
True DC RMS Meter using Core Independent Peripherals

Introduction

Author: June Anthony Asistio, Microchip Technology Inc.

This technical brief demonstrates a solution for measuring the True DC RMS of a periodic DC waveform using the Core Independent Peripherals (CIPs) that are found on the PIC18 microcontrollers. The project uses less code and CPU cycles since the averaging operation, frequency calibration and data transfer are implemented using the CIPs.

The demonstration uses the following CIPs:

- Signal Measurement Timer (SMT)
- Zero Crossing Detector (ZCD)
- Numerically Controlled Oscillator (NCO)
- Direct Memory Access Controllers (DMAs)
- Configurable Logic Cell (CLC)
- Fixed Voltage Reference (FVR)
- Digital-to-Analog Converter (DAC)
- 8-Bit Timers (TMR2, TMR4)
- Peripheral Pin Select (PPS)

The following on-chip peripherals are also used:

- Analog-to-Digital Converter with Computation (ADC²)
- Universal Asynchronous Receiver/Transmitter (UART)
- Vectored Interrupt Controller (VIC)

The period of the signal can be measured directly by SMT and ZCD. These two peripherals are useful for calibrating the frequency of the RMS meter when taking the measurement.

The summing and averaging operations are done using the NCO accumulator.

The computed RMS data is transferred to the UART transmit and DAC output buffer registers using two separate DMA channels. The functions for transferring data are no longer necessary on the main code and data transfers are not executed by the CPU. The advantage with utilizing the DMAs for data transfer gives the CPU the freedom to perform other tasks.

The square and square root values are retrieved from the Look-up Table (LUT) during the RMS data processing, instead of using the CPU cycles for multiplication and getting square roots.

The TMR4 with interrupt can act as a counter that replaces the use of a nested “for” loop in the code.

The VIC provides each interrupt source a vector address that contains the Interrupt Service Routine (ISR). This method has the advantage of directly executing the interrupt routine from the interrupt vector, rather than scanning each interrupt source that is implemented on software legacy interrupts.

This document will cover the design process and configuration of each peripheral to perform the True DC RMS measurement.

Table of Contents

Introduction.....	1
1. Definition of True DC RMS.....	3
2. True DC RMS Meter Implementation.....	4
3. Testing and Verification.....	8
4. Conclusion.....	9
5. Appendix.....	10
The Microchip Website.....	16
Product Change Notification Service.....	16
Customer Support.....	16
Microchip Devices Code Protection Feature.....	16
Legal Notice.....	16
Trademarks.....	17
Quality Management System.....	17
Worldwide Sales and Service.....	18

1. Definition of True DC RMS

Electrical signals are characterized by parameters such as amplitude and frequency. The most common representation of amplitude are average and RMS values.

V_{AVE} is computed by getting the arithmetic mean of a signal in a given time as shown in [Equation 1-1](#).

Equation 1-1. V_{AVE} of a signal

$$V_{AVE} = \sum_{i=1}^n \frac{V_i}{n}$$

AC voltage signals have both positive and negative values, [Equation 1-2](#) shows that V_{AC_RMS} is also computed by getting the square root of the arithmetic mean of the squares of the signal for a given time.

Equation 1-2. V_{AC_RMS} of an AC signal

$$V_{AC_RMS} = \sum_{i=1}^n \sqrt{\frac{V_i^2}{n}}$$

[Equation 1-2](#) is valid only for getting the V_{AC_RMS} of AC voltage signals. In measuring the V_{AC_RMS} of a periodic DC voltage signal, the DC offset must be subtracted first from each sample before squaring, averaging, and getting the square root. This is illustrated in [Equation 1-3](#).

Equation 1-3. V_{AC_RMS} of a DC signal

$$V_{AC_RMS} = \sum_{i=1}^n \sqrt{\frac{(V_i - V_{DC_OFFSET})^2}{n}}$$

Another parameter, the DC RMS of a periodic DC waveform, can be computed in [Equation 1-4](#). DC voltage signals are best represented by V_{AVE} , while AC voltage signals are described by V_{AC_RMS} . One possible application of the V_{DC_RMS} is to measure the RMS voltage of a rectified AC signal. The True DC RMS meter presented in this document uses this mathematical definition.

Equation 1-4. V_{DC_RMS} of a DC signal

$$V_{DC_RMS} = \sum_{i=1}^n \sqrt{\frac{V_i^2}{n}}$$

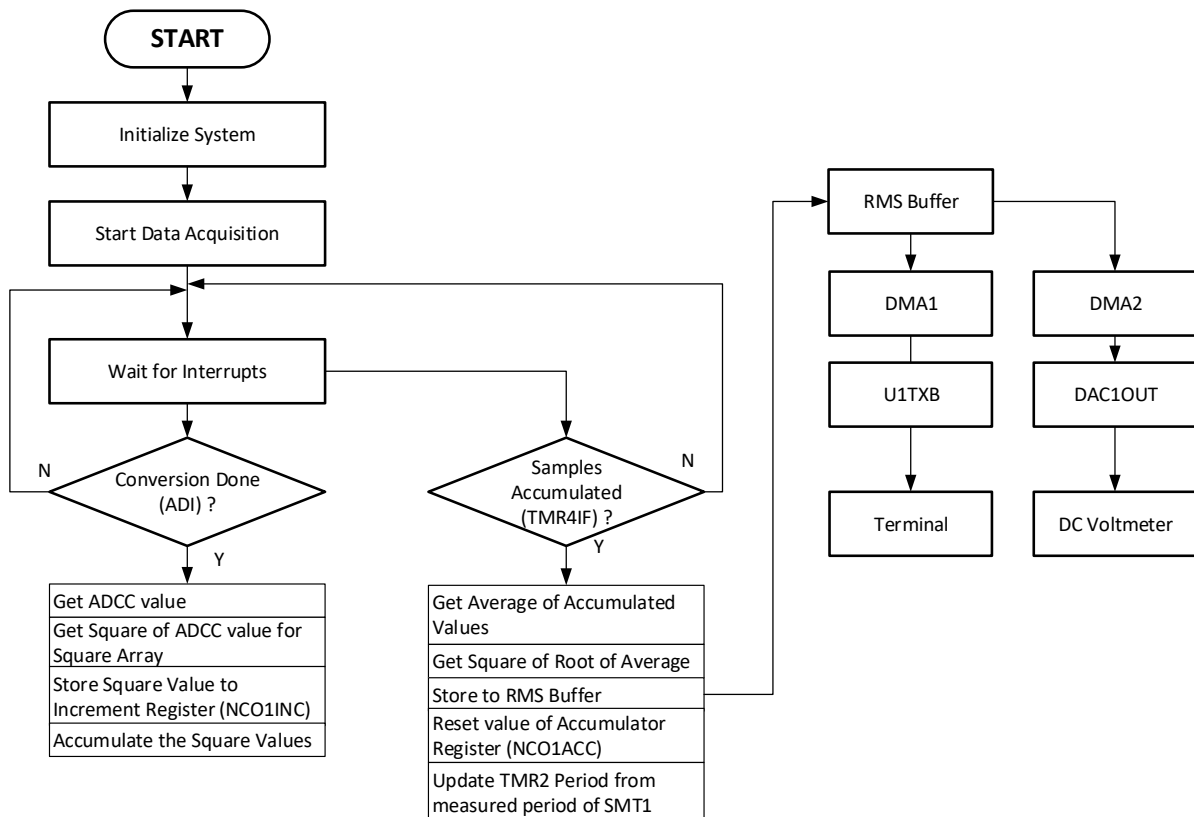
2.2 Firmware Flowchart

The simplified firmware operation is shown in [Figure 2-2](#). After the system and all the peripherals are initialized, the microcontroller waits for completed ADC² conversion interrupts and TMR4 overflow interrupts.

For each completed ADC² conversion, the ADC² value is processed to produce the square and store the square on the NCO1 increment register.

For an occurring TMR4 interrupt, the squares of 256 samples have been accumulated. The average is computed from the NCO1, and square root of the average is retrieved from the square root table. The RMS result is stored in an RMS buffer. The data from the RMS buffer is later transferred to UART1 transmit buffer through the DMA1 channel and DAC1 output buffer through the DMA2 channel.

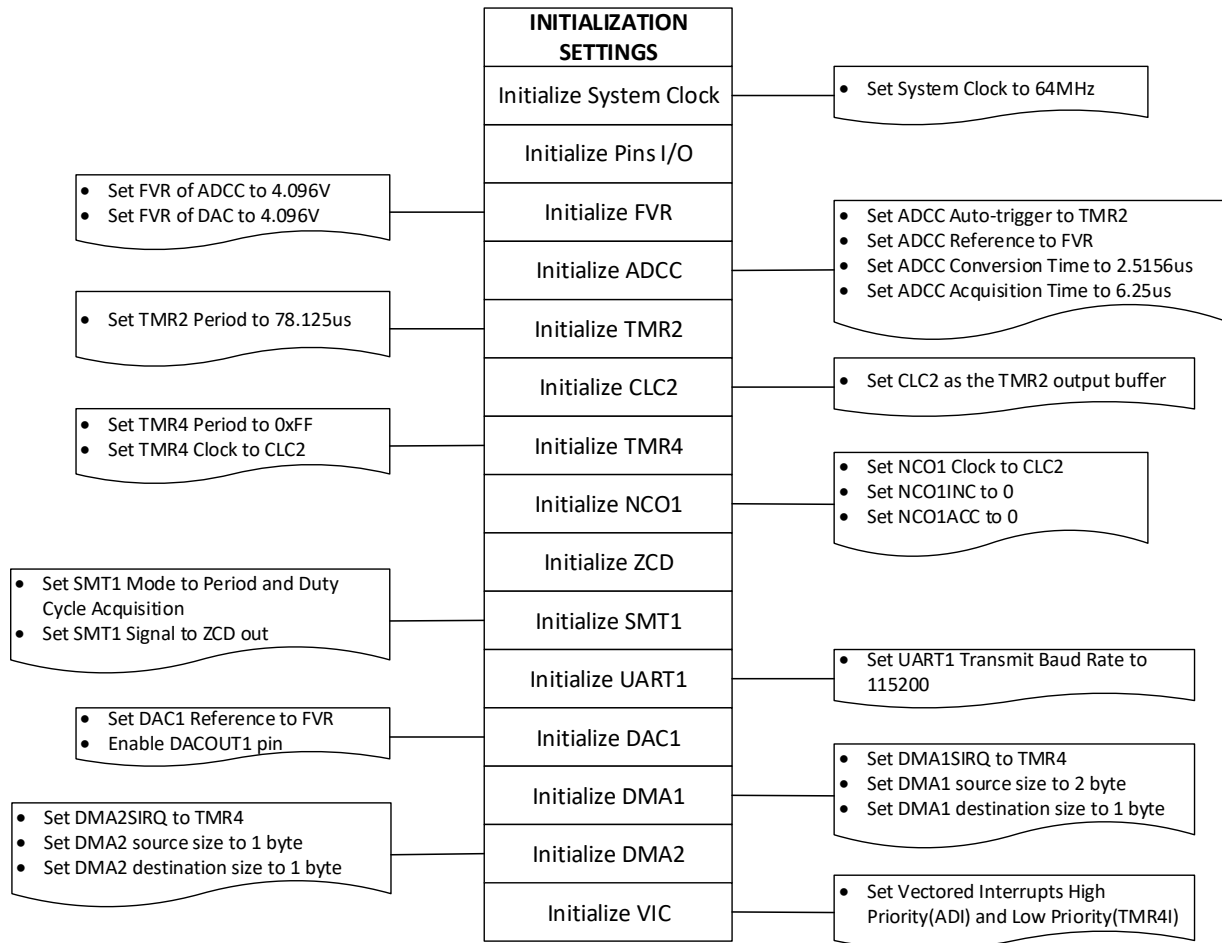
Figure 2-2. Firmware Flowchart



2.3 Initial System Settings

The system clock is set to the highest available frequency, which is 64 MHz. The peripherals follow the connection of the process diagram and the firmware flowchart. The initial settings are summarized in [Figure 2-3](#).

Figure 2-3. Initial System Settings



2.4 Square and Square Root Array

The digital square and square root values can be calculated by using a spreadsheet program. The square and square roots are normalized to one in order to maintain the result to 12-bit size. The procedure for creating the square and square root array are summarized by the following procedure. Table 2-1 shows part of the spreadsheet table used for calculating the 12-bit squares and square roots.

1. Create first column of Analog Values from 0 to 4V with 1 mV increment.
2. Create a column of Normalize Values by dividing all the Analog Values to 4V.
3. Create a column of Normalize Square Values by getting the square of all the Normalize Values.
4. Create a column of Normalize Square Roots by getting the square root of all the Normalize Values.
5. Multiply the Normalize Values, Normalize Square Values and the Normalize Square Roots by 4000 to get the Digital Values and Digital Square Values.
6. Use this 12-bit Square and Square Root Data as working files for SquareArray.csv and SquareRootArray.csv.
7. For SquareArray.csv, delete columns Analog Values, Normalize Values, Normalize Square Values, Normalize Square Roots, Digital Values, Digital Square Roots, and delete the entire first row and last row.
8. For SquareRootArray.csv, delete columns Analog Values, Normalize Values, Normalize Square Values, Normalize Square Roots, Digital Values, Digital Square Values, and delete the entire first row and last row.
9. Insert the data as squareValue and squareRootValue arrays on the code of header file rms.h.

Table 2-1. 12-Bit Square and Square Root Values

Analog Values	Normalize Values	Normalize Square Values	Normalize Square Roots	Digital Values	Digital Square Values	Digital Square Roots
0	0	0	0	0	0	0
0.001	0.00025	6.25E-08	0.015811388	1	0	63
0.002	0.0005	0.00000025	0.02236068	2	0	89
0.003	0.00075	5.625E-07	0.027386128	3	0	110
0.004	0.001	0.000001	0.031622777	4	0	126
0.005	0.00125	1.5625E-06	0.035355339	5	0	141
0.006	0.0015	0.00000225	0.038729833	6	0	155
0.007	0.00175	3.0625E-06	0.041833001	7	0	167
0.008	0.002	0.000004	0.04472136	8	0	179
0.009	0.00225	50.625E-06	0.047434165	9	0	190
0.01	0.0025	0.00000625	0.05	10	0	200
0.011	0.00275	7.5625E-06	0.052440442	11	0	210
0.012	0.003	0.000009	0.054772256	12	0	219
0.013	0.00325	1.05625E-05	0.057008771	13	0	228
...
...
...
...
3.987	0.99675	0.993510563	0.998373678	3987	3974	3993
3.988	0.997	0.994009	0.998498873	3988	3976	3994
3.989	0.99725	0.994507563	0.998624053	3989	3978	3994
3.99	0.9975	0.99500625	0.998749218	3990	3980	3995
3.991	0.99775	0.995505063	0.998874366	3991	3982	3995
3.992	0.998	0.996004	0.998999499	3992	3984	3996
3.993	0.99825	0.996503063	0.999124617	3993	3986	3996
3.994	0.9985	0.99700225	0.999249719	3994	3988	3997
3.995	0.99875	0.997501563	0.999374805	3995	3990	3997
3.996	0.999	0.998001	0.999499875	3996	3992	3998
3.997	0.99925	0.998500563	0.99962493	3997	3994	3998
3.998	0.9995	0.99900025	0.999749969	3998	3996	3999
3.999	0.99975	0.999500063	0.999874992	3999	3998	3999
4	1	1	1	4000	4000	4000

4. Conclusion

The CIPs and on-chip peripherals provide a fast and reliable design solution for developing a hardware-based True DC RMS meter application that uses less code and CPU resources. The combination of hardware peripherals can simplify the implementation of the timing, measuring, computation, and data transfer operations that are otherwise difficult to realize using a full software-based solution.

5. Appendix

5.1 Appendix A: Test Results

The comparative measurements using different test waveforms are shown below. The UART1 terminal displays True DC RMS as 16-bit value in 1 mV resolution. A voltmeter at DAC10OUT displays the same DC RMS of the waveform.

Figure 5-1. DC RMS of a 50 Hz Triangular Waveform

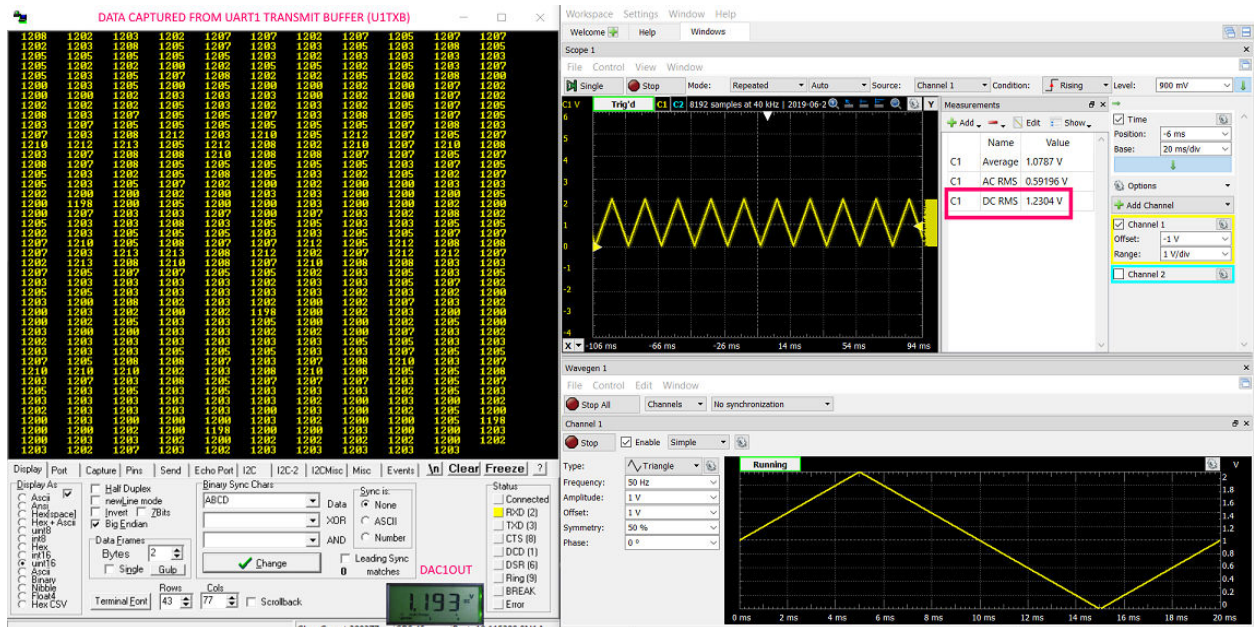


Figure 5-2. DC RMS of a 50 Hz 50% Duty PWM Waveform

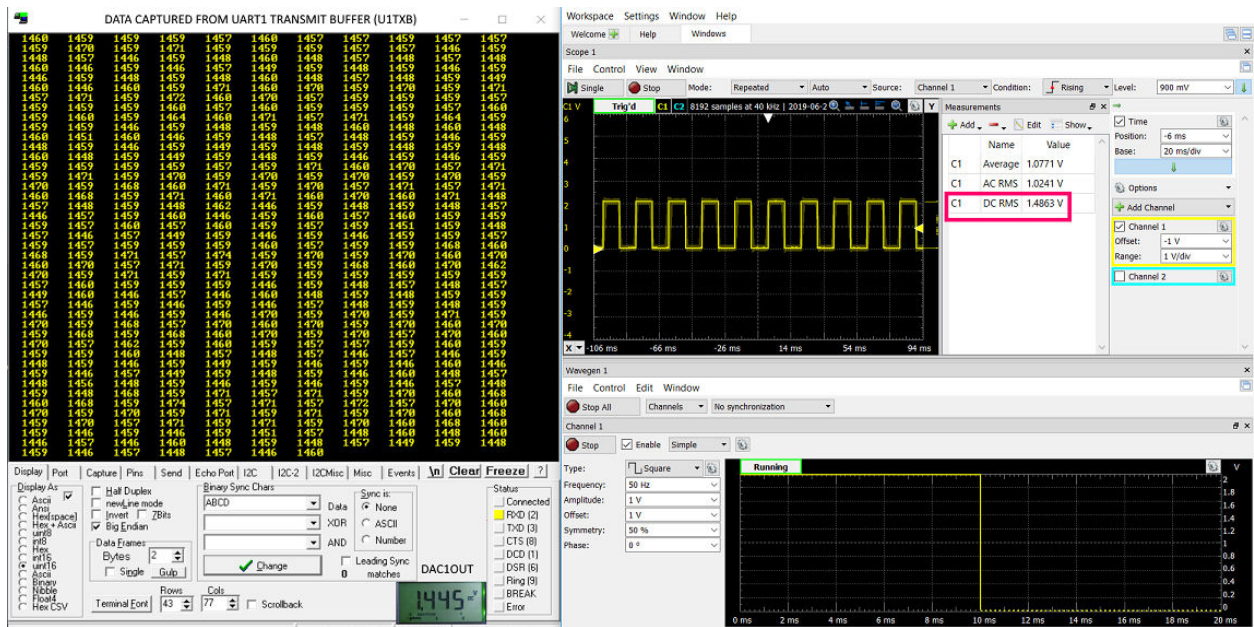


Figure 5-3. DC RMS of a 50 Hz 20% Duty PWM Waveform

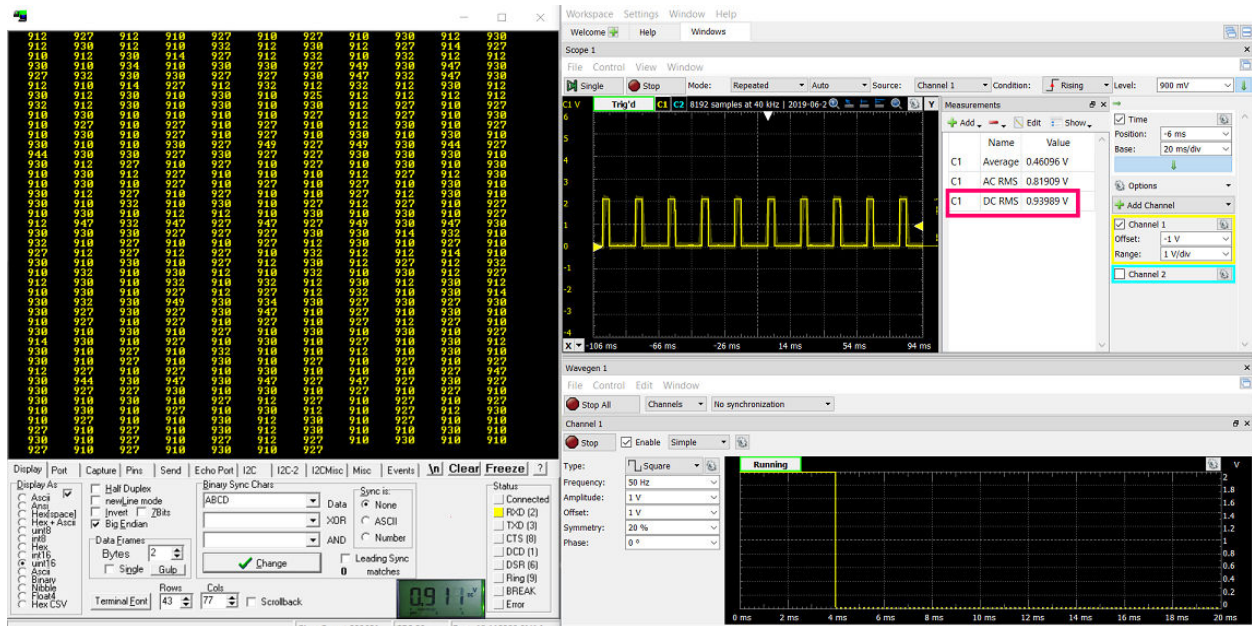


Figure 5-4. DC RMS of a 50 Hz 10% Duty PWM Waveform

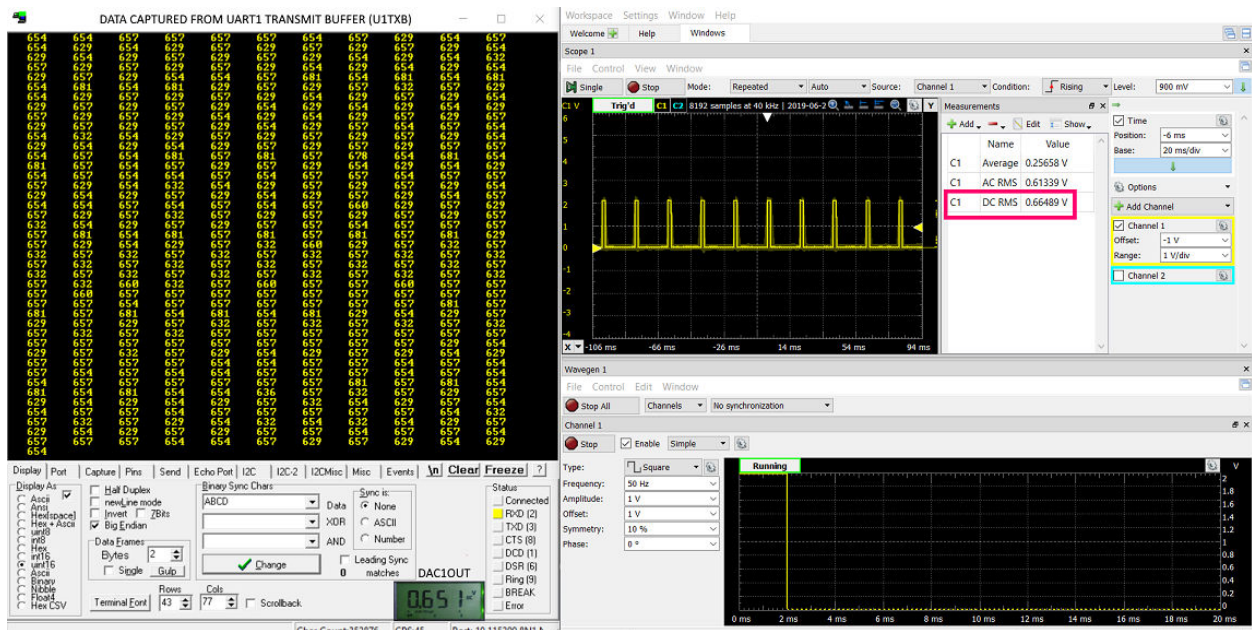


Figure 5-5. DC RMS of a 50 Hz Haversine Waveform

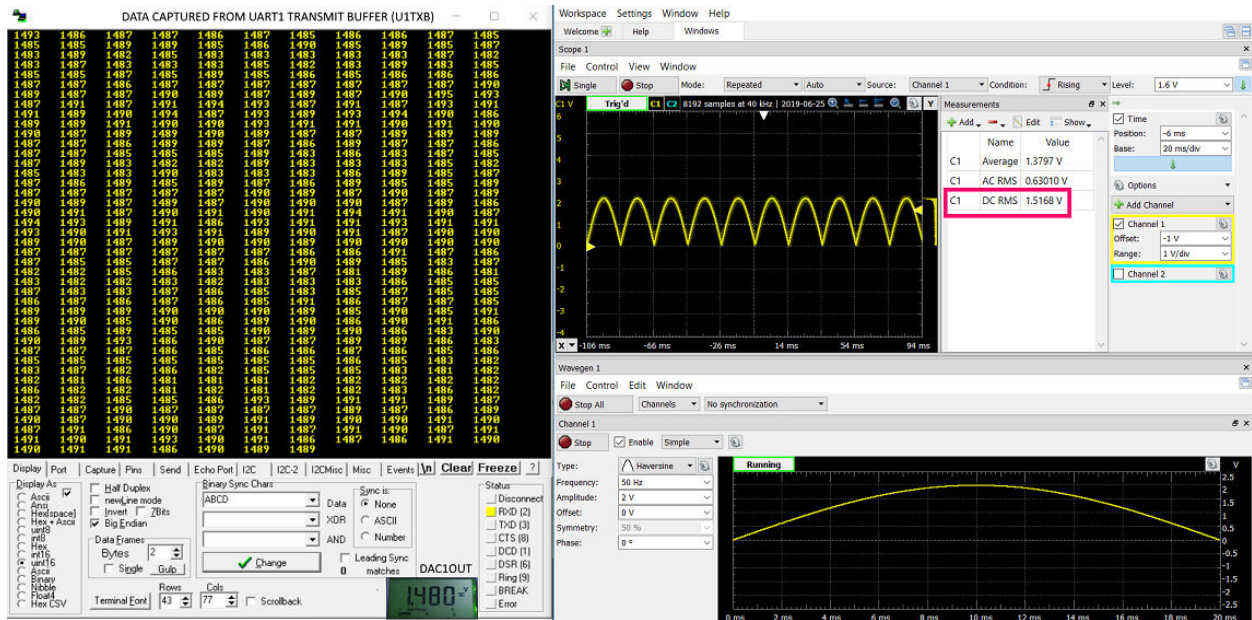


Figure 5-6. DC RMS of a 50 Hz 1/2 Haversine Waveform

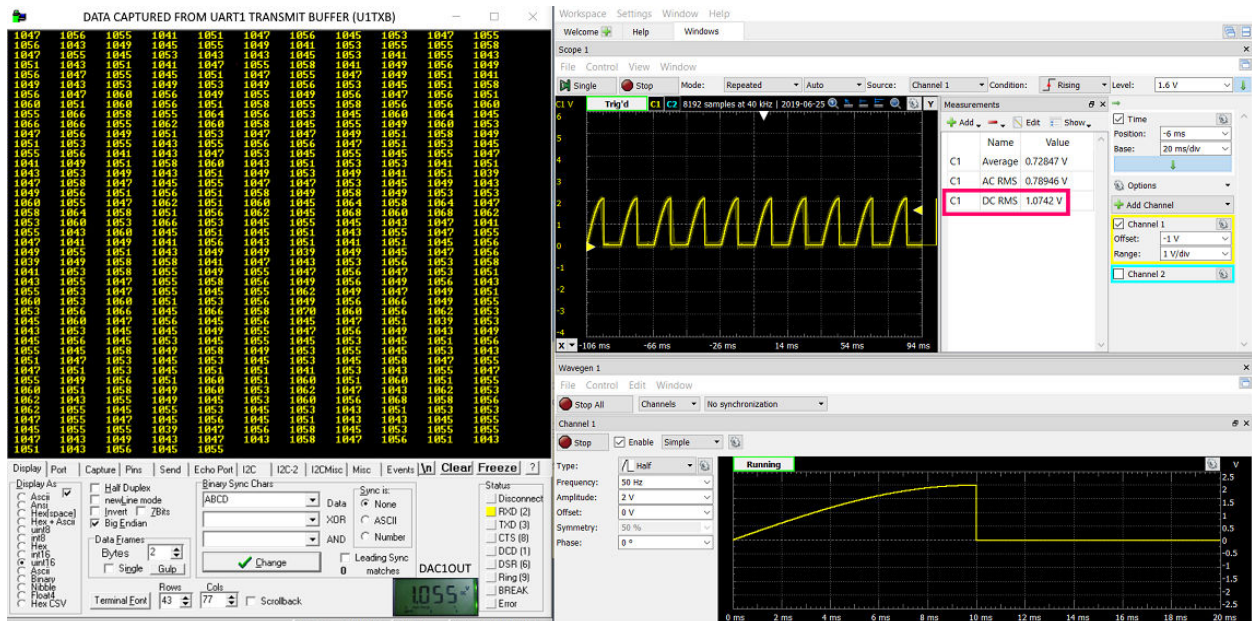


Figure 5-7. DC RMS of a 50 Hz 1/4 Haversine Waveform

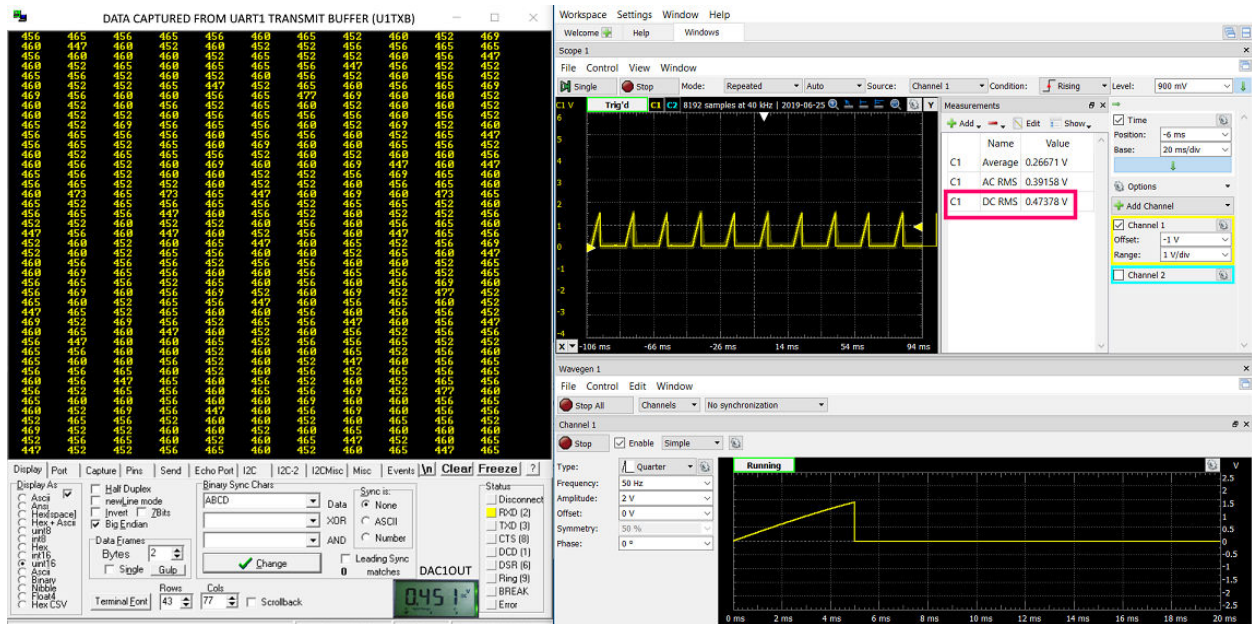
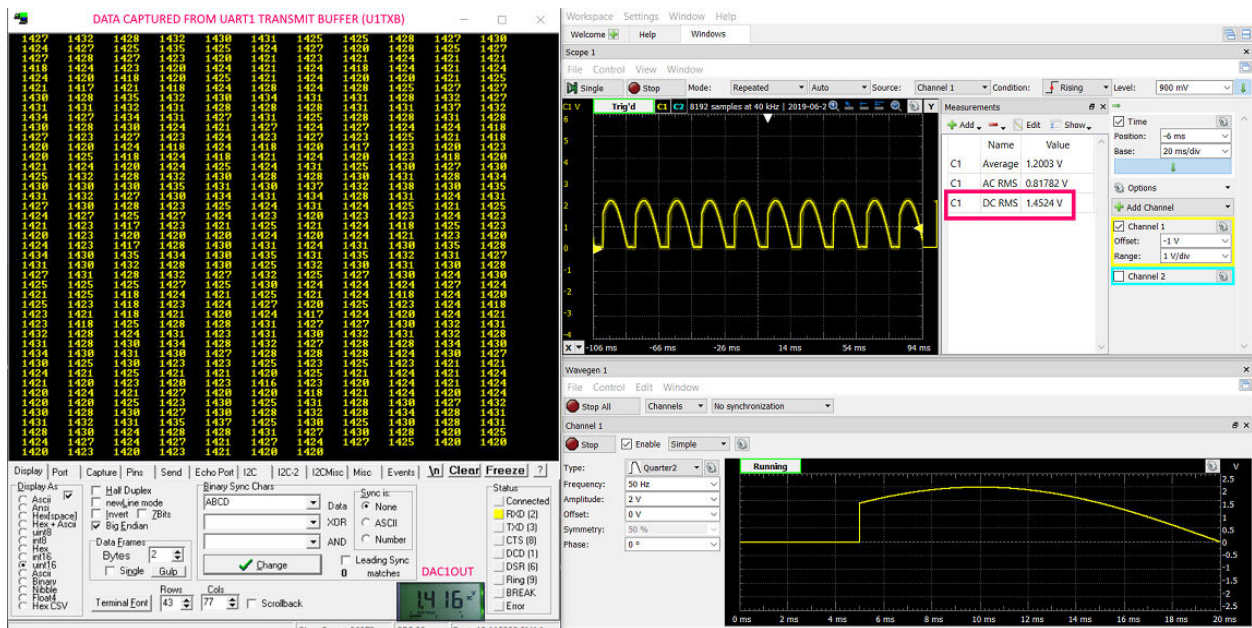


Figure 5-8. DC RMS of a 50 Hz 3/4 Haversine Waveform



5.2 Appendix B: Peripheral Usage

Table 5-1 summarizes the operation of the peripherals used in this project.

Table 5-1. Peripheral Module Usage

Module	Function/Operation
FVR	FVR sets ADC ² and DAC reference voltages to 4.096V.
ADC ²	ADC ² gets V _{IN} samples from ANA0. ADC ² is set to auto-trigger from TMR2 overflow.

.....continued	
Module	Function/Operation
TMR2	TMR2 sets the sampling frequency. Initially this is set 50 Hz divided by 256. This is updated by SMT1 period measurement after succeeding RMS computation.
CLC2	CLC2 acts as a buffer for TMR2 signal.
TMR4	TMR4 acts as the 0-255 counter to get 256 samples of the signal in one period.
NCO1	The Accumulator of NCO1 is used to get the sum of the squares of the ADC ² samples.
ZCD	The AC component of the signal is passed to the ZCD pin. The output of the ZCD is fed to the SMT1 to measure the period.
SMT1	SMT1 measures the period of the AC component of the signal through the ZCD. The TMR2 sampling time is updated from SMT1 period measurement.
UART1	UART1 transmit buffer displays the RMS value to the computer terminal.
DAC1	DAC1 outputs the DC RMS of the signal.
DMA1	DMA1 channels the RMS value to the UART transmit buffer U1TXB.
DMA2	DMA2 channels the RMS value to the DAC1CON1.
VIC	ADIF is set to high priority while TMR4 is set to low priority.

5.3 Appendix C: User Defined Functions

Additional functions are built to facilitate the True DC RMS computation using the peripherals. The True DC RMS functions are described below.

5.3.1 RMSInterruptHandler_Initialize()

This function sets up ADC² and TMR4 interrupt handlers.

```
void RMSInterruptHandler_Initialize(void)
{
    ADCC_SetADIInterruptHandler(ADCC_RMS_InterruptHandler);
    TMR4_SetInterruptHandler(TMR4_RMS_InterruptHandler);
}
```

5.3.2 StartDataAcquisition()

This function sets up the DMA1 and DMA2 Source Address; DMA1 and DMA2 Destination Address; starts SMT1; enables DMA1 and DMA2 Start Transfer Request; and starts TMR2.

```
void StartDataAcquisition(void)
{
    DMA1_SetSourceAddress();
    DMA2_SetSourceAddress();
    DMA1_SetDestinationAddress();
    DMA2_SetDestinationAddress();
    SMT1_DataAcquisitionEnable();
    DMA1_StartTransferRequest();
    DMA2_StartTransferRequest();
    TMR2_Start();
}
```

5.3.3 Accumulate()

This function stores the squareValue to the NCO1INC increment register.

```
void Accumulate(void)
{
    NCO1INCH = squareValue >> 8;
}
```

```
NCO1INCL = squareValue;
}
```

5.3.4 GetAverageValue()

This function returns the averageValue of the NCO1ACC accumulate register after 256 samples. The NCO1ACC is right-shifted by 8 bits.

```
uint16_t GetAverageValue(void)
{
    return (uint16_t) (NCO1ACCU << 8) + NCO1ACCH;
}
```

5.3.5 BufferRmsValue()

This function stores data of 12-bit RMS result in 2 bytes for DMA1 channel of UART1 and 8-bit RMS value in 1 byte for DMA2 channel of DAC1 output buffer.

```
void BufferRmsValue(void)
{
    rmsValue[0] = (uint8_t) (squareRootValue >> 8);
    rmsValue[1] = (uint8_t) (squareRootValue);
    rmsOutput = (uint8_t) (squareRootValue >> 4);
}
```

5.3.6 ResetAccumulator()

This function clears NCO1ACC Accumulator Register after getting the DC RMS result of 256 samples.

```
void ResetAccumulator(void)
{
    NCO1ACCU = 0;
    NCO1ACCH = 0;
    NCO1ACCL = 0;
}
```

5.3.7 SetPeriod()

This function updates TMR2 Period by shifting the measured SMT1CPR period 8 bits to the right. The factor is computed by equating SMT1 and TMR2 settings as shown in [Equation 5-1](#).

```
void SetPeriod(void)
{
    T2PR = (SMT1CPR) >> 8;
}
```

Equation 5-1. TMR2 Period update with SMT1 Period Measurement

$$SMT1CPR = \frac{20ms \cdot 64MHz}{8 \cdot 4}$$

$$T2PR = \frac{20ms \cdot 64MHz}{256 \cdot 32}$$

$$T2PR = \frac{SMT1CPR}{2^8}$$

The Microchip Website

Microchip provides online support via our website at <http://www.microchip.com/>. This website is used to make files and information easily available to customers. Some of the content available includes:

- **Product Support** – Data sheets and errata, application notes and sample programs, design resources, user's guides and hardware support documents, latest software releases and archived software
- **General Technical Support** – Frequently Asked Questions (FAQs), technical support requests, online discussion groups, Microchip design partner program member listing
- **Business of Microchip** – Product selector and ordering guides, latest Microchip press releases, listing of seminars and events, listings of Microchip sales offices, distributors and factory representatives

Product Change Notification Service

Microchip's product change notification service helps keep customers current on Microchip products. Subscribers will receive email notification whenever there are changes, updates, revisions or errata related to a specified product family or development tool of interest.

To register, go to <http://www.microchip.com/pcn> and follow the registration instructions.

Customer Support

Users of Microchip products can receive assistance through several channels:

- Distributor or Representative
- Local Sales Office
- Embedded Solutions Engineer (ESE)
- Technical Support

Customers should contact their distributor, representative or ESE for support. Local sales offices are also available to help customers. A listing of sales offices and locations is included in this document.

Technical support is available through the website at: <http://www.microchip.com/support>

Microchip Devices Code Protection Feature

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.

Legal Notice

Information contained in this publication regarding device applications and the like is provided only for your convenience and may be superseded by updates. It is your responsibility to ensure that your application meets with

your specifications. MICROCHIP MAKES NO REPRESENTATIONS OR WARRANTIES OF ANY KIND WHETHER EXPRESS OR IMPLIED, WRITTEN OR ORAL, STATUTORY OR OTHERWISE, RELATED TO THE INFORMATION, INCLUDING BUT NOT LIMITED TO ITS CONDITION, QUALITY, PERFORMANCE, MERCHANTABILITY OR FITNESS FOR PURPOSE. Microchip disclaims all liability arising from this information and its use. Use of Microchip devices in life support and/or safety applications is entirely at the buyer's risk, and the buyer agrees to defend, indemnify and hold harmless Microchip from any and all damages, claims, suits, or expenses resulting from such use. No licenses are conveyed, implicitly or otherwise, under any Microchip intellectual property rights unless otherwise stated.

Trademarks

The Microchip name and logo, the Microchip logo, Adaptec, AnyRate, AVR, AVR logo, AVR Freaks, BesTime, BitCloud, chipKIT, chipKIT logo, CryptoMemory, CryptoRF, dsPIC, FlashFlex, flexPWR, HELDO, IGLOO, JukeBlox, KeeLoq, Kleer, LANCheck, LinkMD, maXStylus, maXTouch, MediaLB, megaAVR, Microsemi, Microsemi logo, MOST, MOST logo, MPLAB, OptoLyzer, PackeTime, PIC, picoPower, PICSTART, PIC32 logo, PolarFire, Prochip Designer, QTouch, SAM-BA, SenGenuity, SpyNIC, SST, SST Logo, SuperFlash, Symmetricom, SyncServer, Tachyon, TempTrackr, TimeSource, tinyAVR, UNI/O, Vectron, and XMEGA are registered trademarks of Microchip Technology Incorporated in the U.S.A. and other countries.

APT, ClockWorks, The Embedded Control Solutions Company, EtherSynch, FlashTec, Hyper Speed Control, HyperLight Load, IntelliMOS, Libero, motorBench, mTouch, Powermite 3, Precision Edge, ProASIC, ProASIC Plus, ProASIC Plus logo, Quiet-Wire, SmartFusion, SyncWorld, Temux, TimeCesium, TimeHub, TimePictra, TimeProvider, Vite, WinPath, and ZL are registered trademarks of Microchip Technology Incorporated in the U.S.A.

Adjacent Key Suppression, AKS, Analog-for-the-Digital Age, Any Capacitor, AnyIn, AnyOut, BlueSky, BodyCom, CodeGuard, CryptoAuthentication, CryptoAutomotive, CryptoCompanion, CryptoController, dsPICDEM, dsPICDEM.net, Dynamic Average Matching, DAM, ECAN, EtherGREEN, In-Circuit Serial Programming, ICSP, INICnet, Inter-Chip Connectivity, JitterBlocker, KleerNet, KleerNet logo, memBrain, Mindi, MiWi, MPASM, MPF, MPLAB Certified logo, MPLIB, MPLINK, MultiTRAK, NetDetach, Omniscient Code Generation, PICDEM, PICDEM.net, PICkit, PICtail, PowerSmart, PureSilicon, QMatrix, REAL ICE, Ripple Blocker, SAM-ICE, Serial Quad I/O, SMART-I.S., SQI, SuperSwitcher, SuperSwitcher II, Total Endurance, TSHARC, USBCheck, VariSense, ViewSpan, WiperLock, Wireless DNA, and ZENA are trademarks of Microchip Technology Incorporated in the U.S.A. and other countries.

SQTP is a service mark of Microchip Technology Incorporated in the U.S.A.

The Adaptec logo, Frequency on Demand, Silicon Storage Technology, and Symmcom are registered trademarks of Microchip Technology Inc. in other countries.

GestIC is a registered trademark of Microchip Technology Germany II GmbH & Co. KG, a subsidiary of Microchip Technology Inc., in other countries.

All other trademarks mentioned herein are property of their respective companies.

© 2019, Microchip Technology Incorporated, Printed in the U.S.A., All Rights Reserved.

ISBN: 978-1-5224-5023-8

Quality Management System

For information regarding Microchip's Quality Management Systems, please visit <http://www.microchip.com/quality>.

Worldwide Sales and Service

AMERICAS	ASIA/PACIFIC	ASIA/PACIFIC	EUROPE
<p>Corporate Office 2355 West Chandler Blvd. Chandler, AZ 85224-6199 Tel: 480-792-7200 Tel: 480-792-7277 Technical Support: http://www.microchip.com/support Web Address: http://www.microchip.com</p> <p>Atlanta Duluth, GA Tel: 678-957-9614 Fax: 678-957-1455</p> <p>Austin, TX Tel: 512-257-3370</p> <p>Boston Westborough, MA Tel: 774-760-0087 Fax: 774-760-0088</p> <p>Chicago Itasca, IL Tel: 630-285-0071 Fax: 630-285-0075</p> <p>Dallas Addison, TX Tel: 972-818-7423 Fax: 972-818-2924</p> <p>Detroit Novi, MI Tel: 248-848-4000</p> <p>Houston, TX Tel: 281-894-5983</p> <p>Indianapolis Noblesville, IN Tel: 317-773-8323 Fax: 317-773-5453 Tel: 317-536-2380</p> <p>Los Angeles Mission Viejo, CA Tel: 949-462-9523 Fax: 949-462-9608 Tel: 951-273-7800</p> <p>Raleigh, NC Tel: 919-844-7510</p> <p>New York, NY Tel: 631-435-6000</p> <p>San Jose, CA Tel: 408-735-9110 Tel: 408-436-4270</p> <p>Canada - Toronto Tel: 905-695-1980 Fax: 905-695-2078</p>	<p>Australia - Sydney Tel: 61-2-9868-6733</p> <p>China - Beijing Tel: 86-10-8569-7000</p> <p>China - Chengdu Tel: 86-28-8665-5511</p> <p>China - Chongqing Tel: 86-23-8980-9588</p> <p>China - Dongguan Tel: 86-769-8702-9880</p> <p>China - Guangzhou Tel: 86-20-8755-8029</p> <p>China - Hangzhou Tel: 86-571-8792-8115</p> <p>China - Hong Kong SAR Tel: 852-2943-5100</p> <p>China - Nanjing Tel: 86-25-8473-2460</p> <p>China - Qingdao Tel: 86-532-8502-7355</p> <p>China - Shanghai Tel: 86-21-3326-8000</p> <p>China - Shenyang Tel: 86-24-2334-2829</p> <p>China - Shenzhen Tel: 86-755-8864-2200</p> <p>China - Suzhou Tel: 86-186-6233-1526</p> <p>China - Wuhan Tel: 86-27-5980-5300</p> <p>China - Xian Tel: 86-29-8833-7252</p> <p>China - Xiamen Tel: 86-592-2388138</p> <p>China - Zhuhai Tel: 86-756-3210040</p>	<p>India - Bangalore Tel: 91-80-3090-4444</p> <p>India - New Delhi Tel: 91-11-4160-8631</p> <p>India - Pune Tel: 91-20-4121-0141</p> <p>Japan - Osaka Tel: 81-6-6152-7160</p> <p>Japan - Tokyo Tel: 81-3-6880-3770</p> <p>Korea - Daegu Tel: 82-53-744-4301</p> <p>Korea - Seoul Tel: 82-2-554-7200</p> <p>Malaysia - Kuala Lumpur Tel: 60-3-7651-7906</p> <p>Malaysia - Penang Tel: 60-4-227-8870</p> <p>Philippines - Manila Tel: 63-2-634-9065</p> <p>Singapore Tel: 65-6334-8870</p> <p>Taiwan - Hsin Chu Tel: 886-3-577-8366</p> <p>Taiwan - Kaohsiung Tel: 886-7-213-7830</p> <p>Taiwan - Taipei Tel: 886-2-2508-8600</p> <p>Thailand - Bangkok Tel: 66-2-694-1351</p> <p>Vietnam - Ho Chi Minh Tel: 84-28-5448-2100</p>	<p>Austria - Wels Tel: 43-7242-2244-39 Fax: 43-7242-2244-393</p> <p>Denmark - Copenhagen Tel: 45-4450-2828 Fax: 45-4485-2829</p> <p>Finland - Espoo Tel: 358-9-4520-820</p> <p>France - Paris Tel: 33-1-69-53-63-20 Fax: 33-1-69-30-90-79</p> <p>Germany - Garching Tel: 49-8931-9700</p> <p>Germany - Haan Tel: 49-2129-3766400</p> <p>Germany - Heilbronn Tel: 49-7131-72400</p> <p>Germany - Karlsruhe Tel: 49-721-625370</p> <p>Germany - Munich Tel: 49-89-627-144-0 Fax: 49-89-627-144-44</p> <p>Germany - Rosenheim Tel: 49-8031-354-560</p> <p>Israel - Ra'anana Tel: 972-9-744-7705</p> <p>Italy - Milan Tel: 39-0331-742611 Fax: 39-0331-466781</p> <p>Italy - Padova Tel: 39-049-7625286</p> <p>Netherlands - Druenen Tel: 31-416-690399 Fax: 31-416-690340</p> <p>Norway - Trondheim Tel: 47-72884388</p> <p>Poland - Warsaw Tel: 48-22-3325737</p> <p>Romania - Bucharest Tel: 40-21-407-87-50</p> <p>Spain - Madrid Tel: 34-91-708-08-90 Fax: 34-91-708-08-91</p> <p>Sweden - Gothenberg Tel: 46-31-704-60-40</p> <p>Sweden - Stockholm Tel: 46-8-5090-4654</p> <p>UK - Wokingham Tel: 44-118-921-5800 Fax: 44-118-921-5820</p>