MICROCHIP

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See What You Can Do with the CTMU

Authors: Padmaraja Yedamale and Jim Bartling
Microchip Technology Inc.

INTRODUCTION

Since its introduction in PIC® microcontrollers, the Charge Time Measurement Unit (CTMU) has become popular for creating simple and low component touch control solutions. Some applications have made use of its ability to resolve the time difference between inputs down to the sub-nanosecond range. But thinking that the CTMU can only deal with time and charge measurements would be a serious underestimation of its abilities.

As proof of its versatility, this application note provides 48 different applications (or, in a few cases, categories of applications) that can be implemented with the CTMU. Many of these implement new functionality in existing control applications, using only a few or no additional components. Keep in mind that these applications are basic ideas, presented in an abbreviated format. Microchip may not offer reference designs or source code for some applications. The reader is invited to use these ideas as the starting point for developing their own solutions.

ABOUT THE CTMU

In a nutshell, the CTMU is an on-chip constant-current source, surrounded by digital circuitry to precisely control its operation (Figure 1). The current source operates over four decade ranges, from 0.55 µA to 550 µA. When combined with the on-chip A/D Converter and comparators, the CTMU can perform a variety of basic functions:

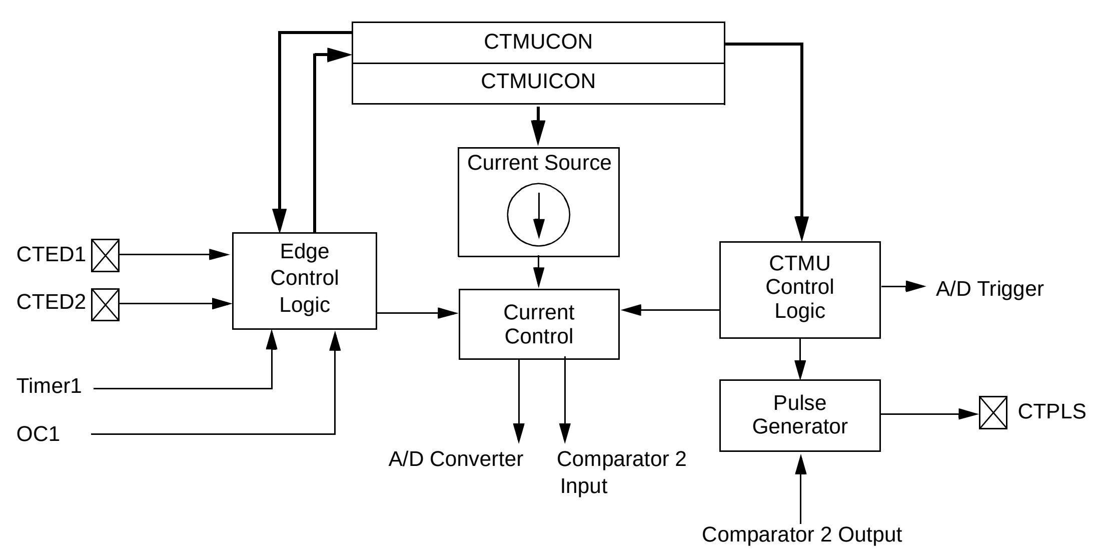
- Capacitance measurement (relative and absolute)
- Inductance measurement (relative)
- Resistance measurement (relative and absolute)
- High-resolution time measurement

While the basic functions are useful for a variety of applications, they can also be used as the basis of more complex applications, such as:

- Temperature measurement
- Current source (constant and variable)
- Precise time delay generation
- Pulse-Width Modulation (PWM) output

The different types of applications are covered in the sections that follow.

FIGURE 1: CTMU BLOCK DIAGRAM



APPLICATIONS BASED ON ELECTRICAL PRINCIPLES

Relative Capacitance Measurement

By far, relative capacitance measurement is the most used principle in designing applications for the CTMU. This is not surprising, because there are numerous applications that require relative capacitance measurement.

When a constant-current source is available, measuring the relative capacitance is easy. The constant-current source (I) charges the unknown external capacitor (C) to a voltage (V) in time, t. From the basic equation for capacitance, $I = C\, dv/dt$, when the current and time are constant, the voltage $(V = I * t/C)$ varies inversely with the capacitor value. In a relative capacitance measurement application, such as capacitive touch sensing, when a finger touches a capacitive touch pad, the capacitance increases, thus decreasing the voltage charged.

As an example, take a simple touch application (shown in Figure 2) with a total capacitance (including parasitics, like the switch (C_{SW}) and circuit (C_{CIR}) of 30 pF. When the external circuit is charged with a current of 5.5 µA for 10 µs, this produces a voltage of 1.83V. When you add the touch of a finger, an additional capacitance (C_F) of up to 10 pF is added. The exact amount of capacitance depends on how much the touch pad is covered by the finger and any covering material over the pad. For a 10 pF change, with the same current and charge time, the voltage is 1.38V.

The voltage is measured at frequent intervals by the microcontroller's A/D Converter. Changes (particularly decreases) can then be interpreted as a touch event.

All of these applications use the same basic principle:

1. **Capacitive Touch Sense Controls**

As just described, relative capacitance change can be used to control an application in the same way as scanning switches, push buttons or touch screens. By using the A/D Converter's multiple input channels with the CTMU, multiple touch controls can be implemented.

2. **Microphone (Direct Audio-to-Digital)**

The capacitance of the microphone's element changes continuously in proportion to the frequency of the vibrations hitting its diaphragm. The microcontroller's A/D constantly samples the resulting voltage and creates a digital signal.

3. **Proximity Sensor**

Very often, a direct touch isn't needed to change the capacitance of a circuit: the near-by presence of a hand to a PCB may be enough. (Just think of the last time you tried to tune a distant station on an old radio if you don't believe this.) With the proper components, software tuning and layout selection, the CTMU can be used to sense proximity in the exact same way as it senses touch.

4. **Stud Finder**

A stud on the other side of the wall (metal or not, with or without nails or metallic fasteners) will change the local capacitance of the wall's surface.

5. **Occupancy Sensing**

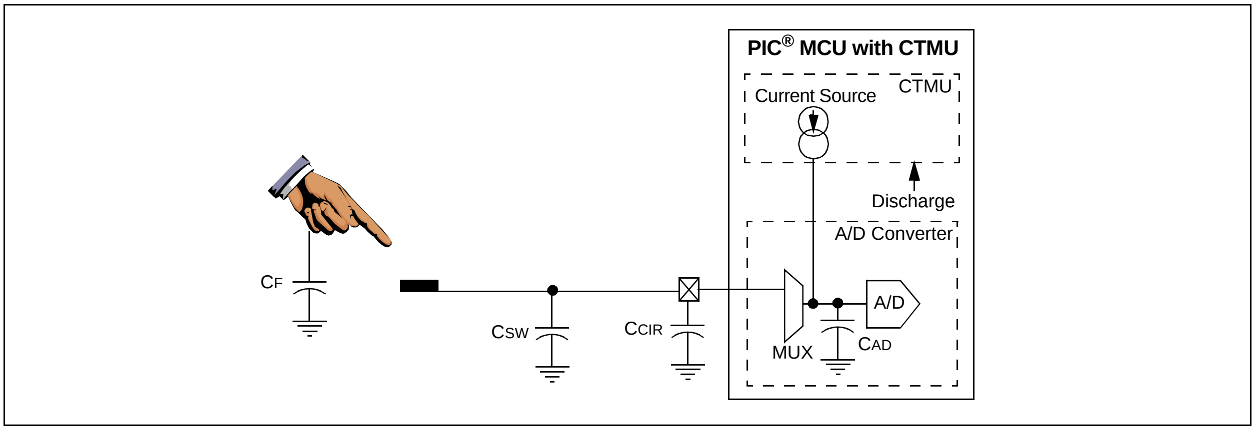
Rather than using the old interrupted photocell principle, a capacitance sensor can be embedded in the doorway. Whenever a person passes through, the sensor's capacitance changes.

6. **Liquid Level Sensing**

Here is a clever twist on capacitance, in a very literal sense. Take a conductive plate and place a container made of an insulating material (say, glass) upon it. Fill the container with a liquid and you have a capacitor. In this setup, the capacitance of the container changes with the level of the liquid. The size of the container and the plate can be scaled according to the application's requirements. (Note, however, that the application requires calibration for each different container, and each type of liquid.)

Level sensing can also be implemented using a conductor running along the length or height of a container. The operating principle is exactly the same.

FIGURE 2: BASIC PRINCIPLE OF CAPACITIVE TOUCH SENSE



7. Pressure/Force Sensor

Take two conductive plates, with one being fixed and the other spring-mounted. Besides having an air dielectric capacitor, you have a sensor which changes capacitance in proportion to the weight or force applied to the spring mounted plate. This gives us a variation of a strain cell, and a method to directly measure pressure (and perhaps weight) with the CTMU.

8. Automatic Litter Box

Relative capacitance sensing is not just for liquids or finger touches. Cat litter, for example, can also be measured for capacitance change – when the litter is unused, and when the cat has finished with it. The change in capacitance can be used to trigger a cleaning cycle.

Absolute Capacitance Measurement

Quantifying a capacitance with some measure of precision is almost as simple as measuring a relative capacitance change. There are two steps required, as shown in Figure 3. First, it is necessary to calibrate the CTMU current source. The calibration procedure is simple; using a high-precision (0.5% tolerance or better) resistor of known value and a precise voltage measurement to calculate the actual current. With this information, the current source is trimmed using the appropriate control bits.

Once the current source is calibrated to the required accuracy for measurement, switch the current source to the ADC/CTMU channel where the target capacitor device is connected. The constant-current source (I) charges the unknown external capacitor (C) for time, T. The capacitance is then calculated by the equation, $I \times T = C \times V$, where I and T have already been defined, and V is measured by the microcontroller's A/D Converter.

For detailed information on calibrating the CTMU current source, refer to Microchip's CTMU reference documents for PIC24F devices, listed at the end of this application note.

There are numerous applications that require absolute capacitance measurement. These include:

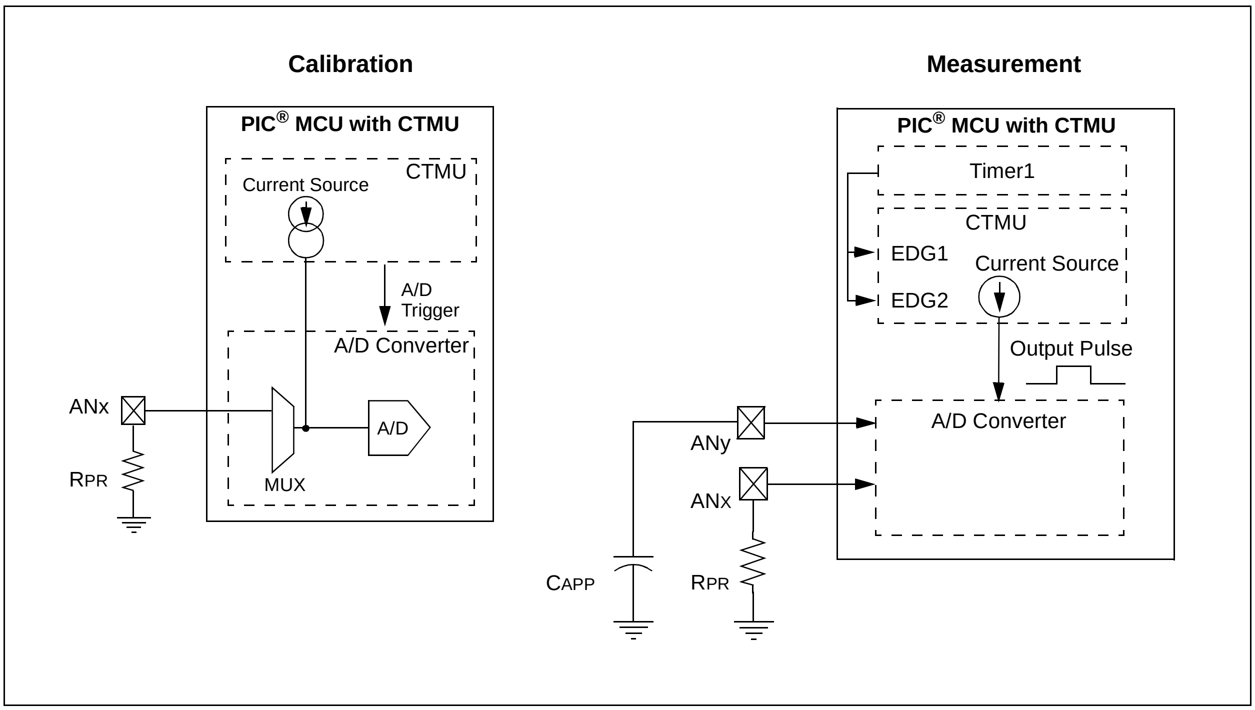
9. LCR Meter (Capacitance Function)

The CTMU can directly measure an unknown capacitor to establish its capacitance or confirm the value of a labeled, but questionable capacitor.

10. Humidity Sensing

The latest generation of precision polymer humidity sensors provides their output as a change in capacitance, rather than the more traditional voltage or current. In an absolute capacitance configuration, the CTMU and A/D can quickly turn a capacitance change into voltage, and from there, into relative humidity.

FIGURE 3: CURRENT SOURCE CALIBRATION AND CAPACITANCE MEASUREMENT



Relative Inductance Measurement

Although most often associated with capacitance and/or current, the CTMU can also be used to measure changes in inductance. Strictly speaking, what is actually being measured is the inductor's time constant. A typical configuration (Figure 4) shows how this is done. An I/O pin is set to output VDD to an inductor; at the same time, Edge 1 in the CTMU is manually set as if it had received a pulse. The voltage from the I/O pin is slightly delayed in reaching CTED2 as it saturates the inductor. The time measured between the initial pulse, and when the voltage on CTED2 reaches its minimum input threshold, VIL (TVIL), is proportional to the inductance. The CTMU takes a continuous series of "snapshots" of the inductor's time constant, and compares it to an established baseline. When the time constant changes, an event is detected.

Example applications include:

11. Metering

Many of the current technology flow meters use a piece of metal on a rotor that comes to the proximity of an inductor. The repeating change of inductance can be used to determine the rate of rotation and thus, the flow through the meter. The CTMU provides another simple method to measure this change and count events.

12. Weather Station (Wind Speed Sensor)

Similar to metering applications, the CTMU can inductively sense and count the number of revolutions per minute of an anemometer; the microcontroller translates this into wind speed. When combined with a humidity sensor and a simple diode, the CTMU can implement a single chip solution for a fully functional weather station (see applications # 10 and # 33 for more information).

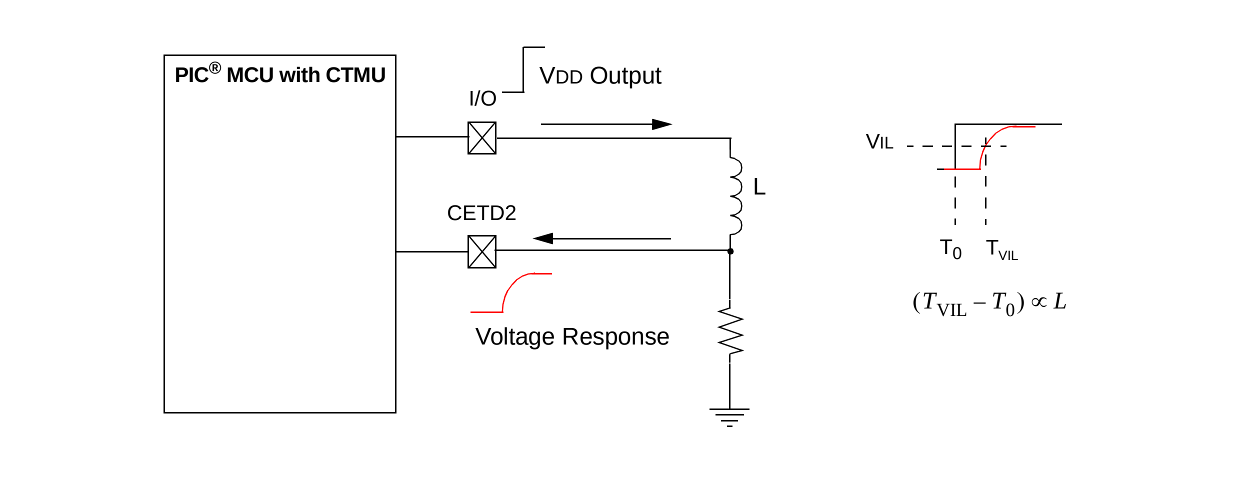
13. Coin Operated Vending Machine

An inductive sensor is used to detect coins as they are inserted. The CTMU can be used to quantify the number and type of coins. It could also be used to detect (and reject) slugs, which have a different magnetic signature than coins.

14. Proximity Sensing, Part Two

All of the above applications are specific cases of the same principle. Any application that is based on inductive or magnetic proximity sensing (e.g., solenoid position) can be implemented with the CTMU as the inductor interface.

FIGURE 4: MEASURING RELATIVE INDUCTANCE CHANGE BY TIME DELAY



Precision Time Measurement

Numerous applications require very precise time measurement. Using the edge trigger pins (CTEDn) on the CTMU, time can be measured precisely to a resolution of under a nanosecond. This is done by charging the A/D Sample-and-Hold (S/H) capacitor between the rising edges of the two pins; the resulting voltage is directly proportional to the time. Figure 5 shows the general scheme for time measurement. CTMU-based time measurement is asynchronous to the clock running the microcontroller.

Applications include:

15. Distance Measurement (Ultrasonic and Laser Devices)

The CTMU is used to measure the round-trip return time between an initial transmitted pulse and its reflected return signal. This can determine a distance measurement, accurate to within one foot.

16. Adaptive Cruise Control

As an extension of the last application, Adaptive Cruise Control (ACC) is the active system that maintains a constant distance between moving vehicles, based on continuous measurements. The CTMU provides an RF or laser-based ranging solution to the system.

17. Safety Braking

This is the partner of Adaptive Cruise Control; it automatically triggers the brakes when the object ahead comes too close. Even when ACC is not used, its CTMU-based ranging solution can be used just as well for an independent, safety breaking application.

18. Coaxial Cable Measurement (Length, Short or Open)

The CTMU can be used to implement a simple Time Domain Reflectometry (TDR) measurement device, used to locate an open or short defect in a coaxial cable. The location of the defect is based on the time it takes for a pulse to be reflected back (Figure 6). When a voltage pulse is injected at Node A, an open or shorted cable will reflect a pulse back at a time that is proportional to twice the distance to the defect (2 TO). A properly terminated cable will not return a reflected pulse.

FIGURE 5: TIME MEASUREMENT USING THE CTMU

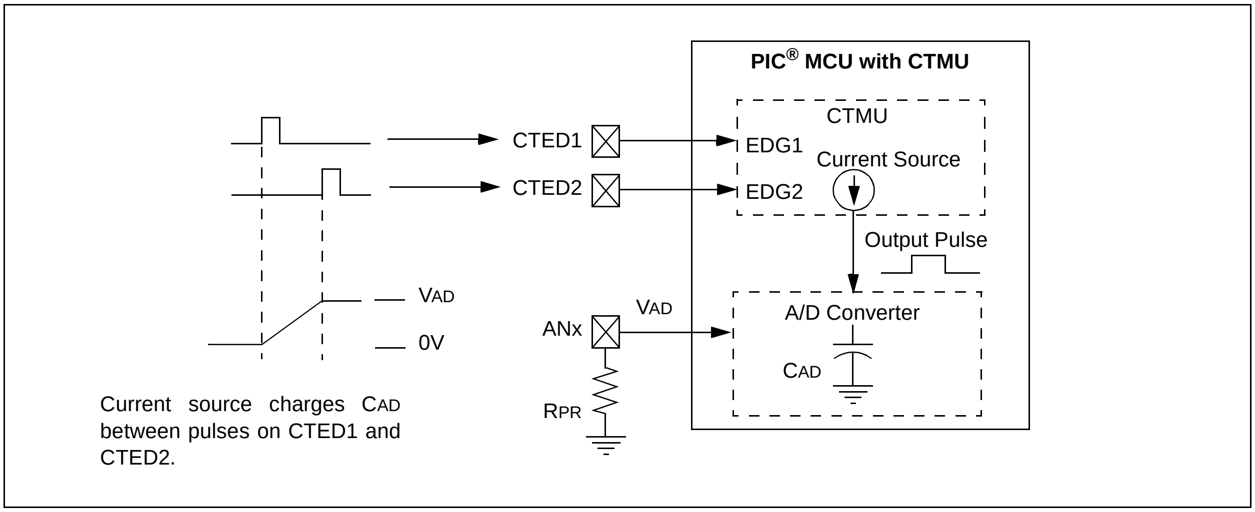
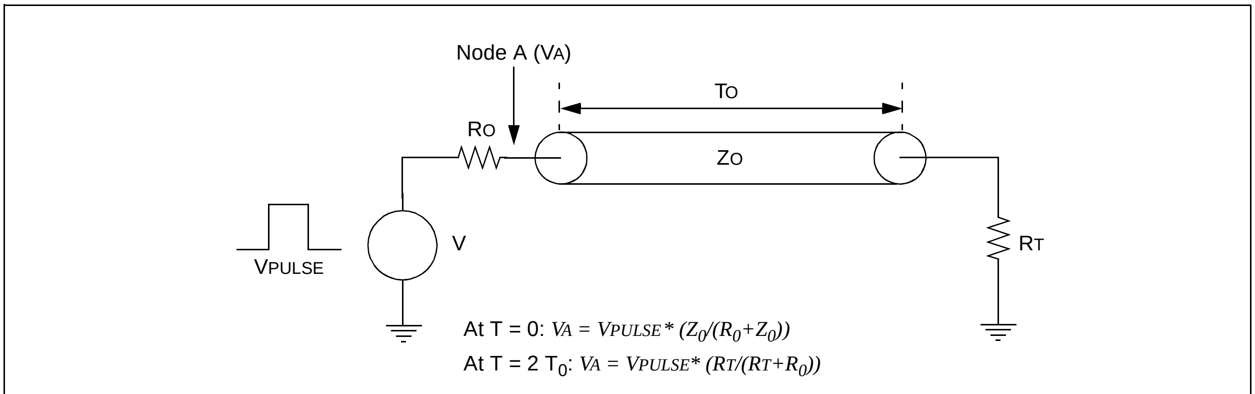


FIGURE 6: MEASURING A COAXIAL CABLE WITH TDR



19. Ultrasonic Flow Meters

Like distance measurement devices, the CTMU measures the time difference between transmitted and received pulses. In this application, however, the time difference between fixed transducers varies with the flow rate of the medium being measured.

A simple flow measurement system is shown in Figure 7. In this setup, the microcontroller sends a pulse for transmission by the ultrasonic transceivers, while the Input Capture and Output Compare modules receive incoming signals from the transceivers. The CTMU uses the received signals that are coupled with the flow to calculate the time difference and thus, the flow rate.

20. Global Positioning System (GPS) Signal Interface

The basis of GPS is to triangulate a position from satellites, based on signal travel time. By using the CTMU to measure the time difference between individual satellite signals, the relative position on the earth can be determined. The high precision of the CTMU's time measurements allows a position accuracy that approaches the accuracy limits of the entire satellite system.

21. Pulse Width/Duty Cycle Decoding

The CTMU can accurately measure individual pulse widths of an incoming pulse train. If data has been encoded in the stream using PWM, the CTMU can be used to demodulate the stream and restore the digital information. PWM is found in many applications, such as infrared remote controls.

22. DTMF Detection and Decoding

The same principles of decoding a width modulated pulse train can also be used in DTMF applications. By measuring the pulse widths of the product signal, it is possible to determine which two frequencies were used to produce it and therefore, which key was pressed.

23. Frequency Meter

Similarly, by measuring the time between the rising edges of a signal with a constant wavelength, it becomes simple to calculate the frequency (from $f = 1/T$). This makes the CTMU a relatively inexpensive front end for any frequency measuring application.

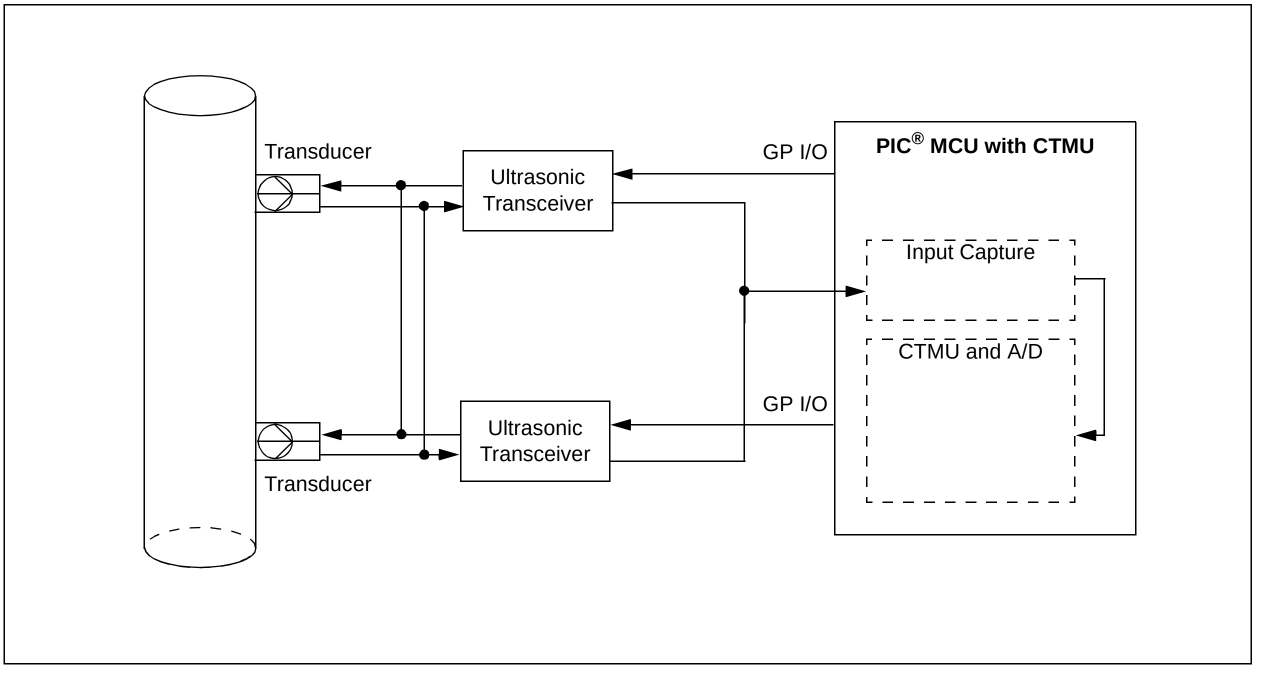
24. Decoder for Optical Encoders

The CTMU can read the incoming pulse trains from the (typically) three outputs of an optical decoder, and determine pulse speed and phase difference between them. This data can be translated into rotational speed and direction, and (with three inputs) absolute rotational position.

25. Optical Gyros

These devices measure changes in position by sensing the phase difference between two light beams traveling in opposite directions around a fiber-optic loop. By sensing the edges of the two signals and comparing them to the single source that created them, the CTMU can be used to calculate the phase difference and thus, any relative motion in the device.

FIGURE 7: ULTRASONIC FLOW MEASUREMENT SYSTEM



Resistance Measurement

Ways of measuring capacitance and inductance have already been demonstrated, so why not resistance? The CTMU's constant-current source and Ohm's law makes this easy: if it is known what the current and the voltage being provided are, or if the voltage can be measured directly, the resistance is simple to calculate.

Examples include:

26. Resistive Temperature Device (RTD)

A platinum resistor, with a known temperature coefficient, is used in many applications to measure precise and high-resolution temperatures to over 1000°F. By driving the RTD with a constant-current source, the voltage read by the microcontroller's A/D varies as the temperature varies. This low component count CTMU solution replaces an analog circuit with many discrete components.

27. PTC and NTC Sensors

Positive or negative coefficient temperature sensors (PTCs or NTCs, respectively) give an alternate way to measure temperature, up to a few hundred degrees Celsius. These thermistors are less expensive and have nonlinearity with respect to temperature. Typically, NTCs and PTCs are implemented in a voltage divider format to measure temperature. Using the CTMU's constant-current source, the resistance can be measured directly and the temperature is derived from the resistance.

APPLICATIONS BASED ON DERIVED PRINCIPLES

Temperature Measurement (Constant-Current Source)

In these applications, the CTMU's constant and accurate current source can be used to exploit a basic principle of semiconductors: the P-N junction's forward band gap voltage. When a diode is driven with a constant-current source, the forward voltage (V_F) varies inversely with the temperature.

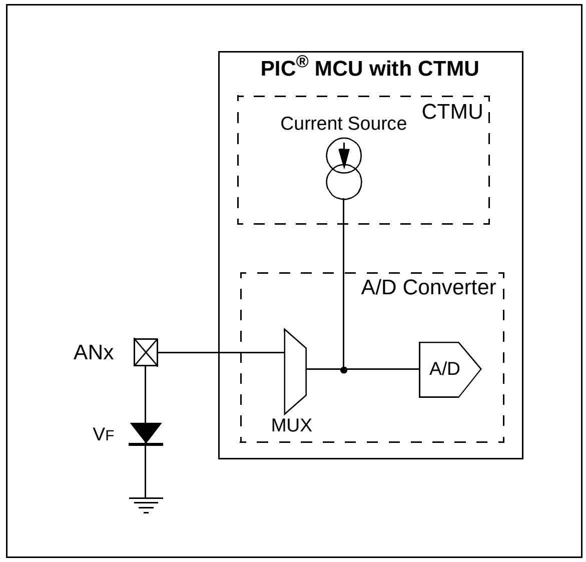
Figure 8 shows how a diode (or any convenient P-N junction) is connected to the CTMU to create temperature measurement. Using the CTMU, together with a 12-bit ADC, temperatures can be measured with a resolution of 1°F. Additional technical details are provided in Microchip's Technical Brief, TB3016, *"Using the PIC® MCU CTMU for Temperature Measurement"* (DS93016).

Applications in this category include:

28. Thermometers

General purpose thermometers can use a cheap silicon diode in place of a more expensive thermistor or dedicated sensor for temperature sensing.

FIGURE 8: CTMU TEMPERATURE MEASUREMENT CIRCUIT



29. Thermostats

The CTMU allows the microcontroller, that is already at the heart of the application, to also monitor the temperature directly, all with only one additional (and inexpensive) component.

30. PCB Temperature Monitoring

In applications where boards are either potted or in an enclosure, the CTMU with a diode can add an inexpensive monitoring solution.

31. Server Temperature Monitoring

In addition to just monitoring temperature, the microcontroller can also serve as a control to one or more chassis cooling fans, providing an extra level of safety to an expensive piece of hardware.

32. RTCC/FRC Calibration

The on-chip RC oscillators on many microcontrollers may have a high-temperature coefficient, with accuracy varying widely across the operating range. Using the CTMU, temperature can be measured right at the application (instead of being approximated from the environment's temperature) and the oscillator's frequency trimmed appropriately.

33. Indoor Weather Monitors

Along with a humidity sensor (see # 10), the CTMU can be used to measure temperature and humidity at the same time. With a microcontroller that can drive an LCD display, this can create a single chip solution. This application can also be the core for more complex weather stations (see # 12).

34. LED Lighting Control

In high-wattage, solid-state lighting applications, the LEDs can generate a lot of heat – perhaps not as much as an incandescent or halogen source, but enough to change the color band reliability or the light output if temperature is not controlled. The CTMU, along with a sensor diode, can measure temperature at the heat sink or in the environment (for forced air cooling). At the same time, another CTMU channel can actually use the LED to measure its own temperature by measuring its own forward bias voltage. This information can be used to reduce power or increase cooling when things get too hot.

35. Motor Temperature Monitoring

For electric motor applications that use a microcontroller to regulate speed and/or power, the CTMU can provide an additional control dimension: measuring the motor winding's temperature, and providing thermal protection by shutting things down before the breakdown temperature is reached.

36. Assorted Home Applications

There are many electronic applications around the house that require temperature sensing or that could benefit from its addition. If the application requires a microcontroller, the CTMU provides an easy way to implement temperature sensing. Examples include:

- Refrigerators
- Freezers (free-standing)
- Coffee makers
- Room air conditioners
- Dehumidifiers
- Space heaters
- Climate controlled storage (e.g., wine chillers)

37. Assorted Automotive Applications

By the same principle, the list can be expanded to include cars. Any system that requires temperature monitoring can use the CTMU as a solution. Cabin climate control (single and multi-zone) and engine temperature monitoring are just two examples.

Variable Current Source

38. Current Loop Control Applications

Industrial process control instruments often use current loop communications to provide noise immunity. For systems operating in the 4-20 mA range, the CTMU's current source can be used with an external current mirror circuit to create a variable current control transmitter.

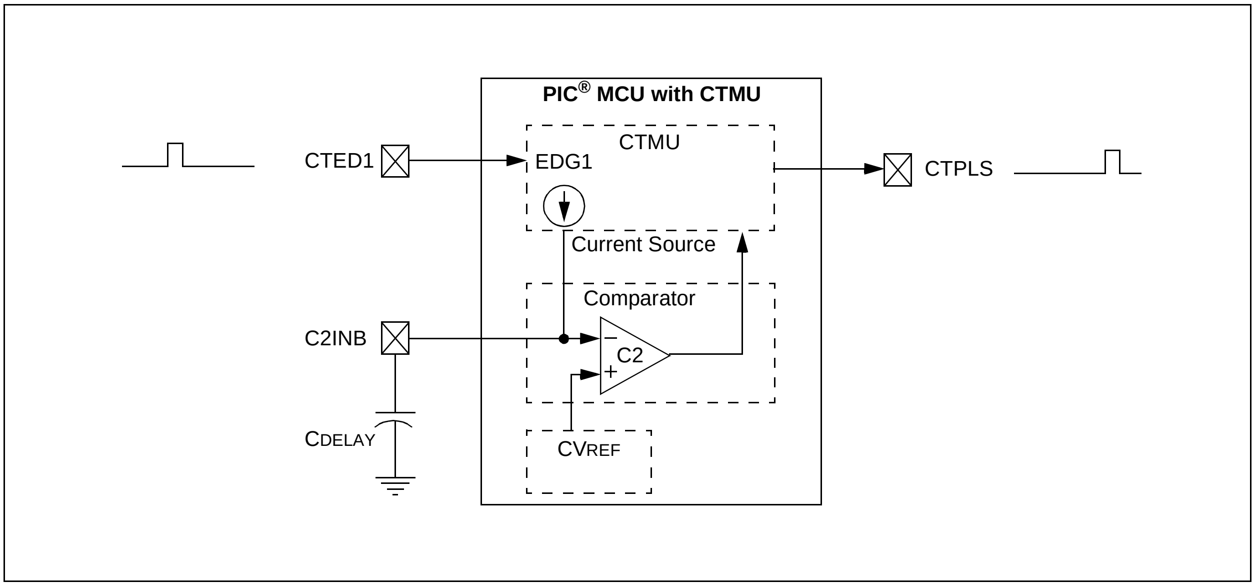
PWM Generation

By using the CTMU with a comparator (either internal or external), there is a way to generate high-resolution, high-frequency Pulse-Width Modulation (Figure 9). The PWM resolution depends on the slope controlled by the internal A/D sampling capacitor (CHOLD), and can be changed by adding an external capacitor parallel to CHOLD.

39. Blanking Pulse for Radar

Modern radar generates transmit pulses at a very high rate, and requires very high-speed display blanking to keep the receiver and display from being overwhelmed. Often, the switching rate is too fast for a conventional PWM generator. When working as a pulse generator, however, the CTMU can operate fast enough to keep up.

FIGURE 9: PWM AND PULSE GENERATION



Digital-to-Analog Conversion (DAC)

By taking PWM generation an additional step, running the high-frequency pulse output through a low-pass filter creates an analog signal. This can be useful in a number of applications:

40. Audio Generator

In a digital world, this is always a popular application: turning a digital bitstream into audio. In appliances where a microcontroller is already present, the CTMU can implement a simple audio generator to create a range of audio feedback prompts (constant or interrupted tones of various frequencies). With enough memory, the CTMU DAC can even reproduce voice samples.

41. Digital LCD Contrast Control

For backlit displays, the CTMU can translate digital control inputs into a control voltage for changing the contrast of an LCD panel.

42. Programmable Voltage Reference

Similar to the preceding application, the CTMU DAC can be configured to generate a known voltage output for a given digital input. This can be used as the constant voltage source for many analog and control applications.

Time Delay Applications

43. Silicon Tester

The CTMU's pulse delay feature makes it easy to create a variable clock delay generator. This can be used for performing Sample-and-Hold sweeps on digital circuits as part of the validation and characterization process.

44. Oscilloscope Enhancement

For slow and inexpensive oscilloscopes, a CTMU-based solution can be used to enhance the input measurement resolution. This uses the pulse delay feature to add delayed triggers to sample the A/D for repetitive waveforms. The time delay works as multiple triggers for the A/D to acquire samples derived from a single trigger, with delays added to it.

45. Time Domain (Delay) Encryption/Decryption

A novel way to encrypt a digital data stream is to add fixed delays of one or more durations to the pulse train. Without knowing where the delays were inserted, it becomes impossible to establish a reference frame to decode the signal. But where the delays are known, the CTMU's pulse delay function can be used to effectively remove the delays and restore the pulse train to its original form. The pulse delay feature can also be used to perform the initial encryption. A simplified version of the process is shown in Figure 10.

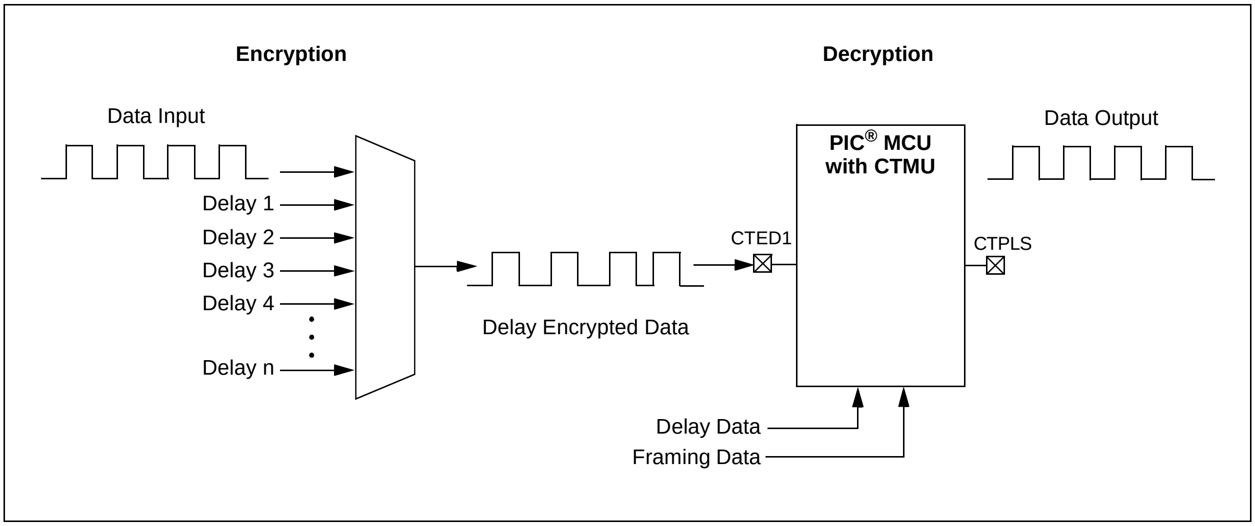
Of course, this involves more than just the CTMU hardware, such as determining a key sequence and frame sync; but the point here is the decoding hardware does not need to be the difficult or expensive piece of the application.

Medical Applications

46. Ultrasound Imaging (Sensor Head)

As described in previous applications, the CTMU can be used to measure the time between transmitted and reflected impulses. This information can be continuously fed in real time to a graphic processor, or processing application, to create an image. This can be implemented directly as an ultrasonic microphone (# 2) or indirectly, through an ultrasonic pick-up (# 15).

FIGURE 10: SIMPLIFIED FLOW FOR DELAY ENCRYPTION/DECRYPTION



Really Complex Applications

47. Solving World Hunger

By mass deploying inexpensive temperature (# 28) and humidity sensors (# 10), it becomes possible to make continuous, fine resolution measurements of climatic variation over large agricultural areas. This makes it possible, at least in theory, to create a closed-loop system of more precise water and nutrient delivery. This, in turn, can push crop yields to their maximum. Do this in enough places, and there will be enough food to feed everyone, everywhere. (Note that it was never said that this would be easy.)

48. Bring About World Peace

Admittedly, World Peace is still being worked on. It's possible that it is beyond the scope of the CTMU, or it could be that it hasn't been given enough time. Perhaps this issue is one that can be left to the readers.

CONCLUSION

At first glance, a constant-current source on a microcontroller might seem to have limited possibilities. What has been shown is that the CTMU, combined with the many other peripherals available in PIC microcontrollers, offers a simple way to create a wide range of applications.

The 48 examples that are shown here just scratch the surface of what is possible. The reader is invited to expand the possibilities.

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Fax: 86-29-8833-7256

China - Xiamen
Tel: 86-592-2388138
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China - Zhuhai
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Fax: 86-756-3210049

ASIA/PACIFIC

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

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

India - Pune
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Japan - Yokohama
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Fax: 81-45-471-6122

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
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Fax: 60-3-6201-9859

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

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

Singapore
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Taiwan - Hsin Chu
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Fax: 886-3-6578-370

Taiwan - Kaohsiung
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Taiwan - Taipei
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