, refer to the family reference manual DS39724

Second, The PICDEM Touch Sense2 board demonstrates CTMU in capacitive touch sensing application.

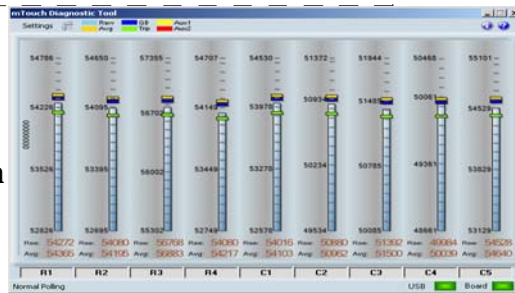Third, Visit www.microchip.com/mtouch for update and all related collaterals.

There are more than 20 PIC microcontrollers with CTMU and many more will follow.

PICDEM™ Touch Sense2

mTouch™ Diagnostic GUI
• For customizing the
  Capacitive Touch Solution

As I mentioned in the earlier slide, the PICDEM Touch sense2 board (DM164128) demonstrates CTMU in capacitive touch sensing application.

This board has implementation of direct keys, matrix keys and a linear slider.

Also this comes with a free GUI for diagnostics and customization purpose. Using this GUI, you can customize your own capacitive touch sensing application.

Please refer to the documentation by visiting www.microchip.com/mtouch

- **Key Features**
- **CTMU functional block diagram**
- **How CTMU is used for Capacitive Touch Sensing application**
- **Other applications using CTMU**
  - **Precise time difference measurement**
  - **Temperature measurement**
- **Resources available from Microchip**

An Overview of Charge Time Measurement Unit Slide 40

To summarize what we discussed so far,

We have seen the key features and detailed block diagram of CTMU

How to use CTMU for capacitive touch sensing, TDR and temperature measuring applications are discussed

Also the resources available from Microchip are discussed.

With this we conclude this webinar. Thank you for watching this webinar. Hope you find this helpful.

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