TB3016

Using the PIC® MCU CTMU for Temperature Measurement

Author: Padmaraja Yedamale
Microchip Technology Inc.

The Charge Time Measurement Unit (CTMU), introduced on the latest generation of PIC24F and PIC18F devices, uses a constant current source to calculate both capacitance changes and the time difference between events. The same current source can also be used to measure temperature by exploiting a basic principle of semiconductor physics. This allows the use of a common and inexpensive diode, in the place of a relatively more expensive thermistor or other temperature sensor. This brief describes the basic concepts of temperature measurement using the CTMU.

BASIC PRINCIPLE

We can show that the forward voltage (V_F) of a P-N junction, such as a diode, is an extension of the equation for the junction's thermal voltage:

$$V_F = \frac{kT}{q}\ln\left(1 - \frac{I_F}{I_S}\right)$$

where k is the Boltzmann constant (1.38×10^{-23} J K^{-1}), T is the absolute junction temperature in kelvin, q is the electron charge (1.6×10^{-19} C), I_F is the forward current applied to the diode, and I_S is the diode's characteristic saturation current.

Since k and q are physical constants, and I_S is a constant for the device, this only leaves T and I_F as independent variables. If I_F is held constant, it follows from the equation that V_F will vary as a function of T. As the natural log term of the equation will always be negative, the temperature will be negatively proportional to V_F. In other words, as temperature increases, V_F decreases.

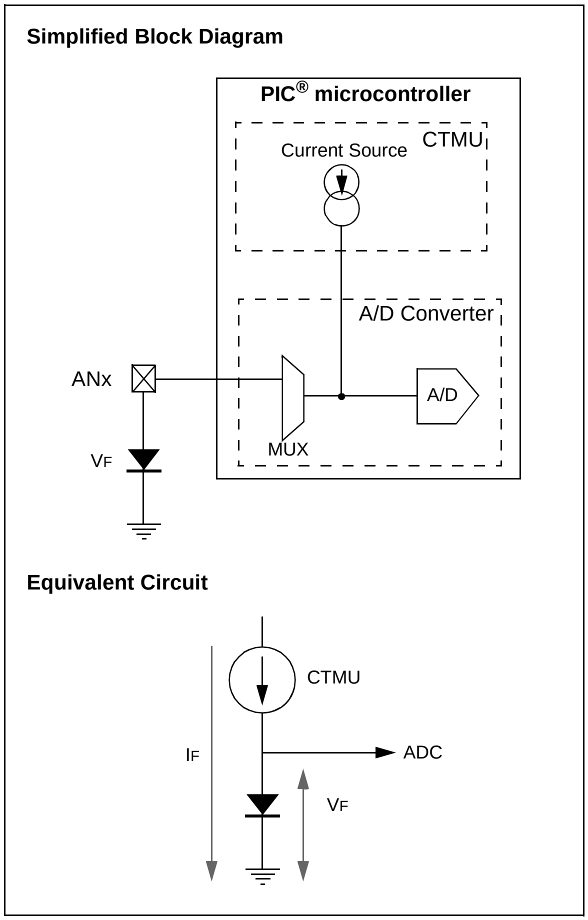
By using the CTMU's current source to provide a constant I_F, it becomes possible to calculate the temperature by measuring the V_F across the diode.

IMPLEMENTATION

To implement this theory, all that is needed is to connect a regular junction diode to one of the microcontroller's A/D pins (Figure 1). The A/D channel multiplexer is shared by the CTMU and the ADC.

To perform a measurement, the multiplexer is configured to select the pin connected to the diode. The CTMU current source is then turned on, and an A/D conversion is performed on the channel. As shown in the equivalent circuit diagram, the diode is driven by the CTMU at I_F. The resulting V_F across the diode is measured by the ADC.

FIGURE 1: CTMU TEMPERATURE MEASUREMENT CIRCUIT



EXPERIMENTAL VALIDATION

To test the theory, several devices with simple P-N junctions were tested in a controlled temperature environment while measuring V_F as previously described. Included in the testing were three common silicon diodes, two common bipolar transistors, and two LEDs. An additional trial was run with two diodes (1N914) connected in parallel as a single unit. Each device was evaluated using an ADC voltage reference (VREF) of 3.3V.

Temperature was varied from 0°C to 105°C inclusive, with 256 conversions being taken at roughly 5°C intervals over this range. The ADC readings (proportional to voltage) were recorded for each temperature point. These readings were used to directly calculate resolution, and converted to voltage to calculate line slope.

Resolution (expressed as temperature per ADC counts) is calculated as:

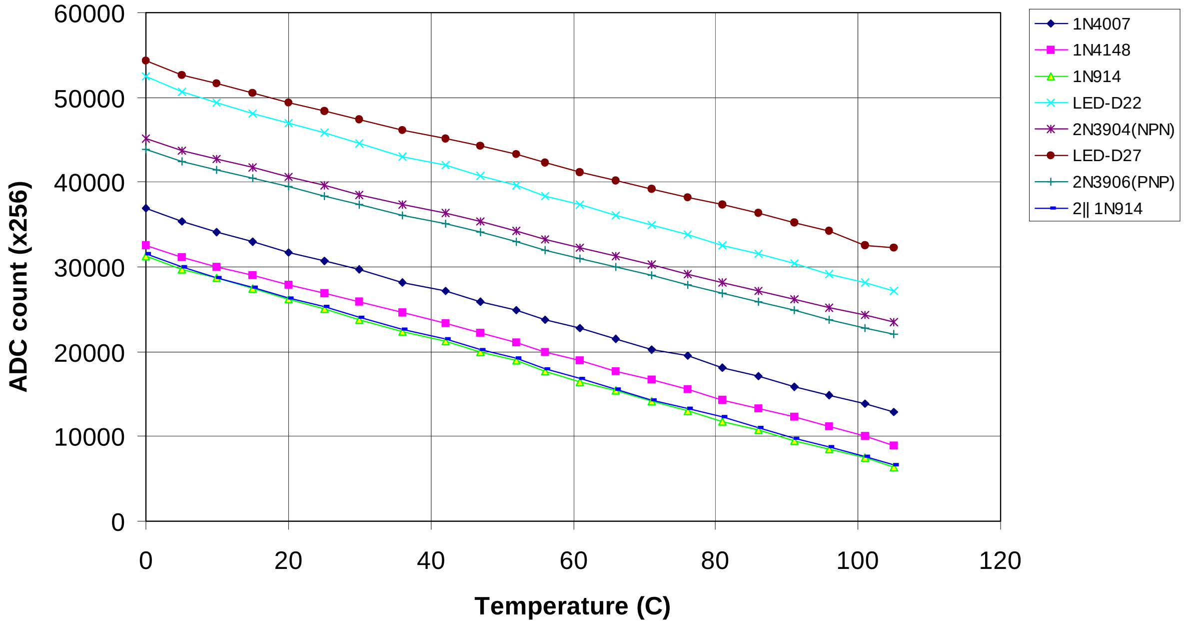
$$\frac{\text{Number of samples} \times \text{Temperature range}}{\text{Counts at min temperature} - \text{Counts at max tempertaure}}$$

The results of the trial are summarized in Table 1, and presented in graphic form in Figure 2. As can be seen, the correlation between temperature and V_F is negative. Also as expected, the relationship between temperature and the forward voltage on the junction is essentially linear. This makes it possible for any readily available diode – or for that matter, any inexpensive semiconductor – to function as a low-resolution temperature sensor in conjunction with the CTMU.

TABLE 1: EXPERIMENTAL VF VALUES (AS ADC COUNTS) FOR DIFFERENT DEVICES AS A FUNCTION OF TEMPERATURE

Component	ADC Readings (256 samples)		Resolution (°C/Count)	Slope
	Min. Temp	Max. Temp		
1N4007	36,890	12,815	1.12	-2.88 mV/°C
1N4148	32,500	8,980	1.15	-2.8 mV/°C
1N914	31,500	6,417	1.08	-2.98 mV/°C
2N3904 (NPN)	45,100	23,560	1.26	-2.56 mV/°C
2N3906 (PNP)	43,860	22,020	1.24	-2.60 mV/°C
SML-LXT0805GW-TR (Green LED)	52,500	27,150	1.07	-3.01 mV/°C
CML 5311F (Red LED)	54,280	32,265	1.23	-2.62 mV/°C
Two 1N914 (parallel)	31,500	6,660	1.09	-2.95 mV/°C

FIGURE 2: ADC VALUES AS A FUNCTION OF TEMPERATURE FOR TESTED DEVICES



INCREASING TEMPERATURE MEASUREMENT RESOLUTION

The method described here is adequate for resolution of about 1°C. In most cases, this represents an A/D channel voltage change of about 3 mV. At this scale, attempts to get better resolution will run into the limitations of the A/D converter. To achieve higher temperature resolutions, some minor changes to the conversion method are needed. These include:

- Using a lower reference voltage for the ADC. One significant determining factor in temperature resolution is the selection of VREF. Smaller values of VREF tend to produce a larger difference voltage to be converted; this produces a larger incremental reading per degree, and thus higher resolution. Table 2 shows the expected temperature resolution for the same experiment, assuming an ADC VREF of 2.0V.
- Using two diodes in series. Although this does not increase resolution *per se*, the resulting doubling of the change in the measured voltage per unit of temperature will result in increased accuracy.
- Adding a single stage of voltage amplification with an op amp. By increasing the voltage to the ADC and matching it to the ADC voltage reference, resolution is increased. Although this adds several external components and some cost to the solution, this may be desirable in applications where a more precise determination of temperature is required.

TABLE 2: EXPECTED TEMPERATURE RESOLUTION FOR VREF OF 2.0V

Component	Resolution (°C/Count)	
	VREF = 3.3V (observed)	VREF = 2.0V (predicted)
1N4007	1.12	0.68
1N4148	1.15	0.69
1N914	1.08	0.66
2N3904	1.26	0.76
2N3906	1.24	0.75
SML-LXT0805GW-TR	1.07	0.64
CML 5311F	1.23	0.74
Two 1N914 (parallel)	1.09	0.66

CONCLUSION

For applications using a PIC18F or PIC24F microcontroller with the CTMU, adding a temperature function does not depend on the use of a special temperature sensor; it can be done using a commodity diode and a small addition of code to the application firmware. This makes the incremental cost of adding the additional feature very small indeed.

REFERENCES

PIC24F Family Reference Manual, Section 11, *“Charge Time Measurement Unit (CTMU)”* (DS39724). Microchip Technology Inc., 2008.

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

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

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

Trademarks

QUALITY MANAGEMENT SYSTEM
CERTIFIED BY DNV
ISO/TS 16949:2002

Microchip received ISO/TS-16949:2002 certification for its worldwide headquarters, design and wafer fabrication facilities in Chandler and Tempe, Arizona; Gresham, Oregon and design centers in California and India. The Company's quality system processes and procedures are for its PIC® MCUs and dsPIC® DSCs, KEELOQ® code hopping devices, Serial EEPROMs, microperipherals, nonvolatile memory and analog products. In addition, Microchip's quality system for the design and manufacture of development systems is ISO 9001:2000 certified.

WORLDWIDE SALES AND SERVICE

AMERICAS

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

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

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

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

Cleveland
Independence, OH
Tel: 216-447-0464
Fax: 216-447-0643

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

Detroit
Farmington Hills, MI
Tel: 248-538-2250
Fax: 248-538-2260

Kokomo
Kokomo, IN
Tel: 765-864-8360
Fax: 765-864-8387

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

Santa Clara
Santa Clara, CA
Tel: 408-961-6444
Fax: 408-961-6445

Toronto
Mississauga, Ontario,
Canada
Tel: 905-673-0699
Fax: 905-673-6509

ASIA/PACIFIC

Asia Pacific Office
Suites 3707-14, 37th Floor
Tower 6, The Gateway
Harbour City, Kowloon
Hong Kong
Tel: 852-2401-1200
Fax: 852-2401-3431

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

China - Beijing
Tel: 86-10-8528-2100
Fax: 86-10-8528-2104

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

China - Hong Kong SAR
Tel: 852-2401-1200
Fax: 852-2401-3431

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

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

China - Shanghai
Tel: 86-21-5407-5533
Fax: 86-21-5407-5066

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

China - Shenzhen
Tel: 86-755-8203-2660
Fax: 86-755-8203-1760

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

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

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

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

ASIA/PACIFIC

India - Bangalore
Tel: 91-80-3090-4444
Fax: 91-80-3090-4080

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

India - Pune
Tel: 91-20-2566-1512
Fax: 91-20-2566-1513

Japan - Yokohama
Tel: 81-45-471- 6166
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
Tel: 60-3-6201-9857
Fax: 60-3-6201-9859

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

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

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

Taiwan - Hsin Chu
Tel: 886-3-572-9526
Fax: 886-3-572-6459

Taiwan - Kaohsiung
Tel: 886-7-536-4818
Fax: 886-7-536-4803

Taiwan - Taipei
Tel: 886-2-2500-6610
Fax: 886-2-2508-0102

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

EUROPE

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

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

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

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

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

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

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

UK - Wokingham
Tel: 44-118-921-5869
Fax: 44-118-921-5820

02/04/09