INTRODUCTION

In this technical brief, a PIC10F322 is being used to implement a simple voltage-controlled oscillator (VCO). Output frequencies range from 16 Hz to 500 kHz, with an internally generated clock source (no external crystal required). The VCO operates from a supply voltage of 2.3 to 5.5V, with current consumption of approximately 2.4 mA (5.0V VDD).

This example illustrates the use of the Analog-to-Digital Converter (ADC), and the Numerically Controlled Oscillator (NCO). Also, the Configurable Logic Cell (CLC) is being used to re-route the NCO output signal and make use of its dynamic update capabilities.

The voltage present on the RA2 pin controls the frequency of the clock output. The RA3/MCLR pin enables/disables the clock output on the RA1 pin. The application makes use of the Configurable Logic Cell (CLC) to re-route the NCO output signal to the RA1 pin. The RA0 pin is available to the user for alternate I/O functions, if desired.

The on-board potentiometer (POT1) provides the analog input voltage and the clock output can be disabled by pressing the push-button switch (SW1). As the potentiometer is rotated, the frequency at which D1 blinks will change.

For flexibility, the VCO has been written in both assembly and ‘C’. The assembly language version uses only 60 locations of program memory and 1 RAM location have been used. Language tool versions: MPASMWIN.exe v5.45, mplink.exe v4.43, mplib.exe v4.43. The assembly version can be found in “Appendix A – VCO.asm”, Figure A1 (Part 1 of 2). The ‘C’ version can be found in “Appendix A – VCO.asm”, Figure A1 (Part 2 of 2).

In order to re-route the NCO output (normally present on RA2) to the RA1 pin, we are using the Configurable Logic Cell (CLC) module. The CLC Designer Tool GUI allows easy configuration of the CLC block. The diagram below (Figure 3) shows how the “NCO” signal is routed to the output of the CLC1 block.

Note that the output of “Gate 1” has been inverted. This creates a “1” at the output. However, when the output signal is disabled (via the RA3/MCLR pin), the application removes the inversion at the output of “GATE 1”. This illustrates that the CLC module is “dynamic” – you are not forced to keep the configuration that is created initially and can modify signal inputs “on the fly”.

The NCO (Numerically Controlled Oscillator) comprises a 16-bit increment register which feeds a 20-bit accumulator. When the 20-bit accumulator overflows, the clock output toggles (as used in this application).
Due to successive remainders being added together in the accumulator, eventually you will get a pulse which is "one clock short". While in some systems, this property would be referred to as "jitter", and would be undesirable, it can be used advantageously by the designer for precise control of how much energy is delivered to a given load.

**FIGURE 3: CLC DESIGNER TOOL – OUTPUT OF ‘NCO’ SIGNAL**
The use of the NCO in conjunction with “Fixed Duty Cycle” mode creates an output with a linear frequency response. This is in contrast with a PWM peripheral, which would create a linear period response. Because the NCO increment register is a 16-bit wide register, and the A/D result register is 8-bits wide, the upper byte of the NCO increment register (NCO1INCH) is loaded with the A/D result. A special case exists for A/D results, which result in zero as a value. In this case, the high byte is loaded with 0x00, and the lower byte is loaded with 0x01 to produce the lowest possible frequency (16 Hz).

The output frequency can be calculated with the following formula (with Fosc = 16 MHz):

**EQUATION 1:**

\[ f = \frac{F_{osc} \times ADRES \times 256}{2^{21}} \]
The scope shot below (Figure 6) shows the clock at 250 kHz with RA2 input voltage = 2.56V. VDD = 5.12V for this example.

The VCO as described in this tech brief demonstrates many of the capabilities of the PIC10F322 ranging from A/D, configurable logic, to the Numerically Controlled Oscillator. The generation of a linear transfer function for the output clock has advantages in simplifying control system design.

The PIC10F322 is one of Microchip's lowest cost parts, and it is our hope that the code provided can serve as a starting point for your application, if not used directly.
APPENDIX A – VCO.ASM

VCO.asm is the assembly language source code for the Voltage Controlled Oscillator.

Software License Agreement

The software supplied herewith by Microchip Technology Incorporated (the “Company”) is intended and supplied to you, the Company’s customer, for use solely and exclusively with products manufactured by the Company.

The software is owned by the Company and/or its supplier, and is protected under applicable copyright laws. All rights are reserved. Any use in violation of the foregoing restrictions may subject the user to criminal sanctions under applicable laws, as well as to civil liability for the breach of the terms and conditions of this license.

THIS SOFTWARE IS PROVIDED IN AN “AS IS” CONDITION. NO WARRANTIES, WHETHER EXPRESS, IMPLIED OR STATUTORY, INCLUDING, BUT NOT LIMITED TO, IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE APPLY TO THIS SOFTWARE. THE COMPANY SHALL NOT, IN ANY CIRCUMSTANCES, BE LIABLE FOR SPECIAL, INCIDENTAL OR CONSEQUENTIAL DAMAGES, FOR ANY REASON WHATSOEVER.

FIGURE A1: PART 1 OF 2

```assembly
#include <p10f322.inc>

list p=p10f322

; PIN_CLC1 is being used for NCO output.
#define PIN_CLC1 PORTA,1
; PIN_OE is the pin that is used for output enable
#define PIN_OE PORTA,3
; TACQ is the number of loops that will be executed for A/D conversion acquisition time
#define TACQ 0x30
; countdown_timer is the RAM location used for countdown timer.
#define countdown_timer 0x40

;; Configuration Fuses
__config _FOSC_INTOSC & _BOREN_OFF & _WDTE_OFF & _PWRTE_OFF & _MCLRE_OFF & _CP_OFF & _WRT_OFF & _LVP_OFF

;; pin-out
;; 1 - RA0 - user defined output - useful for scope trigger or other indicator signals.
;; 2 - VSS
;; 3 - RA1 - NCO output routed to this pin through CLC block
;; 4 - RA2 - Analog input for VCO
;; 5 - VDD
;; 6 - MCLR/RA3 - enable/disable signal

org 0x00
start

bcf LATA,1 ; RA1 output low by default.
movlw 0x0C
movwf TRISA ; RA3, RA2 input; RA1, RA0 output
movlw 0x04
movwf ANSELA ; RA2 analog, RA1 and RA0 are digital.
movlw 0x70
movwf OSCCON ; 16 MHz clock - change this value to change clock frequency
; and to lower current consumption.

#include "pass-through.inc" ; routes NCO output to the RA1 pin.

bcf NCO1CLK,NICKS1 ; this sets the FOSC as input for the NCO
bsf NCO1CLK,NICKS0 ; rev. A of the datasheet is incorrect for the NICKSx
settings,
; but is shown correctly in the erratas

bsf NCO1CON,NIEN ; enable NCO module

movlw 0xc8
movwf ADCON ; select AN2 analog input channel, div by 64 clock
bsf ADCON,ADON ; turn on A/D
```

© 2012 Microchip Technology Inc.
FIGURE A1: PART 1 OF 2 (CONTINUED)

```assembly
btfss PIN_OE ; Is output enabled?
goto output_enabled ; No.
output_enabled
    movlw TACQ ; load acquisition time
    movwf countdown_timer ; to countdown timer
    tacqdelay
        decfsz countdown_timer ; Has countdown timer expired?
        goto tacqdelay ; No - continue to wait.
        bsf ADCON,GO_NOT_DONE ; Yes - start A/D conversion.

a2dconversion
    btfsc ADCON,GO_NOT_DONE ; Am I done with the A/D conversion?
    goto a2dconversion ; No.
    movf ADRES,W ; Yes - move A/D result to
    btfsc STATUS,Z ; Was A/D result = 0?
    goto minimum_frequency ; Yes.
    movwf NCO1INCH ; NCO increment high register = ADRES
    movlw 0x00
    movwf NCO1INCL ; and this causes the update to occur.
    bsf NCO1CON,N1EN ; enable NCO1 module after update of NCO1INCx registers.
    goto enable_check

minimum_frequency
    clrf NCO1INCH ; A value of 0 would cause the NCO to never overflow.
    movlw 0x01 ; A value of 1 gives the minimum frequency.
    movwf NCO1INCL

enable_check
    btfsc PIN_OE ; Is output disabled?
    goto output_enabled ; No.
output_disabled
    bcf CLC1POL,LC1G1POL ; clear inversion at "GATE 1" output to disable output
    btfss PIN_OE ; has output been re-enabled?
    goto output_disabled ; No.
    bcf NCO1CON,N1EN ; Yes - disable NCO,
    clrf NCO1ACCU ; and clear out accumulator so that I get clean start-up.
    clrf NCO1ACCH
    clrf NCO1ACCL
    bsf CLC1POL,LC1G1POL ; set inversion at "GATE 1" output to enable "NCO" signal
output
    goto output_enabled

end
```
FIGURE A1: PART 2 OF 2

#include "pic.h";

__CONFIG (FOSC_INTOSC & BOREN_OFF & WDTE_OFF & PWRT_OFF & MCLRE_OFF & CP_OFF & WRT_OFF & LVP_OFF);

#define PIN_CLC1 PORTA1
#define PIN_OE PORTA3
#define TACQ 0x30

void main(void)
{
    // acquisition timer workspace
    char i;

    // initialization
    OSCCON = 0x70; // 16 MHz
    LATA1 = 0; // RA1 is freq output. Set latch output to 0.
    TRISA = 0x0C; // RA0,1 = outputs, RA2,3 = inputs
    ANSELA = 0x04; // RA2 = analog input

    // CLC design output in C format
    #include "pass-through_C.inc";

    // set Fosc as NCO input and enable NCO
    // Note: Rev A of the data sheet has some clock source settings identified improperly
    // See Errata document DS80529 for alternate clock settings
    N1CKS1 = 0;
    N1CKS0 = 1;
    NIEN = 1;

    // ADC: TAD = Fosc/32 (2 us), AN2 input, enabled
    ADCON = 0x48;
    ADON = 1;
    while(1)
    {
        // switch output on
        LC1G1POL = 1;

        // continue to read ADC and set NCO freq
        // as long as input pin is high
        while(PIN_OE == 1)
        {
            // wait for specified acquisition time
            for(i=TACQ;i!=0;i--);
            // start ADC and wait for result
            GO_nDONE = 1;
            while(GO_nDONE == 1);
            // if result is zero set minimum freq
            // otherwise set freq to ADC result
            if(ADRES == 0)
            {
                NCO1INCH = 0;
                NCO1INCL = 1;
            }
            else
            {
                NCO1INCH = ADRES;
                NCO1INCL = 0;
            }
        }
    }
    // input pin was low - switch output off
    LC1G1POL = 0;
    // wait for pin input high to restart
    while(PIN_OE == 0);
}
APPENDIX B – PASS-THROUGH.INC

PASS-THROUGH.INC defines the configuration of the Configurable Logic Cell block in assembly code, and was created using the CLC Designer tool.

Software License Agreement

The software supplied herewith by Microchip Technology Incorporated (the “Company”) is intended and supplied to you, the Company’s customer, for use solely and exclusively with products manufactured by the Company.

The software is owned by the Company and/or its supplier, and is protected under applicable copyright laws. All rights are reserved. Any use in violation of the foregoing restrictions may subject the user to criminal sanctions under applicable laws, as well as to civil liability for the breach of the terms and conditions of this license.

THIS SOFTWARE IS PROVIDED IN AN "AS IS" CONDITION. NO WARRANTIES, WHETHER EXPRESS, IMPLIED OR STATUTORY, INCLUDING, BUT NOT LIMITED TO, IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE APPLY TO THIS SOFTWARE. THE COMPANY SHALL NOT, IN ANY CIRCUMSTANCES, BE LIABLE FOR SPECIAL, INCIDENTAL OR CONSEQUENTIAL DAMAGES, FOR ANY REASON WHATSOEVER.

FIGURE B1: PASS-THROUGH.INC

BANKSEL  CLC1GLS0
movlw H'00'
movwf CLC1GLS0
movlw H'08'
movwf CLC1GLS1
movlw H'00'
movwf CLC1GLS2
movlw H'00'
movwf CLC1GLS3
movlw H'50'
movwf CLC1SEL0
movlw H'00'
movwf CLC1SEL1
movlw H'01'
movwf CLC1POL
movlw H'CO'
movwf CLC1CON

pass-through_C.inc defines the configuration of the Configurable Logic Cell block in ‘C’ code, and was created using the CLC Designer tool.

FIGURE B2: PASS-THROUGH.C.INC

// File: pass-through_C.inc
// Generated by CLC Designer, Version: 1.0.0
// Date: 11/5/2012 8:08 AM
// Device: PIC10(LF320/2

    CLC1GLS0 = 0x00;
    CLC1GLS1 = 0x08;
    CLC1GLS2 = 0x00;
    CLC1GLS3 = 0x00;
    CLC1SEL0 = 0x50;
    CLC1SEL1 = 0x00;
    CLC1POL = 0x01;
    CLCICON = 0x0C;
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.

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.

Trademarks
The Microchip name and logo, the Microchip logo, dsPIC, FlashFlex, KEELOQ, KEELOQ logo, MPLAB, PIC, PICmicro, PICSTART, PIC32 logo, rPIC, SST, SST Logo, SuperFlash and UNI/O are registered trademarks of Microchip Technology Incorporated in the U.S.A. and other countries.
FilterLab, Hampshire, Hi-TECH C, Linear Active Thermistor, MTP, SEEVAL and The Embedded Control Solutions Company are registered trademarks of Microchip Technology Incorporated in the U.S.A.
Silicon Storage Technology is a registered trademark of Microchip Technology Inc. in other countries.
Analog-for-the-Digital Age, Application Maestro, BodyCom, chipKIT, chipKIT logo, CodeGuard, dsPICDEM, dsPICDEM.net, dsPICworks, dsSPEAK, ECAN, ECONOMONITOR, FanSense, HI-TIDE, In-Circuit Serial Programming, ICSP, Mindi, MiWi, MPASM, MFP, MPLAB Certified logo, MPLIB, MPLINK, mTouch, Omnicent Code Generation, PICC, PICC-18, PICDEM, PICDEM.net, PICkit, PICtail, REAL ICE, rFLAB, Select Mode, SQI, Serial Quad I/O, Total Endurance, TSHARC, UniWinDriver, WiperLock, ZENA and Z-Scale 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.
GestIC and ULPP are registered trademarks 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.
© 2012, Microchip Technology Incorporated, Printed in the U.S.A., All Rights Reserved.
Printed on recycled paper.
ISBN: 9781620766682
Microchip received ISO/TS-16949:2009 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://www.microchip.com/support
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

**Indianapolis**
Noblesville, IN
Tel: 317-773-8323
Fax: 317-773-5453

**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: 86-10-8569-7000
Fax: 86-10-8528-2104

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

**China - Chongqing**
Tel: 86-23-8980-9588
Fax: 86-23-8980-9500

**China - Hangzhou**
Tel: 86-571-2819-3187
Fax: 86-571-2819-3189

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

**China - Xiamen**
Tel: 86-592-2388138
Fax: 86-592-2308130

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

**ASIA/PACIFIC**

**India - Bangalore**
Tel: 91-80-3090-4444
Fax: 91-80-3090-4123

**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 - Osaka**
Tel: 81-66-152-7160
Fax: 81-66-152-9310

**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: 886-3-5778-366
Fax: 886-3-5770-955

**Taiwan - Kaohsiung**
Tel: 886-7-213-7828
Fax: 886-7-330-9305

**Taiwan - Taipei**
Tel: 886-2-2508-8600
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