
Section 16. Analog-to-Digital Converter (ADC)

HIGHLIGHTS

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Note: This family reference manual section is meant to serve as a complement to device data sheets. Depending on the device variant, this manual section may not apply to all dsPIC33E/PIC24E devices.

Please consult the note at the beginning of the “**Analog-to-Digital Converter (ADC)**” chapter in the current device data sheet to check whether this document supports the device you are using.

Device data sheets and family reference manual sections are available for download from the Microchip Worldwide Web site at: <http://www.microchip.com>

16.1 INTRODUCTION

This document describes the features and associated operational modes of the Successive Approximation (SAR) Analog-to-Digital Converter (ADC) modules available on the dsPIC33E/PIC24E families of devices.

This ADC module can be configured by the user application to function as a 10-bit, 4-channel ADC or a 12-bit, single channel ADC.

On devices with Direct Memory Access (DMA), this ADC module can be configured to use DMA or use a dedicated, 16-word memory mapped buffer instead of DMA.

An ADC module block diagram for devices without op amps is provided in [Figure 16-1](#). The ADC module block diagram for devices with op amps is provided in [Figure 16-2](#).

Note: Op amps are not available on all devices. Refer to the “**Op Amp/Comparator**” chapter in the specific device data sheet for availability.

The following key features are common to all dsPIC33E/PIC24E devices:

- SAR conversion
- Up to 1.1 Msps conversion speed in 10-bit mode
- Up to 500 kps conversion speed in 12-bit mode
- Up to 32 analog input pins
- External voltage reference input pins
- Four unipolar, differential Sample-and-Hold (S&H) amplifiers
- Simultaneous sampling of up to four analog input pins
- Automatic Channel Scanning mode
- Selectable conversion trigger source
- Up to 16-word conversion result buffer
- Operation during CPU Sleep and Idle modes

Additional features are available on select dsPIC33E/PIC24E devices:

- Connections for up to three internal op amps (not available on all devices)
- Connections to the Charge Time Measurement Unit (CTMU) and temperature measurement diode (not available on all devices)
- Channel selection and triggering can be controlled by the Peripheral Trigger Generator (PTG) (not available on all devices)
- Selectable Buffer Fill modes (not available on all devices)
- DMA support, including Peripheral Indirect Addressing (PIA) (not available on all devices)

Note: Refer to the “**Analog-to-Digital Converter (ADC)**” chapter in the specific device data sheet to determine the availability of these additional features.

Depending on the device variant, the ADC module may have up to 49 analog input pins, designated AN0-AN48, and four op amp outputs, designated OA1-OA3 and OA5. These analog inputs and op amp outputs are connected by multiplexers to four S&H amplifiers, designated CH0-CH3. The analog input multiplexers have two sets of control bits, designated as MUXA (CHySA/CHyNA) and MUXB (CHySB/CHyNB). These control bits select a particular analog input for conversion. The MUXA and MUXB control bits can alternatively select the analog input for conversion. Unipolar differential conversions are possible on all channels using certain input pins.

Channel Scanning mode can be enabled for the CH0 S&H amplifier. Any subset of the analog inputs or op amp outputs (based on availability) can be selected by the user application. The selected inputs are converted in ascending order using CH0.

The ADC module supports simultaneous sampling using multiple S&H channels to sample the inputs at the same time, and then performs the conversion for each channel sequentially. By default, the multiple channels are sampled and converted sequentially.

For devices with DMA and with the ADC DMA Enable bit (ADDMAEN) set, the ADC module is connected to a single-word result buffer. However, multiple conversion results can be stored in a DMA RAM buffer with no CPU overhead when DMA is used with the ADC module. Each conversion result is converted to one of four 16-bit output formats when it is read from the buffer.

For devices without DMA, and for devices with DMA that have the ADC DMA Enable bit (ADDMAEN) clear, the ADC module is connected to a 16-word result buffer. The ADC result is available in four different numerical formats (see [Figure 16-14](#)).

Note 1: A 'y' is used with MUXA and MUXB control bits to specify the S&H channel numbers ($y = 0$ or 123). Refer to [Section 16.6.2 "Alternate Input Selection Mode"](#) for more details.

- 2: Depending on a particular device pinout, the ADC can have up to 49 analog input pins, designated AN0 through AN48, and four op amp outputs, designated OA1-OA3 and OA5. In addition, there are two analog input pins for external voltage reference connections (VREF+, VREF-). These analog inputs are shared with op amp inputs and outputs, comparator inputs, and external voltage references. When op amp/comparator functionality is enabled or an external voltage reference is used, the analog input that shares that pin is no longer available. The actual number of analog input pins and external voltage reference input configuration depends on the specific device. For more details, refer to the specific device data sheet.

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Figure 16-1: ADC Block Diagram for dsPIC33E/PIC24E Devices without Op Amps

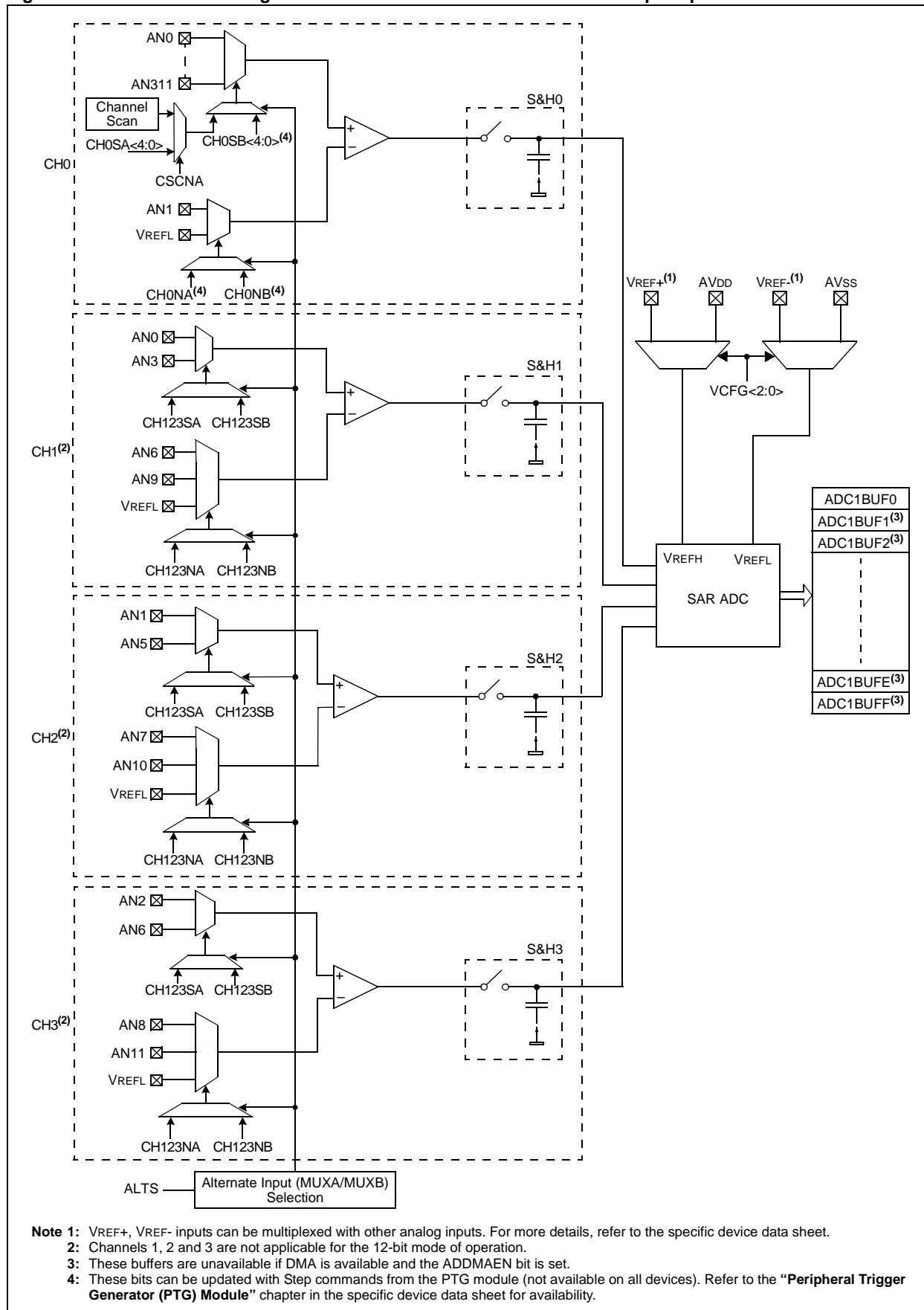
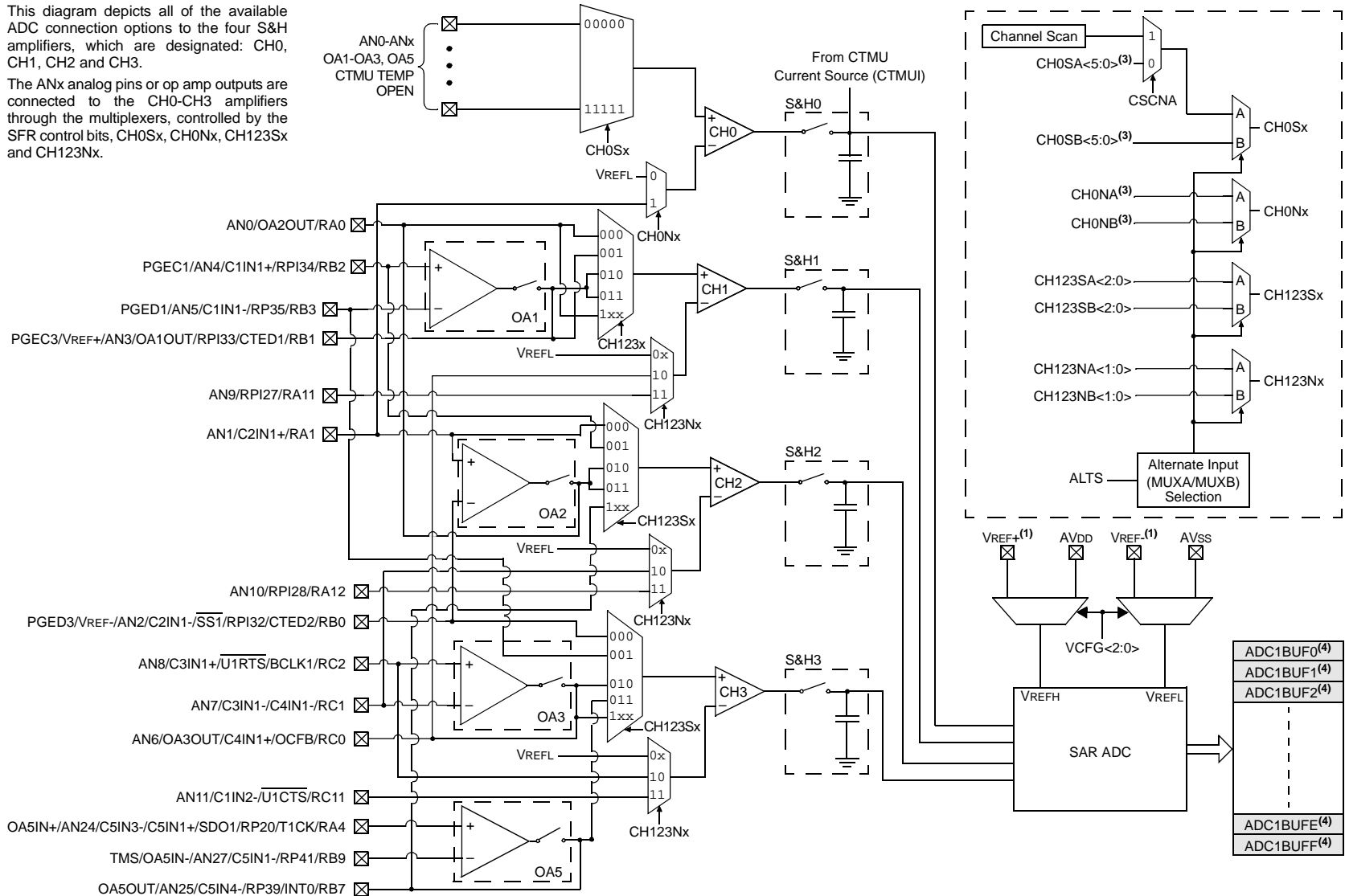


Figure 16-2: ADC Module Block Diagram with Connection Options for ANx Pins and Op Amps

This diagram depicts all of the available ADC connection options to the four S&H amplifiers, which are designated: CH0, CH1, CH2 and CH3.

The ANx analog pins or op amp outputs are connected to the CH0-CH3 amplifiers through the multiplexers, controlled by the SFR control bits, CH0Sx, CH0Nx, CH123Sx and CH123Nx.



Note 1: VREF+, VREF- inputs can be multiplexed with other analog inputs.

2: Channels 1, 2 and 3 are not applicable for the 12-bit mode of operation.

3: These bits can be updated with Step commands from the PTG module. For more information, refer to the “Peripheral Trigger Generator (PTG)” chapter in the specific device data sheet.

4: When ADDMAEN (ADxCON4<8>) = 1 enabling DMA, only ADCxBUF0 is used.

16.2 CONTROL REGISTERS

The ADC module has nine Control and Status registers:

- **ADxCON1: ADCx Control Register 1**
- **ADxCON2: ADCx Control Register 2**
- **ADxCON3: ADCx Control Register 3**
- **ADxCON4: ADCx Control Register 4**
- **ADxCHS123: ADCx Input Channel 1, 2, 3 Select Register**
- **ADxCHS0: ADCx Input Channel 0 Select Register**
- **ADxCSSH: ADCx Input Scan Select Register High**
- **ADxCSSL: ADCx Input Scan Select Register Low**
- **ANSELY: Analog/Digital Pin Selection Register**

The ADxCON1, ADxCON2 and ADxCON3 registers control the operation of the ADC module. For devices with DMA, the ADxCON4 register sets up the number of conversion results stored in a DMA buffer for each analog input in the Scatter/Gather mode. The ADxCHS123 and ADxCHS0 registers select the input pins to be connected to the S&H amplifiers. The ADCSSH/L registers select inputs to be sequentially scanned. The ANSELY register specifies the input collection of device pins used as analog inputs. Along with the Data Direction register (TRISx) in the Parallel I/O Port module, ANSELY registers control the operation of the ADC pins.

16.2.1 ADC Result Buffer

For devices with DMA and with the ADC DMA Enable bit (ADDMAEN) set, the ADC module contains a single-word result buffer, ADC1BUF0. For devices without DMA, and for devices with DMA that have the ADC DMA Enable bit (ADDMAEN) clear, the ADC module contains a 16-word dual port RAM to buffer the results. The 16 buffer locations are referred to as ADC1BUF0, ADC1BUF1, ADC1BUF2, ..., ADC1BUFE and ADC1BUFF.

Note: After a device Reset, the ADC Buffer register(s) will contain unknown data.
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Register 16-1: ADxCON1: ADCx Control Register 1

R/W-0	U-0	R/W-0	R/W-0	U-0	R/W-0	R/W-0	R/W-0
ADON	—	ADSIDL	ADDMA BM ⁽¹⁾	—	AD12B ⁽¹⁾	FORM<1:0>	
bit 15							bit 8
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0, HC, HS	R/C-0, HC, HS
SSRC<2:0>			SSRCG	SIMSAM	ASAM ⁽²⁾	SAMP	DONE ⁽²⁾
bit 7							bit 0

Legend:	HC = Hardware Clearable bit	HS = Hardware Settable bit	C = Clearable bit
R = Readable bit	W = Writable bit	U = Unimplemented bit, read as '0'	
-n = Value at POR	'1' = Bit is set	'0' = Bit is cleared	x = Bit is unknown

- bit 15 **ADON:** ADC Operating Mode bit
1 = ADC module is operating
0 = ADC is off
- bit 14 **Unimplemented:** Read as '0'
- bit 13 **ADSIDL:** ADC Stop in Idle Mode bit
1 = Discontinues module operation when device enters Idle mode
0 = Continues module operation in Idle mode
- bit 12 **ADDMA BM:** DMA Buffer Build Mode bit⁽¹⁾
1 = DMA buffers are written in the order of conversion; the module provides an address to the DMA channel that is the same as the address used for the non-DMA stand-alone buffer
0 = DMA buffers are written in Scatter/Gather mode; the module provides a Scatter/Gather mode address to the DMA channel, based on the index of the analog input and the size of the DMA buffer
- bit 11 **Unimplemented:** Read as '0'
- bit 10 **AD12B:** ADC 10-Bit or 12-Bit Operation Mode bit⁽¹⁾
1 = 12-bit, 1-channel ADC operation
0 = 10-bit, 4-channel ADC operation
- bit 9-8 **FORM<1:0>:** Data Output Format bits
For 10-Bit Operation:
11 = Signed fractional (DOUT = sddd dddd dd00 0000, where s = sign, d = data)
10 = Fractional (DOUT = dddd dddd dd00 0000)
01 = Signed integer (DOUT = ssss sssd dddd dddd, where s = sign, d = data)
00 = Integer (DOUT = 0000 00dd dddd dddd)
For 12-Bit Operation:
11 = Signed fractional (DOUT = sddd dddd dddd 0000, where s = sign, d = data)
10 = Fractional (DOUT = dddd dddd dddd 0000)
01 = Signed Integer (DOUT = ssss sddd dddd dddd, where s = sign, d = data)
00 = Integer (DOUT = 0000 dddd dddd dddd)
- bit 7-5 **SSRC<2:0>:** Sample Clock Source Select bits
These settings vary by device. Refer to the ADxCON1 register in the “**Analog-to-Digital Converter (ADC)**” chapter in the specific device data sheet for availability.
- bit 4 **SSRCG:** Sample Clock Source Group bit
These settings vary by device. Refer to the ADxCON1 register in the “**Analog-to-Digital Converter (ADC)**” chapter in the specific device data sheet for availability.

Note 1: This bit or setting is not available on all devices. Refer to the “**Analog-to-Digital Converter (ADC)**” chapter in the specific device data sheet for availability.

2: Do not clear the DONE bit in software if ADC Sample Auto-Start is enabled (ASAM = 1).

Register 16-1: ADxCON1: ADCx Control Register 1 (Continued)

- bit 3 **SIMSAM**: Simultaneous Sample Select bit (only applicable when CHPS<1:0> = 01 or 1x)
In 12-bit mode (AD21B = 1), SIMSAM is unimplemented and is read as '0'.
1 = Samples CH0, CH1, CH2, CH3 simultaneously (when CHPS<1:0> = 1x); or samples CH0 and CH1 simultaneously (when CHPS<1:0> = 01)
0 = Samples multiple channels individually in sequence
- bit 2 **ASAM**: ADC Sample Auto-Start bit⁽²⁾
1 = Sampling begins immediately after last conversion; SAMP bit is auto-set
0 = Sampling begins when SAMP bit is set
- bit 1 **SAMP**: ADC Sample Enable bit
1 = ADC Sample-and-Hold amplifiers are sampling
0 = ADC Sample-and-Hold amplifiers are holding
If ASAM = 0, software can write '1' to begin sampling. Automatically set by hardware if ASAM = 1.
If SSRC<2:0> = 000 and SSRG = 0, software can write '0' to end sampling and start conversion. If SSRC<2:0> ≠ 000, automatically cleared by hardware to end sampling and start conversion.
- bit 0 **DONE**: ADC Conversion Status bit⁽²⁾
1 = ADC conversion cycle has completed
0 = ADC conversion has not started or is in progress
Automatically set by hardware when Analog-to-Digital conversion is complete. Software can write '0' to clear the DONE status (software not allowed to write '1'). Clearing this bit does NOT affect any operation in progress. Automatically cleared by hardware at the start of a new conversion.

Note 1: This bit or setting is not available on all devices. Refer to the “**Analog-to-Digital Converter (ADC)**” chapter in the specific device data sheet for availability.

2: Do not clear the DONE bit in software if ADC Sample Auto-Start is enabled (ASAM = 1).

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Register 16-2: ADxCON2: ADCx Control Register 2

R/W-0	R/W-0	R/W-0	U-0	U-0	R/W-0	R/W-0	R/W-0
VCFG<2:0>			—	—	CSCNA	CHPS<1:0>	
bit 15							bit 8

R-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0
BUFS	SMPI<4:0> ^(1,2,3)					BUFM	ALTS
bit 7							bit 0

Legend:

R = Readable bit

W = Writable bit

U = Unimplemented bit, read as '0'

-n = Value at POR

'1' = Bit is set

'0' = Bit is cleared

x = Bit is unknown

bit 15-13 **VCFG<2:0>**: ADC Converter Voltage Reference Configuration bits

	VREFH	VREFL
000	AVDD	AVSS
001	External VREF+	AVSS
010	AVDD	External VREF-
011	External VREF+	External VREF-
1xx	AVDD	AVSS

bit 12-11 **Unimplemented**: Read as '0'

bit 10 **CSCNA**: Input Scan Select bit

1 = Scans inputs for CH0+ during Sample A bit

0 = Does not scan inputs

bit 9-8 **CHPS<1:0>**: Channel Select bits

When AD12B = 1, CHPS<1:0> is: U-0 (Unimplemented: Read as '0')

1x = Converts CH0, CH1, CH2 and CH3

01 = Converts CH0 and CH1

00 = Converts CH0

bit 7 **BUFS**: Buffer Fill Status bit (only valid when BUFM = 1)

1 = ADC is currently filling the second half of the buffer; the user application should access data in the first half of the buffer

0 = ADC is currently filling the first half of the buffer; the user application should access data in the second half of the buffer

Note 1: For devices with DMA and with the ADC DMA Enable bit (ADDMAEN) set, the SMPI<4:0> bits are referred to as the "Increment Rate for DMA Address Select bits".

2: For devices without DMA, and for devices with DMA that have the ADC DMA Enable bit (ADDMAEN) clear, the SMPI<4:0> bits are referred to as the "Number of Samples per Interrupt Select bits".

3: For ADC2, the sample and conversion operation bits are only four bits (SMPI<3:0>), which provide an ADC interrupt (for devices without DMA), and incrementation of the DMA address (for devices with DMA) at the completion of up to 16 sample and conversion operations.

Register 16-2: ADxCON2: ADCx Control Register 2 (Continued)

- bit 6-2 **SMPI<4:0>**: Sample and Conversion Operation bits^(1,2,3)
For Devices with DMA and with the ADC DMA Enable bit (ADDMAEN) Set:
x1111 = Increments the DMA address after completion of every 16th sample/conversion operation
x1110 = Increments the DMA address after completion of every 15th sample/conversion operation
•
•
•
x0001 = Increments the DMA address after completion of every 2nd sample/conversion operation
x0000 = Increments the DMA address after completion of every sample/conversion operation
For Devices without DMA and for Devices with DMA that have the ADC DMA Enable bit (ADDMAEN) Clear:
11111 = ADC interrupt is generated at the completion of every 32nd sample/conversion operation
11110 = ADC interrupt is generated at the completion of every 31st sample/conversion operation
•
•
•
00001 = ADC interrupt is generated at the completion of every 2nd sample/conversion operation
00000 = ADC interrupt is generated at the completion of every sample/conversion operation
- bit 1 **BUFM**: Buffer Fill Mode Select bit
1 = Starts buffer filling the first half of the buffer on the first interrupt and the second half of the buffer on the next interrupt
0 = Always starts filling the buffer from the Start address
- bit 0 **ALTS**: Alternate Input Sample Mode Select bit
1 = Uses channel input selects for Sample MUXA on first sample and Sample MUXB on next sample
0 = Always uses channel input selects for Sample MUXA

- Note 1:** For devices with DMA and with the ADC DMA Enable bit (ADDMAEN) set, the SMPI<4:0> bits are referred to as the “Increment Rate for DMA Address Select bits”.
- 2:** For devices without DMA, and for devices with DMA that have the ADC DMA Enable bit (ADDMAEN) clear, the SMPI<4:0> bits are referred to as the “Number of Samples per Interrupt Select bits”.
- 3:** For ADC2, the sample and conversion operation bits are only four bits (SMPI<3:0>), which provide an ADC interrupt (for devices without DMA), and incrementation of the DMA address (for devices with DMA) at the completion of up to 16 sample and conversion operations.

Register 16-3: ADxCON3: ADCx Control Register 3

R/W-0	U-0	U-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0
ADRC	—	—	SAMC<4:0> ^(1,2)				
bit 15							bit 8
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0
ADCS<7:0> ⁽³⁾							
bit 7							bit 0

Legend:

R = Readable bit

W = Writable bit

U = Unimplemented bit, read as '0'

-n = Value at POR

'1' = Bit is set

'0' = Bit is cleared

x = Bit is unknown

bit 15 **ADRC:** ADC Conversion Clock Source bit

1 = ADC internal RC clock

0 = Clock derived from system clock

bit 14-13 **Unimplemented:** Read as '0'

bit 12-8 **SAMC<4:0>:** Auto-Sample Time bits^(1,2)

11111 = 31 TAD

•

•

•

00001 = 1 TAD

00000 = 0 TAD

bit 7-0 **ADCS<7:0>:** ADC Conversion Clock Select bits⁽³⁾

11111111 = T_{CY} • (ADCS<7:0> + 1) = 256 • T_{CY} = TAD

•

•

•

00000010 = T_{CY} • (ADCS<7:0> + 1) = 3 • T_{CY} = TAD

00000001 = T_{CY} • (ADCS<7:0> + 1) = 2 • T_{CY} = TAD

00000000 = T_{CY} • (ADCS<7:0> + 1) = 1 • T_{CY} = TAD

Note 1: These bits are only used when the SSRC<2:0> bits (ADxCON1<7:5>) = 111 and SSRCG = 0.

2: If SSRC<2:0> = 111 and SSRCG = 0, the SAMC<4:0> bits should be set to at least '11111' when using one S&H channel or using simultaneous sampling. When using multiple S&H channels with sequential sampling, the SAMCx bits should be set to '00000' for the fastest possible conversion rate.

3: These bits are not used if the ADRC bit (ADxCON3<15>) = 1.

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Register 16-4: ADxCON4: ADCx Control Register 4

U-0	U-0	U-0	U-0	U-0	U-0	U-0	R/W-0
—	—	—	—	—	—	—	ADDMAEN ⁽¹⁾
bit 15							bit 8

U-0	U-0	U-0	U-0	U-0	R/W-0	R/W-0	R/W-0
—	—	—	—	—	DMABL<2:0>		
bit 7							bit 0

Legend:

R = Readable bit

W = Writable bit

U = Unimplemented bit, read as '0'

-n = Value at POR

'1' = Bit is set

'0' = Bit is cleared

x = Bit is unknown

bit 15-9 **Unimplemented:** Read as '0'

bit 8 **ADDMAEN:** ADC DMA Enable bit⁽¹⁾

1 = Conversion results stored in ADCxBUF0 register for transfer to RAM using DMA

0 = Conversion results stored in ADCxBUF0 through ADCxBUFF registers; DMA is not used

bit 7-3 **Unimplemented:** Read as '0'

bit 2-0 **DMABL<2:0>:** Selects Number of DMA Buffer Locations per Analog Input bits

111 = Allocates 128 words of buffer to each analog input

110 = Allocates 64 words of buffer to each analog input

101 = Allocates 32 words of buffer to each analog input

100 = Allocates 16 words of buffer to each analog input

011 = Allocates 8 words of buffer to each analog input

010 = Allocates 4 words of buffer to each analog input

001 = Allocates 2 words of buffer to each analog input

000 = Allocates 1 word of buffer to each analog input

Note 1: If this bit is cleared to disable DMA, the DMABL<2:0> and ADDMABM bits have no effect.

Note: This register is not available in all devices. Refer to the “**Analog-to-Digital Converter (ADC)**” chapter in the specific device data sheet for availability.

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Register 16-5: ADxCHS123: ADCx Input Channel 1, 2, 3 Select Register

U-0	U-0	U-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0
—	—	—	CH123SB<2:1>		CH123NB<1:0>		CH123SB0
bit 15							bit 8

U-0	U-0	U-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0
—	—	—	CH123SA<2:1>		CH123NA<1:0>		CH123SA0
bit 7							bit 0

Legend:

R = Readable bit

W = Writable bit

U = Unimplemented bit, read as '0'

-n = Value at POR

'1' = Bit is set

'0' = Bit is cleared

x = Bit is unknown

bit 15-13	Unimplemented: Read as '0'
bit 12-11	CH123SB<2:1>: Channels 1, 2, 3 Positive Input Select for Sample B bits
bit 10-9	CH123NB<1:0>: Channels 1, 2, 3 Negative Input Select for Sample B bits
bit 8	CH123SB0: Channels 1, 2, 3 Positive Input Select for Sample B bit
bit 7-5	Unimplemented: Read as '0'
bit 4-3	CH123SA<2:1>: Channels 1, 2, 3 Positive Input Select for Sample A bits
bit 2-1	CH123NA<1:0>: Channels 1, 2, 3 Negative Input Select for Sample A bits
bit 0	CH123SA0: Channels 1, 2, 3 Positive Input Select for Sample A bit

Note: The bit settings in this register vary by device. Refer to the ADxCHS123 register in the “Analog-to-Digital Converter (ADC)” chapter in the specific device data sheet for availability.

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Register 16-6: ADxCHS0: ADCx Input Channel 0 Select Register

R/W-0	U-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0
CH0NB	—	CH0SB<5:0> ⁽¹⁾					
bit 15							bit 8

R/W-0	U-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0
CH0NA	—	CH0SA<5:0> ⁽¹⁾					
bit 7							bit 0

Legend:

R = Readable bit

W = Writable bit

U = Unimplemented bit, read as '0'

-n = Value at POR

'1' = Bit is set

'0' = Bit is cleared

x = Bit is unknown

bit 15 **CH0NB:** Channel 0 Negative Input Select for Sample B bit

bit 14 **Unimplemented:** Read as '0'

bit 13-8 **CH0SB<5:0>:** Channel 0 Positive Input Select for Sample B bits⁽¹⁾

bit 7 **CH0NA:** Channel 0 Negative Input Select for Sample A bit

bit 6 **Unimplemented:** Read as '0'

bit 5-0 **CH0SA<5:0>:** Channel 0 Positive Input Select for Sample A bits⁽¹⁾

Note 1: These bits have no effect when the CSCNA bit (ADxCON2<10>) = 1.

Note: The bit settings in this register vary by device. Refer to the ADxCHS0 register in the “**Analog-to-Digital Converter (ADC)**” chapter in the specific device data sheet for availability.

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Register 16-7: ADxCSSH: ADCx Input Scan Select Register High

R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0
CSS31	CSS30	CSS29	CSS28	CSS27	CSS26	CSS25	CSS24
bit 15							bit 8
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0
CSS23	CSS22	CSS21	CSS20	CSS19	CSS18	CSS17	CSS16
bit 7							bit 0

Legend:

R = Readable bit

W = Writable bit

U = Unimplemented bit, read as '0'

-n = Value at POR

'1' = Bit is set

'0' = Bit is cleared

x = Bit is unknown

bit 15-0 **CSS<31:16>**: ADC Input Scan Selection bits

1 = Selects ANx for input scan

0 = Skips ANx for input scan

Note: Refer to the “Analog-to-Digital Converter (ADC)” chapter in the specific device data sheet for availability of channel scan selections.

Register 16-8: ADxCSSL: ADCx Input Scan Select Register Low

R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0
CSS15	CSS14	CSS13	CSS12	CSS11	CSS10	CSS9	CSS8
bit 15							bit 8
R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0
CSS7	CSS6	CSS5	CSS4	CSS3	CSS2	CSS1	CSS0
bit 7							bit 0

Legend:

R = Readable bit

W = Writable bit

U = Unimplemented bit, read as '0'

-n = Value at POR

'1' = Bit is set

'0' = Bit is cleared

x = Bit is unknown

bit 15-0 **CSS<15:0>**: ADC Input Scan Selection bits

1 = Selects ANx for input scan

0 = Skips ANx for input scan

Note: Refer to the “Analog-to-Digital Converter (ADC)” chapter in the specific device data sheet for availability of channel scan selections.

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Register 16-9: ANSELy: Analog/Digital Pin Selection Register

R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1
ANSy15	ANSy14	ANSy13	ANSy12	ANSy11	ANSy10	ANSy9	ANSy8
bit 15							bit 8

R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1
ANSy7	ANSy6	ANSy5	ANSy4	ANSy3	ANSy2	ANSy1	ANSy0
bit 7							bit 0

Legend:

R = Readable bit

W = Writable bit

U = Unimplemented bit, read as '0'

-n = Value at POR

'1' = Bit is set

'0' = Bit is cleared

x = Bit is unknown

bit 15-0

ANSy<15:0>: Analog/Digital Pin Selection bits

1 = Pin is configured as an analog input

0 = Pin is configured as a digital I/O pin

Note: Refer to the “I/O Ports” chapter in the specific device data sheet for availability of I/O ports. The 'y' in ANSELy refers to PORTA, PORTB, PORTC, etc.

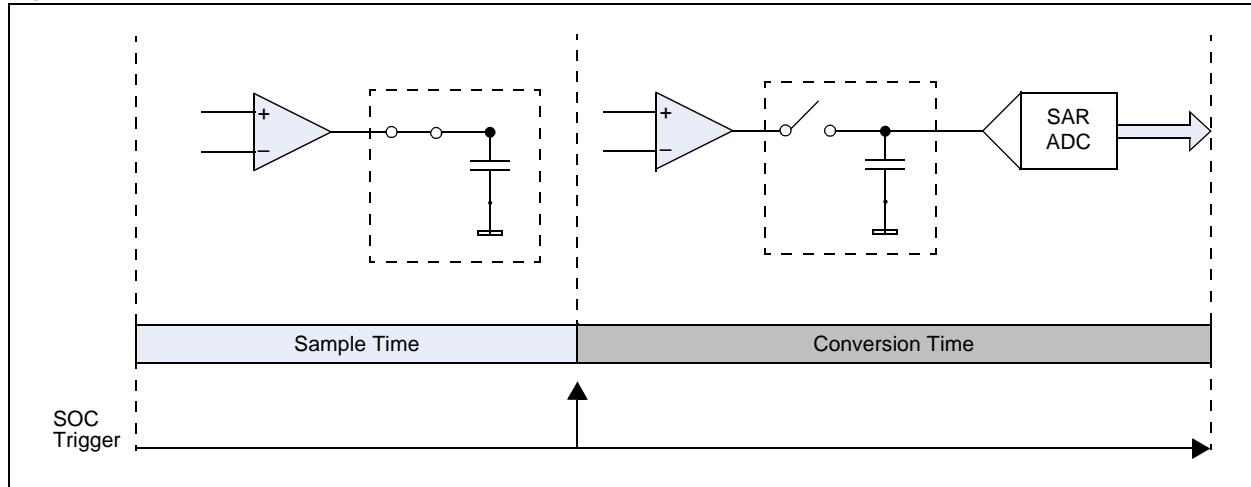
16.3 OVERVIEW OF SAMPLE AND CONVERSION SEQUENCE

Figure 16-3 illustrates the three-step process of the Analog-to-Digital conversion:

1. The input voltage signal is connected to the sample capacitor.
2. The sample capacitor is disconnected from the input.
3. The stored voltage is converted to equivalent digital bits.

The two distinct phases, sample and convert, are independently controlled.

Figure 16-3: Sample Conversion Sequence



16.3.1 Sample Time

Sample time is when the selected analog input is connected to the sample capacitor. There is a minimum sample time to ensure that the S&H amplifier provides a desired accuracy for the Analog-to-Digital conversion (see [Section 16.13 “Analog-to-Digital Sampling Requirements”](#)).

Note: The ADC module requires a finite number of Analog-to-Digital clock cycles to start conversion after receiving a conversion trigger or ending the sampling process. For more details, refer to the TPCS parameter in the “**Electrical Characteristics**” chapter of the specific device data sheet.

The sampling phase can be set up to start automatically upon conversion or by manually setting the Sample bit (SAMP) in the ADC Control Register 1 (ADxCON1<1>). The sampling phase is controlled by the Auto-Sample bit (ASAM) in the ADC Control Register 1 (ADxCON1<2>). [Table 16-1](#) lists the options selected by the specific bit configuration.

Table 16-1: Start of Sampling Selection

ASAM	Start of Sampling Selection
0	Manual Sampling
1	Automatic Sampling

If automatic sampling is enabled, the Sampling Time (T_{SMP}) taken by the ADC module is equal to the number of T_{AD} cycles defined by the SAMC<4:0> bits (ADxCON3<12:8>), as shown in [Equation 16-1](#).

Equation 16-1: Sampling Time Calculation

$$T_{SMP} = SAMC<4:0> \cdot T_{AD}$$

If manual sampling is desired, the user software must provide sufficient time to ensure adequate sampling time.

16.3.2 Conversion Time

The Start of Conversion (SOC) trigger ends the sampling time and begins an Analog-to-Digital conversion. During the conversion period, the sample capacitor is disconnected from the multiplexer and the stored voltage is converted to equivalent digital bits. The conversion times for 10-bit and 12-bit modes are shown in [Equation 16-2](#) and [Equation 16-3](#). The sum of the sample time and the Analog-to-Digital conversion time provides the total conversion time.

For correct Analog-to-Digital conversion, the Analog-to-Digital Conversion Clock (TAD) must be selected to ensure a minimum TAD time. Refer to the “**Electrical Characteristics**” chapter of the specific device data sheet for the minimum TAD specifications for 10-bit and 12-bit modes.

Equation 16-2: 10-Bit ADC Conversion Time

$T_{CONV} = 12 \cdot TAD$	Where:
	T_{CONV} = Conversion Time
	TAD = ADC Clock Period

Equation 16-3: 12-Bit ADC Conversion Time

$T_{CONV} = 14 \cdot TAD$	Where:
	T_{CONV} = Conversion Time
	TAD = ADC Clock Period

The SOC can be triggered by a variety of hardware sources or controlled manually in user software. The trigger source to initiate conversion is selected by the SOC Trigger Source Select bits (SSRC<2:0>) in the ADCx Control Register 1 (ADxCON1<7:5>). The Sample Clock Source Group bit, SSR CG (ADxCON1<4>), selects between the two groups. The SSR Cx bits provide different sample clock sources based on the group selected.

Note: Refer to the “**Analog-to-Digital Converter (ADC)**” chapter in the specific device data sheet for the available SOC trigger sources.

[Table 16-2](#) lists the sample conversion sequence with different sample and conversion phase selections.

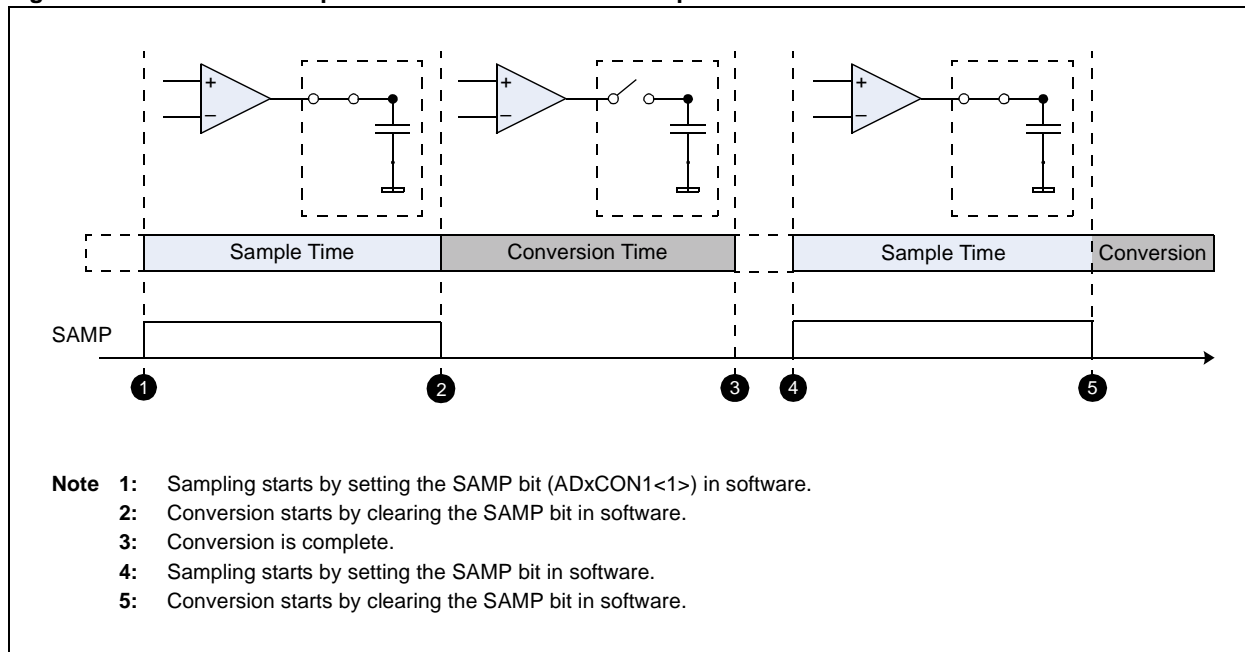
Table 16-2: Sample Conversion Sequence Selection

ASAM	SSRCG	SSRC<2:0>	Description
0	0	000	Manual Sample and Manual Conversion Sequence
0	0	111	Manual Sample and Automatic Conversion Sequence
0	0 or 1	001	Manual Sample and Triggered Conversion Sequence
		010	
		011	
		100	
	1	000	
		111	
1	0	000	Automatic Sample and Manual Conversion Sequence
1	0	111	Automatic Sample and Automatic Conversion Sequence
1	0 or 1	001	Automatic Sample and Triggered Conversion Sequence
		010	
		011	
		100	
	1	000	
		111	

16.3.3 Manual Sample and Manual Conversion Sequence

In the Manual Sample and Manual Conversion Sequence, setting the Sample bit (SAMP) in the ADCx Control Register 1 (ADxCON1<1>) initiates sampling, and clearing the SAMP bit terminates sampling and starts the conversion (see Figure 16-4). The user application must time the setting and clearing of the SAMP bit to ensure adequate sampling time for the input signal. Example 16-1 shows a code sequence for Manual Sample and Manual Conversion.

Figure 16-4: Manual Sample and Manual Conversion Sequence



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Example 16-1: Code Sequence for Manual Sample and Manual Conversion

```
#include <p33Exxxx.h>

/*****CONFIGURATION*****/
_FOSCSEL(FNOSC_FRC);
_FOSC(FCKSM_CSECMD & POSCMD_XT & OSCIOFNC_OFF & IOL1WAY_OFF);
_FWDT(FWDTEN_OFF);
_FPOR(FPWRT_PWR128 & BOREN_ON & ALTI2C1_ON & ALTI2C2_ON);
_FICD(ICS_PGD1 & RSTPRI_PF & JTAGEN_OFF);

void initAdc1(void);
void Delay_us(unsigned int);
int ADCValue, i;

int main(void)
{
    // Configure the device PLL to obtain 40 MIPS operation. The crystal frequency is 8 MHz.
    // Divide 8 MHz by 2, multiply by 40 and divide by 2. This results in Fosc of 80 MHz.
    // The CPU clock frequency is Fcy = Fosc/2 = 40 MHz.
    PLLFBD = 38;                /* M = 40 */
    CLKDIVbits.PLLPOST = 0;      /* N1 = 2 */
    CLKDIVbits.PLLPRE = 0;      /* N2 = 2 */
    OSCTUN = 0;

    /* Initiate Clock Switch to Primary Oscillator with PLL (NOSC = 0x3) */
    __builtin_write_OSCCONH(0x03);
    __builtin_write_OSCCONL(0x01);
    while (OSCCONbits.COSC != 0x3);
    while (_LOCK == 0);          /* Wait for PLL lock at 40 MIPS */

    initAdc1();

    while(1)
    {
        AD1CON1bits.SAMP = 1;    /* Start sampling
        Delay_us(10);            /* Wait for sampling time (10 us)
        AD1CON1bits.SAMP = 0;    /* Start the conversion
        while (!AD1CON1bits.DONE); /* Wait for the conversion to complete
        ADCValue = ADC1BUF0;     /* Read the ADC conversion result
    }
}

void initAdc1(void)
{
    /* Set port configuration */
    ANSELA = ANSELB = ANSELC = ANSELD = ANSELE = ANSELG = 0x0000;
    ANSELBbits.ANSB5 = 1;        /* Ensure AN5/RB5 is analog

    /* Initialize and enable ADC module */
    AD1CON1 = 0x0000;
    AD1CON2 = 0x0000;
    AD1CON3 = 0x000F;
    AD1CON4 = 0x0000;
    AD1CHS0 = 0x0005;
    AD1CHS123 = 0x0000;
    AD1CSSH = 0x0000;
    AD1CSSL = 0x0000;
    AD1CON1bits.ADON = 1;
    Delay_us(20);
}

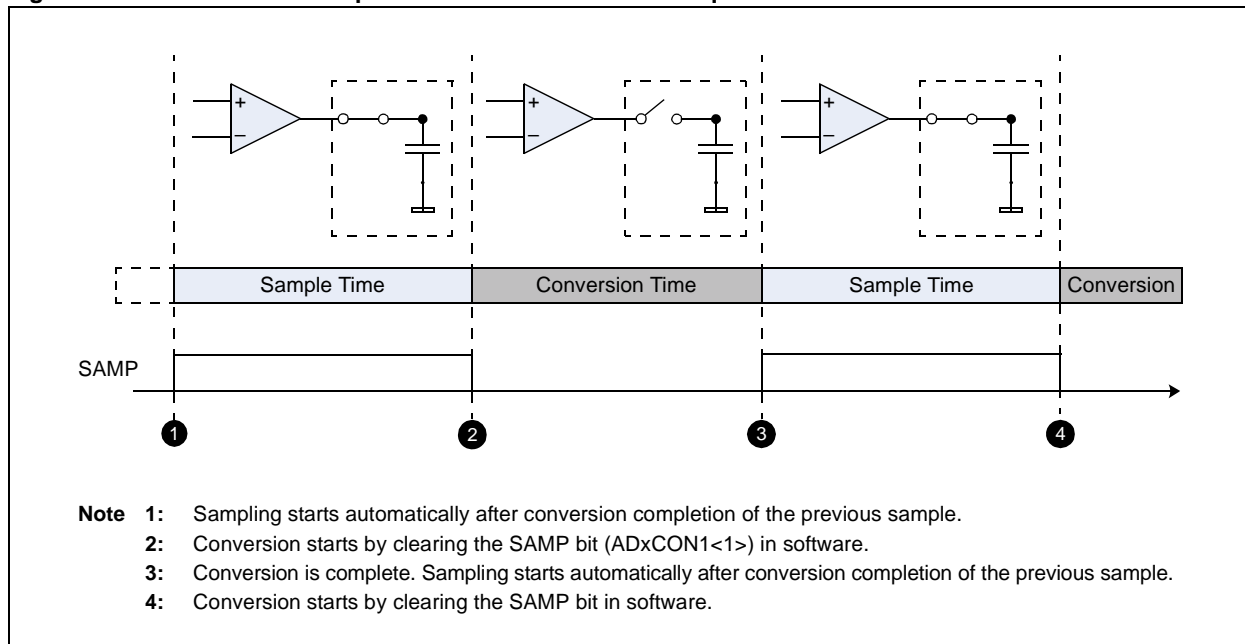
void Delay_us(unsigned int delay)
{
    for (i = 0; i < delay; i++)
    {
        __asm__ volatile ("repeat #39");
        __asm__ volatile ("nop");
    }
}
```

Note: Due to the internal delay within the ADC module, the SAMP bit (ADxCON1<1>) will read as '0' to the user software. This change occurs in a small interval of time after the conversion has started. In general, the time interval is 2 TCY.

16.3.4 Automatic Sample and Manual Conversion Sequence

In the Automatic Sample and Manual Conversion Sequence, sampling starts automatically after conversion of the previous sample. The user application must allocate sufficient time for sampling before clearing the SAMP bit (ADxCON1<1>). Clearing the SAMP bit initiates the conversion (see Figure 16-5).

Figure 16-5: Automatic Sample and Manual Conversion Sequence



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Example 16-2: Code Sequence for Automatic Sample and Manual Conversion

```
#include <p33Exxxx.h>

/*****CONFIGURATION*****/
_FOSCSEL(FNOSC_FRC);
_FOSC(FCKSM_CSECMD & POSCMD_XT & OSCIOFNC_OFF & IOL1WAY_OFF);
_FWDT(FWDTEN_OFF);
_FPOR(FPWRT_PWR128 & BOREN_ON & ALTI2C1_ON & ALTI2C2_ON);
_FICD(ICS_PGD1 & RSTPRI_PF & JTAGEN_OFF);

void initAdcl(void);
void Delay_us(unsigned int);
int  ADCValue, i, j;

int  main(void)
{
    // Configure the device PLL to obtain 40 MIPS operation. The crystal frequency is 8 MHz.
    // Divide 8 MHz by 2, multiply by 40 and divide by 2. This results in Fosc of 80 MHz.
    // The CPU clock frequency is Fcy = Fosc/2 = 40 MHz.
    PLLFBD = 38;                /* M = 40 */
    CLKDIVbits.PLLPOST = 0;     /* N1 = 2 */
    CLKDIVbits.PLLPRE = 0;     /* N2 = 2 */
    OSCTUN = 0;

    /* Initiate Clock Switch to Primary Oscillator with PLL (NOSC = 0x3) */
    __builtin_write_OSCCONH(0x03);
    __builtin_write_OSCCONL(0x01);
    while (OSCCONbits.COSC != 0x3);
    while (_LOCK == 0);        /* Wait for PLL lock at 40 MIPS */

    initAdcl();

    while(1)
    {
        Delay_us(100);        /* Sample for 100 us
        AD1CON1bits.SAMP = 0;    /* Start the conversion
        while (!AD1CON1bits.DONE); /* Wait for the conversion to complete
        AD1CON1bits.DONE = 0;    /* Clear conversion done status bit
        ADCValue = AD1BUF0;      /* Read the ADC conversion result
    }
}

void initAdcl(void)
{
    /* Set port configuration */
    ANSELA = ANSELB = ANSELC = ANSELD = ANSELE = ANSELG = 0x0000;
    ANSELBbits.ANSB5 = 1;      /* Ensure AN5/RB5 is analog

    /* Initialize and enable ADC module */
    AD1CON1 = 0x0004;
    AD1CON2 = 0x0000;
    AD1CON3 = 0x000F;
    AD1CON4 = 0x0000;
    AD1CHS0 = 0x0005;
    AD1CHS123 = 0x0000;
    AD1CSSH = 0x0000;
    AD1CSSL = 0x0000;
    AD1CON1bits.ADON = 1;
    Delay_us(20);
}

void Delay_us(unsigned int delay)
{
    for (i = 0; i < delay; i++)
    {
        __asm__ volatile ("repeat #39");
        __asm__ volatile ("nop");
    }
}
```

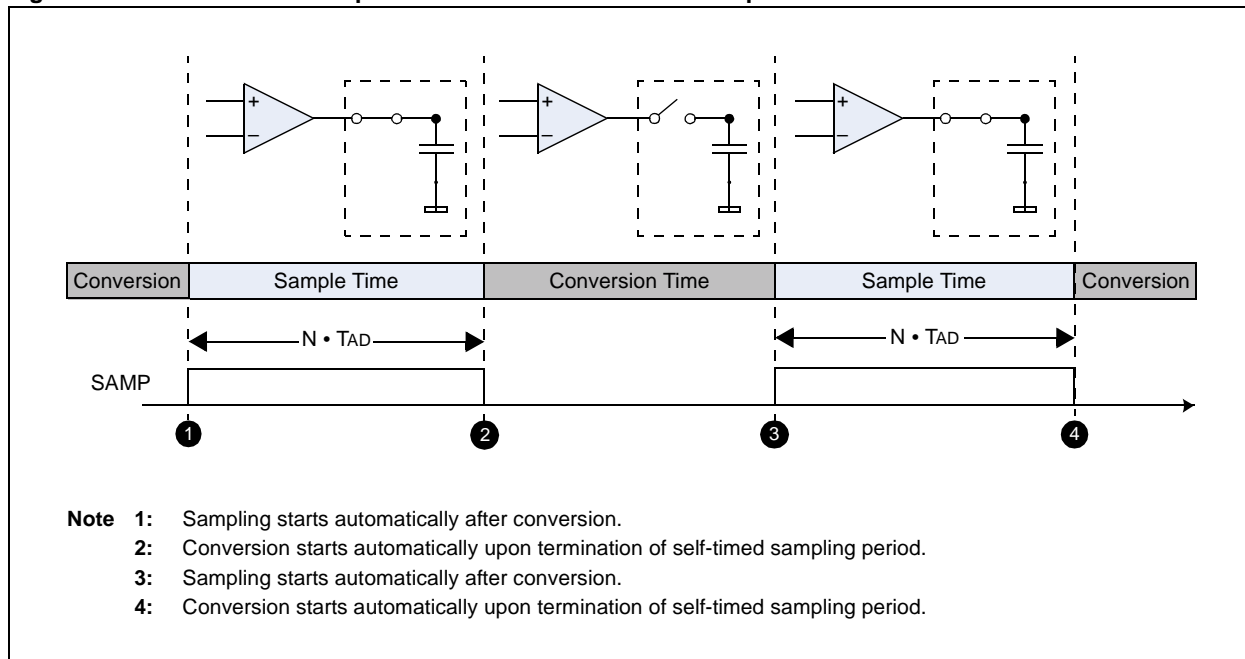
16.3.5 Automatic Sample and Automatic Conversion Sequence

16.3.5.1 CLOCKED CONVERSION TRIGGER

The auto-conversion method provides a more automated process to sample and convert the analog inputs, as shown in Figure 16-6. The sampling period is self-timed and the conversion starts automatically upon termination of a self-timed sampling period. The Auto-Sample Time bits (SAMC<4:0>) in the ADxCON3 register (ADxCON3<12:8>) select 0 to 31 ADC clock cycles (TAD) for the sampling period. Refer to the “**Electrical Characteristics**” chapter of the specific device data sheet for a minimum recommended sampling time (SAMCx bits value).

The SSRCG bit is set to ‘0’ and the SSRC<2:0> bits are set to ‘111’ to choose the internal counter as the sample clock source, which ends sampling and starts conversion.

Figure 16-6: Automatic Sample and Automatic Conversion Sequence

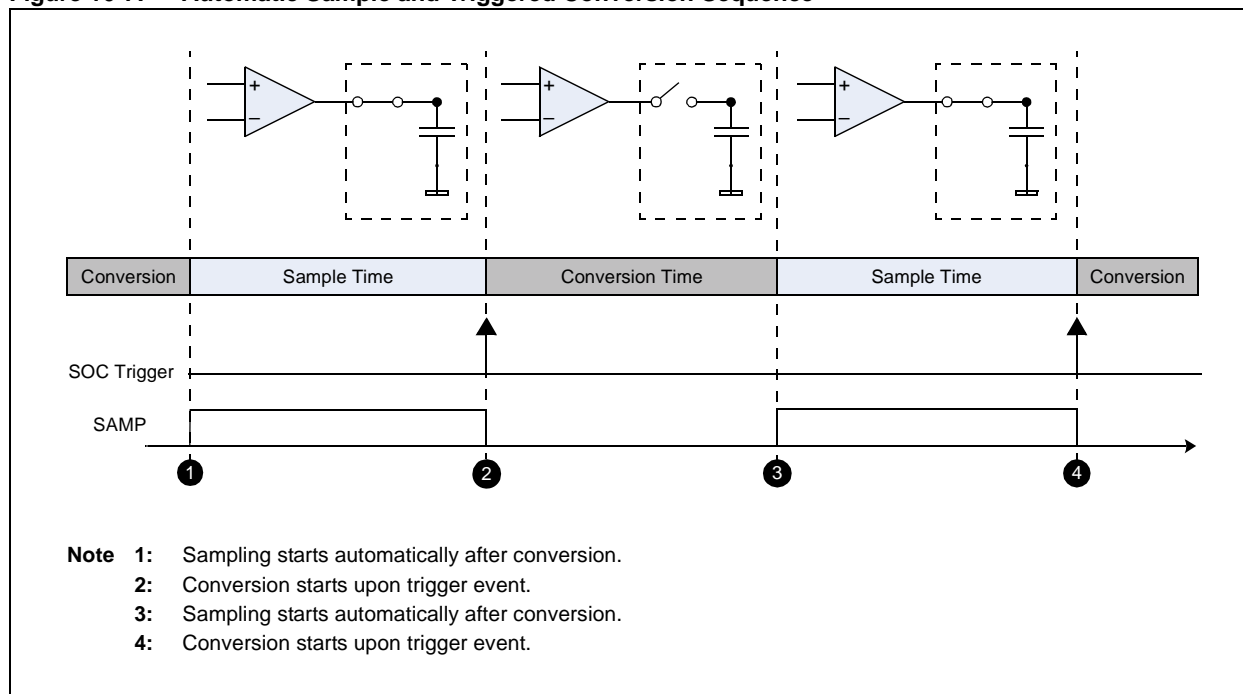


16.3.5.2 EXTERNAL CONVERSION TRIGGER

In an Automatic Sample and Triggered Conversion Sequence, sampling starts automatically after conversion and the conversion starts upon a trigger event from the selected peripheral, as shown in [Figure 16-7](#). This enables ADC conversion to be synchronized with the internal or external events. The external conversion trigger is selected by configuring the SSRC<2:0> bits as shown in [Table 16-2](#). Refer to [Section 16.4.8 “Conversion Trigger Sources”](#) for various external conversion trigger sources.

The ASAM bit must not be modified while the ADC is turned on. If automatic sampling is desired, the ASAM bit must be set before turning the module on. The ADC module takes some amount of time to stabilize (see the TDPU parameter in the specific device data sheet). If automatic sampling is enabled, there is no assurance that the initial ADC results are correct until the ADC module stabilizes. It may be necessary to discard the first few ADC results depending on the Analog-to-Digital clock speed.

Figure 16-7: Automatic Sample and Triggered Conversion Sequence



16.3.6 Multi-Channel Sample Conversion Sequence

Multi-channel Analog-to-Digital Converters typically convert each input channel sequentially using an input multiplexer. Simultaneously sampling multiple signals ensures that the snapshot of the analog inputs occurs at precisely the same time for all inputs, as shown in Figure 16-8.

Certain applications require simultaneous sampling, especially when phase information exists between different channels. Sequential sampling takes a snapshot of each analog input just before conversion starts on that input, as shown in Figure 16-8. The sampling of multiple inputs is not correlated. For example, motor control and power monitoring requires voltage and current measurements, and the phase angle between them.

Figure 16-8: Simultaneous and Sequential Sampling

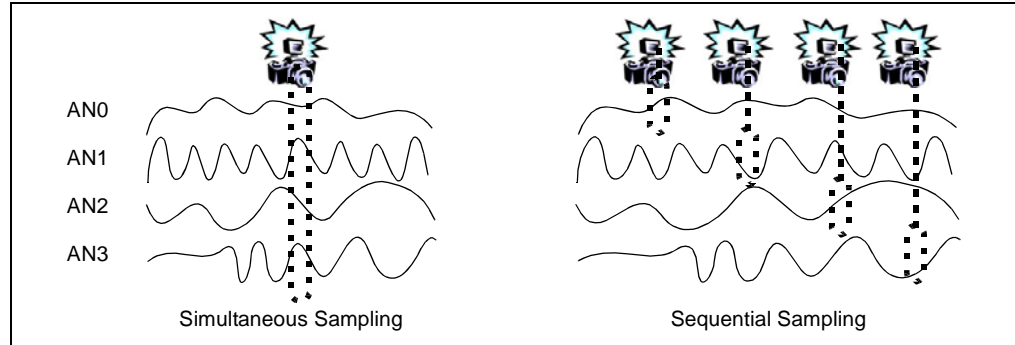


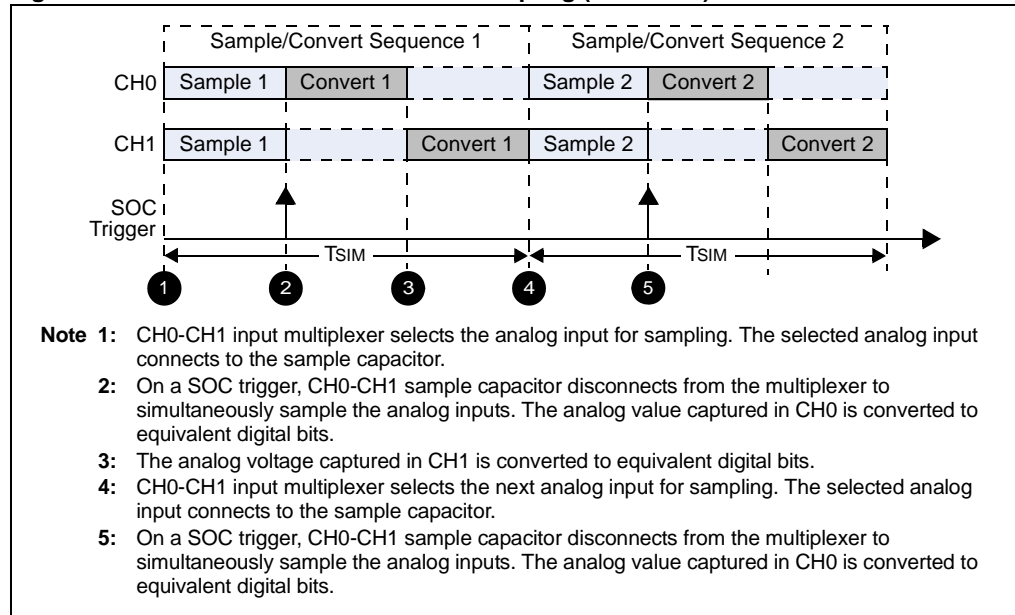
Figure 16-9 and Figure 16-10 illustrate that the ADC module supports simultaneous sampling using two S&H or four S&H channels to sample the inputs at the same time, and then performs the conversion for each channel sequentially.

The Simultaneous Sampling mode is selected by setting the Simultaneous Sampling bit (SIMSAM) in the ADCx Control Register 1 (ADxCON1<3>). By default, the channels are sampled and converted sequentially. Table 16-3 lists the options selected by a specific bit configuration. The CHPS<1:0> bits determine the channels to be sampled, either sequentially or simultaneously.

Table 16-3: Start of Sampling Selection

SIMSAM	Sampling Mode
0	Sequential Sampling
1	Simultaneous Sampling

Figure 16-9: 2-Channel Simultaneous Sampling (ASAM = 1)



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For simultaneous sampling, the total time taken to sample and convert the channels is shown in [Equation 16-4](#).

Equation 16-4: Channel Sample and Conversion Total Time, Simultaneous Sampling Selected

$$T_{SIM} = T_{SMP} + (M \cdot T_{CONV})$$

Where:

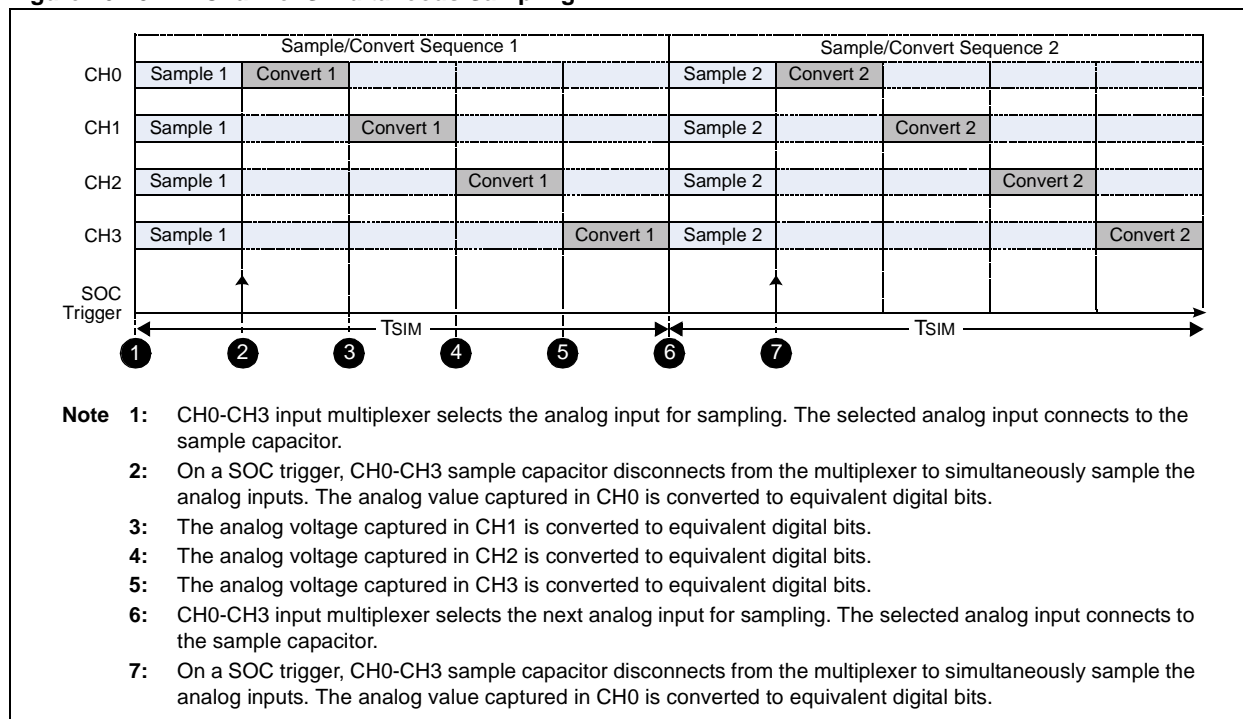
T_{SIM} = Total Time to Sample and Convert multiple channels with simultaneous sampling

T_{SMP} = Sampling Time (see [Equation 16-1](#))

T_{CONV} = Conversion Time (see [Equation 16-2](#))

M = Number of Channels selected by the CHPS<1:0> bits

Figure 16-10: 4-Channel Simultaneous Sampling



[Figure 16-11](#) and [Figure 16-12](#) illustrate that, by default, multiple channels are sampled and converted sequentially.

For sequential sampling, the total time taken to sample and convert channels is shown in [Equation 16-5](#).

Equation 16-5: Channel Sample and Conversion Total Time, Sequential Sampling Selected

When $T_{SMP} < T_{CONV}$,

$$T_{SEQ} = M \cdot T_{CONV} \quad (\text{if } M > 1)$$

$$T_{SEQ} = T_{SMP} + T_{CONV} \quad (\text{if } M = 1)$$

Where:

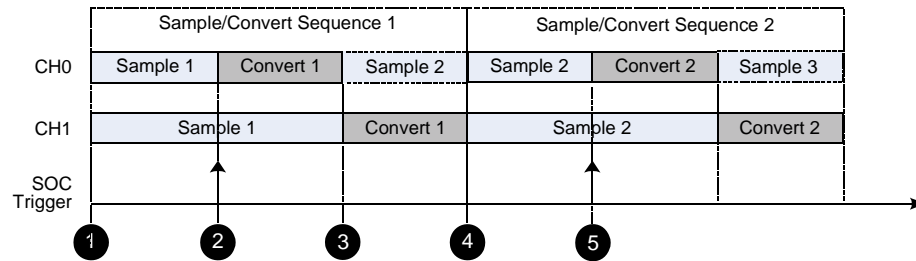
T_{SEQ} = Total Time to Sample and Convert multiple channels with sequential sampling

T_{CONV} = Conversion Time (see [Equation 16-2](#))

T_{SMP} = Sampling Time (see [Equation 16-1](#))

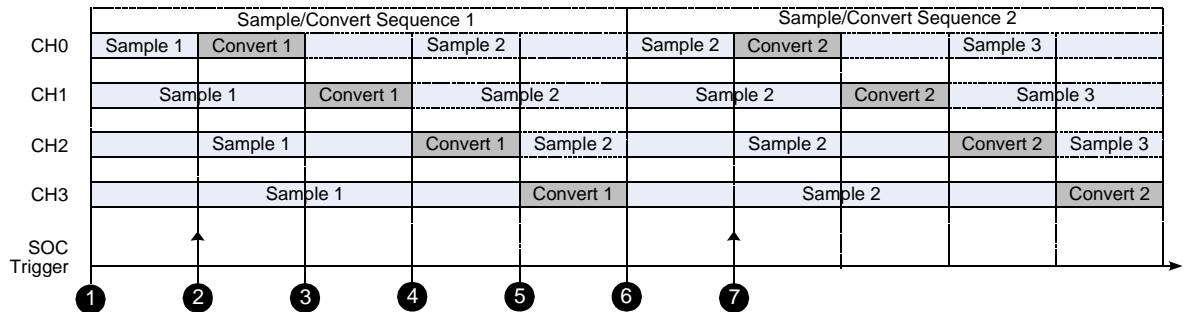
M = Number of Channels selected by the CHPS<1:0> bits

Figure 16-11: 2-Channel Sequential Sampling (ASAM = 1)



- Note 1:** CH0-CH1 input multiplexer selects the analog input for sampling. The selected analog input connects to the sample capacitor.
- 2:** On a SOC trigger, CH0 sample capacitor disconnects from the multiplexer to hold the input voltage constant during conversion. The analog value captured in CH0 is converted to equivalent digital bits.
- 3:** The CH0 multiplexer output connects to the sample capacitor after conversion. CH1 sample capacitor disconnects from the multiplexer to hold the input voltage constant during conversion. The analog value captured in CH1 is converted to equivalent digital bits.
- 4:** The CH1 multiplexer output connects to the sample capacitor after conversion. CH0-CH1 input multiplexer selects the next analog input for sampling.
- 5:** On a SOC trigger, CH0 sample capacitor disconnects from the multiplexer to hold the input voltage constant during conversion. The analog value captured in CH0 is converted to equivalent digital bits.

Figure 16-12: 4-Channel Sequential Sampling



- Note 1:** CH0-CH3 input multiplexer selects the analog input for sampling. The selected analog input connects to the sample capacitor.
- 2:** On a SOC trigger, CH0 sample capacitor disconnects from the multiplexer to hold the input voltage constant during conversion. The analog value captured in CH0 is converted to equivalent digital bits.
- 3:** The CH0 multiplexer output connects to the sample capacitor after conversion. CH1 sample capacitor disconnects from the multiplexer to hold the input voltage constant during conversion. The analog value captured in CH1 is converted to equivalent digital bits.
- 4:** The CH1 multiplexer output connects to the sample capacitor after conversion. CH2 sample capacitor disconnects from the multiplexer to hold the input voltage constant during conversion. The analog value captured in CH2 is converted to equivalent digital bits.
- 5:** The CH2 multiplexer output connects to the sample capacitor after conversion. CH3 sample capacitor disconnects from the multiplexer to hold the input voltage constant during conversion. The analog value captured in CH3 is converted to equivalent digital bits.
- 6:** The CH3 multiplexer output connects to the sample capacitor after conversion. CH0-CH3 input multiplexer selects the next analog input for sampling.
- 7:** On a SOC trigger, CH0 sample capacitor disconnects from the multiplexer to hold the input voltage constant during conversion. The analog value captured in CH0 is converted to equivalent digital bits.

16.4 ADC CONFIGURATION

16.4.1 Disabling the Use of DMA with the ADC Module

When the ADDMAEN bit (ADxCON4<8>) is '1' (default), the ADC module can use DMA to transfer conversion results from the ADCxBUF0 register to DMA RAM.

When the ADDMAEN bit is '0', the DMA cannot be used with the ADC module and the DMABL<2:0> and ADDMABM bits have no effect. Additionally, the conversion results are stored in the ADCxBUF0-ADCxBUFF registers.

Note: The ADDMAEN bit is only available on devices with DMA. Refer to the specific device data sheet for availability.

16.4.2 ADC Operational Mode Selection

The 12-Bit ADC Operation Mode bit (AD12B) in the ADCx Control Register 1 (ADxCON1<10>) enables the ADC module to function as either a 10-bit, 4-channel ADC (default configuration) or a 12-bit, single channel ADC. [Table 16-4](#) lists the options selected by different bit settings.

Note: The ADC module must be disabled before the AD12B bit is modified.

Table 16-4: ADC Operational Mode

AD12B	Channel Selection
0	10-Bit, 4-Channel ADC
1	12-Bit, Single Channel ADC

16.4.3 ADC Channel Selection

In 10-bit mode (AD12B = 0), the user application can select 1-Channel (CH0), 2-Channel (CH0, CH1) or 4-Channel mode (CH0-CH3) using the Channel Select bits (CHPS<1:0>) in the ADCx Control Register 2 (ADxCON2<9:8>). In 12-bit mode, the user application can only use CH0. [Table 16-5](#) lists the number of channels selected for the different bit settings.

Note: ADC2 can operate only in 10-bit mode.

Table 16-5: 10-Bit ADC Channel Selection

CHPS<1:0>	Channel Selection
00	CH0
01	Dual Channel (CH0, CH1)
1x	Multi-Channel (CH0-CH3)

16.4.4 Voltage Reference Selection

The voltage references for Analog-to-Digital conversions are selected using the Voltage Reference Configuration bits (VCFG<2:0>) in the ADCx Control Register 2 (ADxCON2<15:13>). [Table 16-6](#) lists the voltage reference selection for different bit settings. The Voltage Reference High (VREFH) and the Voltage Reference Low (VREFL) to the ADC module can be supplied from the internal AVDD and AVSS voltage rails or the external VREF+ and VREF- input pins. The external voltage reference pins can be shared with the AN0 and AN1 inputs on low pin count devices. The ADC module can still perform conversions on these pins when they are shared with the VREF+ and VREF- input pins. The voltages applied to the external reference pins must meet certain specifications. For more details, refer to the “**Electrical Characteristics**” chapter of the specific device data sheet.

Table 16-6: Voltage Reference Selection

VCFG<2:0>	VREFH	VREFL
000	AVDD	AVSS
001	VREF+	AVSS
010	AVDD	VREF-
011	VREF+	VREF-
1xx	AVDD	AVSS

16.4.5 ADC Clock Selection

The ADC module can be clocked from the instruction cycle clock (TCY) or by using the dedicated internal RC clock (see [Figure 16-13](#)). When using the instruction cycle clock, a clock divider drives the instruction cycle clock and enables a lower frequency to be chosen. The clock divider is controlled by the ADC Conversion Clock Select bits (ADCS<7:0>) in the ADCx Control Register 3 (ADxCON3<7:0>), which enables 256 settings, from 1:1 to 1:256, to be chosen.

[Equation 16-6](#) shows the ADC clock period (TAD) as a function of the ADCSx control bits and the device instruction cycle clock period, TCY.

Note: Refer to the “**Electrical Characteristics**” chapter in the specific device data sheet for minimum TAD specifications.

Equation 16-6: ADC Clock Period

If ADRC = 0:

$$ADC\ Clock\ Period\ (TAD) = TCY \cdot (ADCS<7:0> + 1)$$

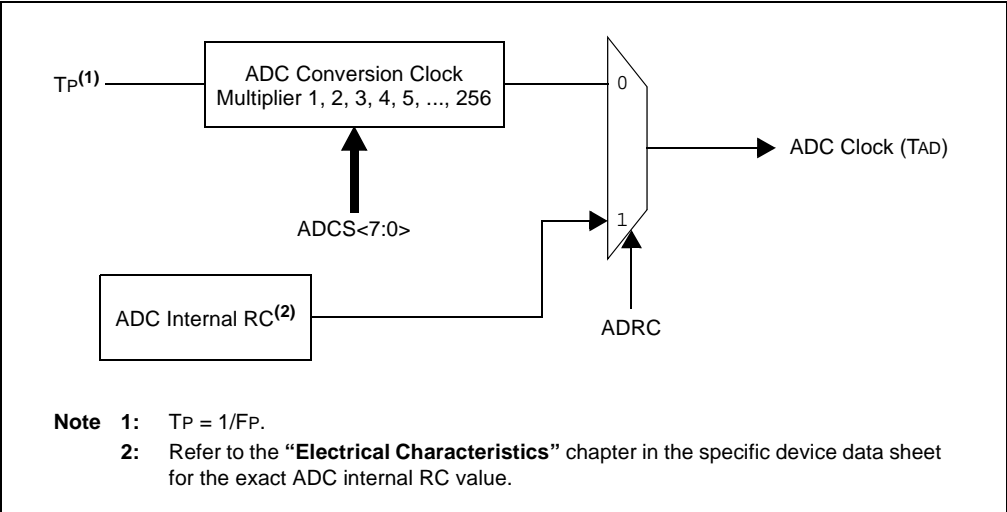
If ADRC = 1:

$$ADC\ Clock\ Period\ (TAD) = TADRC$$

The ADC module has a dedicated internal RC clock source that can be used to perform conversions. The internal RC clock source is used when Analog-to-Digital conversions are performed while the device is in Sleep mode. The internal RC oscillator is selected by setting the ADC Conversion Clock Source bit (ADRC) in ADCx Control Register 3 (ADxCON3<15>). When the ADRC bit is set, the ADCS<7:0> bits have no effect on the ADC operation.

Note: Refer to the “**Electrical Characteristics**” chapter in the specific device data sheet for ADRC frequency specifications.

Figure 16-13: ADC Clock Generation



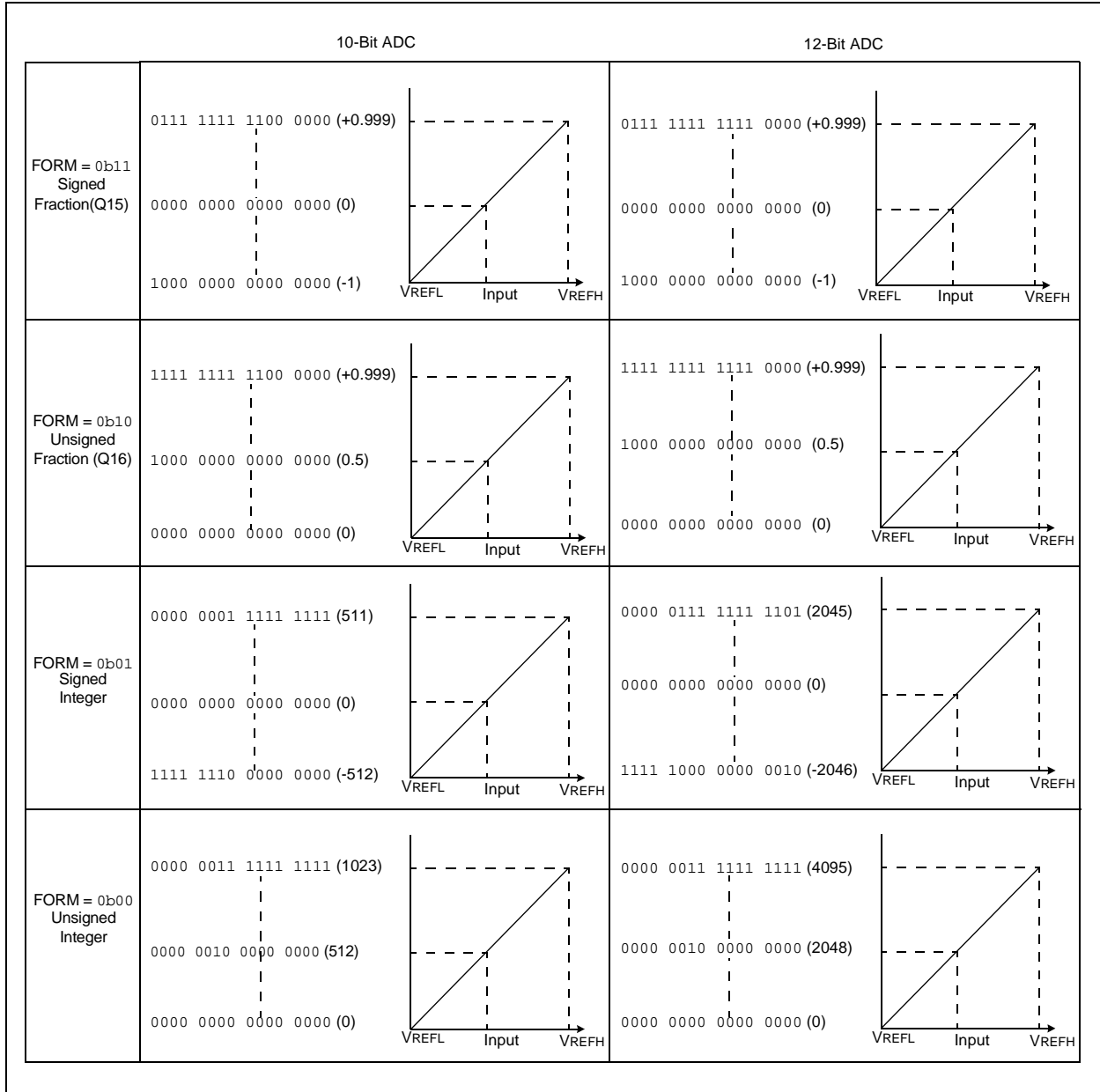
16.4.6 Output Data Format Selection

Figure 16-14 illustrates that the ADC result is available in four different numerical formats. The Data Output Format bits (FORM<1:0>) in the ADCx Control Register 1 (ADxCON1<9:8>) select the output data format. Table 16-7 lists the ADC output format for different bit settings.

Table 16-7: Voltage Reference Selection

FORM<1:0>	Data Information Selection
11	Signed Fractional Format
10	Unsigned Fractional Format
01	Signed Integer Format
00	Unsigned Integer Format

Figure 16-14: ADC Output Format



16.4.7 Sample and Conversion Operation (SMPI) Bits

The function of the Samples Per Interrupt control bits (SMPI<4:0>) in the ADC Control Register 2 (ADxCON2<6:2>) for devices with DMA is completely different from the function of the SMPI<4:0> bits for devices without DMA, and for devices with DMA that have the ADC DMA Enable bit (ADDMAEN) clear.

For devices without DMA or with the ADC DMA Enable bit (ADDMAEN) clear, the SMPI<4:0> bits are referred to as the “Number of Samples Per Interrupt Select” bits. For devices with DMA and the ADDMAEN bit set, the SMPI<4:0> bits are referred to as the “Increment Rate for DMA Address Select” bits.

16.4.7.1 SMPIx BITS FOR DEVICES WITHOUT DMA OR WITH THE ADC DMA ENABLE BIT (ADDMAEN) CLEAR

For devices without DMA or with the ADC DMA Enable bit (ADDMAEN) clear, an interrupt can be generated at the end of each sample/convert sequence, or after multiple sample/convert sequences, as determined by the value of the SMPI<4:0> bits. The number of sample/convert sequences between interrupts can vary between 1 and 32. The total number of conversion results between interrupts is the product of the number of channels per sample created by the CHPS<1:0> bits and the value of the SMPI<4:0> bits. See [Section 16.5 “ADC Interrupt Generation”](#) for the SMPIx values for various sampling modes.

Note: If a manual conversion trigger is used and the number of samples per interrupt is greater than the number of channels per sample, the SAMP bit (ADxCON1<1>) must be manually cleared at suitable intervals in order to generate a sufficient number of ADC conversions.

16.4.7.2 SMPIx BITS FOR DEVICES WITH DMA AND WITH THE ADC DMA ENABLE BIT (ADDMAEN) SET

For devices with DMA and with the ADC DMA Enable bit (ADDMAEN) set, if multiple conversion results need to be buffered, DMA must be used with the ADC module to store the conversion results in a DMA buffer. In this case, the SMPI<4:0> bits are used to select how often the DMA RAM Buffer Pointer is incremented. The number of increments of the DMA RAM Buffer Pointer must not exceed the DMA RAM buffer length per input, as specified by the DMABL<2:0> bits. An ADC interrupt is generated after completion of every conversion, regardless of the setting of the SMPI<4:0> bits.

When single, dual or multiple channels are enabled in Simultaneous or Sequential Sampling modes (and CH0 channel scanning is disabled), the SMPI<4:0> bits are set to ‘0’, indicating the DMA Address Pointer increments every sample.

When all single, dual or multiple channels are enabled in Simultaneous or Sequential Sampling modes with Alternate Input Selection mode enabled (and CH0 channel scanning is disabled), set SMPI<4:0> = 0001 to allow two samples per DMA address point increment.

When channel scanning is used (and Alternate Input Selection mode is disabled), the SMPI<4:0> bits must be set to the number of inputs being scanned, minus one (i.e., SMPI<4:0> = N – 1).

16.4.8 Conversion Trigger Sources

It is often desirable to synchronize the end of sampling and the Start of Conversion with some other time event. The ADC module can use one of the following sources as a conversion trigger:

- External Interrupt Trigger (INT0 only)
- Timer Interrupt Trigger
- Motor Control PWM Special Event Trigger
- PTG Trigger

16.4.8.1 EXTERNAL INTERRUPT TRIGGER (INT0 ONLY)

When $SSRCG = 0$ and $SSRC<2:0> = 001$, the Analog-to-Digital conversion is triggered by an active transition on the INT0 pin. The INT0 pin can be programmed for either a rising edge input or a falling edge input.

16.4.8.2 TIMER INTERRUPT TRIGGER

This ADC module Trigger mode is configured by setting $SSRCG = 0$ and $SSRC<2:0> = 010$ or 100 . When $SSRC<2:0> = 010$, TMR3 is used to trigger the start of the Analog-to-Digital conversion when a match occurs between the 16-bit Timer Count register (TMR3) and the 16-bit Timer Period register (PR3). The 32-bit timer can also be used to trigger the start of the Analog-to-Digital conversion. When $SSRCG = 0$ and $SSRC<2:0> = 100$, TMR5 is used to trigger the start of the Analog-to-Digital conversion when a match occurs between the 16-bit Timer Count Register (TMR5) and the 16-bit Timer Period Register (TPR5).

16.4.8.3 MOTOR CONTROL PWM TRIGGERS

The PWM module has a Special Event Trigger that enables Analog-to-Digital conversions to be synchronized to the PWM time base. When $SSRCG = 0$ and $SSRC<2:0> = 011$ or 101 , the Analog-to-Digital sampling and conversion times occur at any user programmable point within the PWM period. The Special Event Trigger enables the user to minimize the delay between the time when the Analog-to-Digital conversion results are acquired and the time when the duty cycle value is updated.

Individual PWM event triggers can also be selected for PWM Generators 1 through 7 by setting $SSRCG = 1$ and $SSRC<2:0> = 000, \dots, 110$.

The application must set the ASAM bit to ensure that the ADC module has sampled the input sufficiently before the next conversion trigger arrives.

16.4.8.4 PTG TRIGGER

The PTG module provides a means to create trigger signals for the ADC and other modules that have complex timing sequences. It offers the user the capability to schedule complex peripheral operations that would be difficult or impossible to achieve through the software solution. When $SSRCG = 1$ and $SSRC = 100, 101$ or 110 , the PTG module generates a trigger that ends sampling and starts the conversion sequence in the ADC.

The trigger source for the PTG module can vary and depends on the user application. For example, the ADC clock source itself can be used as a trigger source and sets up the PTG to generate a trigger output to the ADC to start the conversion sequence.

16.4.9 Configuring Analog Port Pins

The Analog/Digital Pin Selection register (ANSELY; y = PORTA, PORTB, PORTC, etc.) specifies the input condition of device pins used as analog inputs. Along with the Data Direction register (TRISx) in the Parallel I/O (PIO) port module, these registers control the operation of the ADC pins.

A pin is configured as an analog input when the corresponding ANSy<n> bit (ANSELY<n>) is set. The ANSELY registers are set at Reset, causing the ADC input pins to be configured for analog inputs by default at Reset.

When configured for analog input, the associated port I/O digital input buffer is disabled so that it does not consume current.

The port pins that are desired as analog inputs must have their corresponding TRIS bits set, specifying the port input. If the I/O pin associated with an Analog-to-Digital input is configured as an output, the TRIS bit is cleared and the digital output level (VOH or VOL) of the port is converted.

After a device Reset, all TRIS bits are set.

A pin is configured as a digital I/O when the corresponding ANSy<n> bit is cleared. In this configuration, the input to the analog multiplexer is connected to AVSS.

Note 1: When the ADC PORT register is read, any pin configured as an analog input reads as a '0'.

2: Analog levels on any pin that is defined as a digital input may cause the input buffer to consume current that is out of the device specification.

16.4.10 Enabling the ADC Module

When the ADON bit (ADxCON1<15>) is '1', the module is in Active mode and is fully powered and functional.

When ADON is '0', the module is disabled. The digital and analog portions of the circuit are turned off for maximum current savings.

To return to the Active mode from the Off mode, the user application must wait for the analog stages to stabilize. For the stabilization time, refer to the “**Electrical Characteristics**” chapter of the device data sheet.

Note: The SSRCG, SSRG<2:0>, SIMSAM, ASAM, CHPS<1:0>, SMPI<4:0>, BUFG and ALTS bits, as well as the ADON3 and ADCSSL registers, must not be written to while ADON = 1. This leads to indeterminate results.

16.4.11 Turning the ADC Module Off

Clearing the ADON bit disables the ADC module (stops any scanning, sampling and conversion processes). In this state, the ADC module still consumes some current. Setting the ADxMD bit in the PMD register disables the ADC module and stops the ADC clock source, which reduces device current consumption. Note that setting the ADxMD bit, and then clearing it, resets the ADC module registers to their default state. Additionally, any digital pins that share their function with an ADC input pin revert to the analog function. While the ADxMD bit is set, these pins will be set to digital function.

Note: Clearing the ADON bit during a conversion aborts the current Analog-to-Digital conversion. The ADC buffer is not updated with the partially completed conversion sample.

16.5 ADC INTERRUPT GENERATION

With DMA enabled, the SMPI<4:0> bits (ADxCON2<6:2>) determine the number of sample/conversion operations per channel (CH0/CH1/CH2/CH3) for every DMA Address/Increment Pointer.

The SMPI<4:0> bits have no effect when the ADC module is set up such that DMA buffers are written in Conversion Order mode.

If DMA transfers are enabled, the SMPI<4:0> bits must be cleared, except when channel scanning or alternate sampling is used. Please see [Section 16.7 “Specifying Conversion Results Buffering for Devices with DMA and with ADC DMA Enable Bit \(ADDMAEN\) Set”](#) for more details on SMPI<4:0> setup requirements.

When the SIMSAM bit (ADxCON1<3>) specifies sequential sampling, regardless of the number of channels specified by the CHPS<1:0> bits (ADxCON2<9:8>), the ADC module samples once for each conversion and data sample in the buffer. The value specified by the DMAx_CNT register for the DMA channel being used corresponds to the number of data samples in the buffer.

For devices with DMA and with the ADC DMA Enable bit (ADDMAEN) set, interrupts are generated after every conversion, which sets the DONE bit since it reflects the ADCx Interrupt Flag (ADxIF) setting.

For devices without DMA or with the ADC DMA Enable bit (ADDMAEN) clear, as conversions are completed, the ADC module writes the results of the conversions into the Analog-to-Digital result buffer. The ADC result buffer is an array of sixteen words, accessed through the SFR space. The user application may attempt to read each Analog-to-Digital conversion result as it is generated. However, this might consume too much CPU time. Generally, to simplify the code, the module fills the buffer with results and generates an interrupt when the buffer is filled. The ADC module supports 16 result buffers. Therefore, the maximum number of conversions per interrupt must not exceed 16.

The number of conversions per ADC interrupt depends on the following parameters, which can vary from one to 16 conversions per interrupt.

- Number of S&H Channels Selected
- Sequential or Simultaneous Sampling
- Samples Convert Sequences Per Interrupt bits (SMPI<4:0>) Settings

[Table 16-8](#) lists the number of conversions per ADC interrupt for different configuration modes.

Table 16-8: Samples Per Interrupt in Alternate Sampling Mode

CHPS<1:0>	SIMSAM	SMPI<4:0>	Conversions/ Interrupt	Description
00	x	N-1	N	1-Channel mode
01	0	N-1	N	2-Channel Sequential Sampling mode
1x	0	N-1	N	4-Channel Sequential Sampling mode
01	1	N-1	2 • N	2-Channel Simultaneous Sampling mode
1x	1	N-1	4 • N	4-Channel Simultaneous Sampling mode

Note 1: In 2-Channel Simultaneous Sampling mode, SMPI<4:0> bit settings must be less than eight.

2: In 4-Channel Simultaneous Sampling mode, SMPI<4:0> bit settings must be less than four.

The DONE bit (ADxCON1<0>) is set when an ADC interrupt is generated to indicate completion of a required sample/conversion sequence. This bit is automatically cleared by the hardware at the beginning of the next sample/conversion sequence.

On devices without DMA or with the ADC DMA Enable bit (ADDMAEN) clear, interrupt generation is based on the SMPI<4:0> and CHPS bits, so the DONE bit is not set after every conversion, but is set when the ADCx Interrupt Flag (ADxIF) is set.

16.5.1 Buffer Fill Mode

When the Buffer Fill Mode bit (BUFM) in the ADC Control Register 2 (ADxCON2<1>) is '1', the 16-word results buffer is split into two 8-word groups: a lower group (ADC1BUF0 through ADC1BUF7) and an upper group (ADC1BUF8 through ADC1BUFF). The 8-word buffers alternately receive the conversion results after each ADC interrupt event. When the BUFM bit is set, each buffer size is equal to eight. Therefore, the maximum number of conversions per interrupt must not exceed eight.

When the BUFM bit is '0', the complete 16-word buffer is used for all conversion sequences. The decision to use the split buffer feature depends on the time available to move the buffer contents, after the interrupt, as determined by the application.

If the application can quickly unload a full buffer within the time taken to sample and convert one channel, the BUFM bit can be '0' and up to 16 conversions may be done per interrupt. The application has one sample/convert time before the first buffer location is overwritten. If the processor cannot unload the buffer within the sample and conversion time, the BUFM bit must be '1'. For example, if an ADC interrupt is generated every eight conversions, the processor has the entire time between interrupts to move the eight conversions out of the buffer.

16.5.2 Buffer Fill Status

When the conversion result buffer is split using the BUFM control bit, the BUFS status bit (ADxCON2<7>) indicates the half of the buffer that the ADC module is currently writing. If BUFS = 0, the ADC module is filling the lower group and the user application should read conversion values from the upper group. If BUFS = 1, the situation is reversed and the user application must read conversion values from the lower group.

16.6 ANALOG INPUT SELECTION FOR CONVERSION

The ADC module provides a flexible mechanism to select analog inputs for conversion:

- Fixed Input Selection
- Alternate Input Selection
- Channel Scanning (CH0 only)

16.6.1 Fixed Input Selection

The 10-bit ADC configuration can use up to four S&H channels, designated CH0-CH3, whereas the 12-bit ADC configuration can use only one S&H channel, CH0. The S&H channels are connected to the analog input pins through the analog multiplexer.

When $ALTS = 0$, the $CH0SA<4:0>$, $CH0NA$, $CH123SA$ and $CH123NA<1:0>$ bits select the analog inputs. [Table 16-9](#) lists the analog inputs and control bits for selecting the channel.

Table 16-9: Analog Input Selection

		MUXA	
		Control Bits	Analog Inputs
CH0	+ve	$CH0SA<5:0>$	AN0 to AN48
	-ve	$CH0NA$	VREF-, AN1
CH1	+ve	$CH123SA$	AN0, AN3
	-ve	$CH123NA<1:0>$	AN6, AN9, VREF-
CH2	+ve	$CH123SA$	AN1, AN4, AN0, AN25
	-ve	$CH123NA<1:0>$	AN7, AN10, VREF-
CH3	+ve	$CH123SA$	AN2, AN5, AN6, AN25
	-ve	$CH123NA<1:0>$	AN8, AN11, VREF-

Note: Availability and configuration of inputs varies by device. Refer to the “**Analog-to-Digital Converter (ADC)**” chapter in the specific device data sheet for availability.

All four channels can be enabled in Simultaneous or Sequential Sampling modes by configuring the $CHPSx$ bits and the $SIMSAM$ bit.

For devices with DMA and with the $ADDMAEN$ bit set, the $SMPI<4:0>$ bits are set to ‘00000’, indicating the DMA Address Pointer increments every sample.

[Example 16-3](#) shows the code sequence to set up ADC inputs for a 4-channel ADC configuration.

Example 16-3: Code Sequence to Set Up ADC Inputs

```
#include <p33Exxxx.h>

/** CONFIGURATION *****/
_FOSCSEL(FNOSC_FRC);
_FOSC(FCKSM_CSECMD & POSCMD_XT & OSCIOFNC_OFF & IOL1WAY_OFF);
_FWDT(FWDTEN_OFF);
_FPOR(FPWRT_PWR128 & BOREN_ON & ALTI2C1_ON & ALTI2C2_ON);
_FICD(ICS_PGD1 & RSTPRI_PF & JTAGEN_OFF);

void initAdcl(void);
void Delay_us(unsigned int);
int ADCValues[4] = {0, 0, 0, 0};
int i;

int main(void)
{
    // Configure the device PLL to obtain 40 MIPS operation. The crystal frequency is 8 MHz.
    // Divide 8 MHz by 2, multiply by 40 and divide by 2. This results in Fosc of 80 MHz.
    // The CPU clock frequency is Fcy = Fosc/2 = 40 MHz.
    PLLFBD = 38;                /* M = 40 */
    CLKDIVbits.PLLPOST = 0;     /* N1 = 2 */
    CLKDIVbits.PLLPRE = 0;     /* N2 = 2 */
    OSCTUN = 0;

    /* Initiate Clock Switch to Primary Oscillator with PLL (NOSC = 0x3) */
    __builtin_write_OSCCONH(0x03);
    __builtin_write_OSCCONL(0x01);
    while (OSCCONbits.COSC != 0x3);
    while (_LOCK == 0);        /* Wait for PLL lock at 40 MIPS */

    initAdcl();

    while(1)
    {
        Delay_us(100);        /* Sample for 100 us
        AD1CON1bits.SAMP = 0;    /* Start the conversions
        while (!_AD1IF);        /* Wait for all 4 conversions to complete
        _AD1IF = 0;            /* Clear conversion done status bit
        ADCValues[0] = ADC1BUF0; /* Read the AN5 conversion result
        ADCValues[1] = ADC1BUF1; /* Read the AN0 conversion result
        ADCValues[2] = ADC1BUF2; /* Read the AN1 conversion result
        ADCValues[3] = ADC1BUF3; /* Read the AN2 conversion result
    }
}

void initAdcl(void)
{
    /* Set port configuration */
    ANSELA = ANSELB = ANSELC = ANSELD = ANSELE = ANSELG = 0x0000;
    ANSELBbits.ANSB0 = 1;      /* Ensure AN0/RB0 is analog
    ANSELBbits.ANSB1 = 1;      /* Ensure AN1/RB1 is analog
    ANSELBbits.ANSB2 = 1;      /* Ensure AN2/RB2 is analog
    ANSELBbits.ANSB5 = 1;      /* Ensure AN5/RB5 is analog

    /* Initialize and enable ADC module */
    AD1CON1 = 0x000C;          /* Enable simultaneous sampling and auto-sample
    AD1CON2 = 0x0300;          /* Sample 4 channels
    AD1CON3 = 0x000F;
    AD1CON4 = 0x0000;
    AD1CSSH = 0x0000;
    AD1CSSL = 0x0000;
    AD1CHS0bits.CH0SA = 5;     /* Select AN5 for CH0 +ve input
    AD1CHS0bits.CH0NA = 0;     /* Select Vref- for CH0 -ve input
    AD1CHS123bits.CH123SA = 0; /* Select AN0 for CH1 +ve input
    AD1CHS123bits.CH123NA = 0; /* Select AN1 for CH2 +ve input
    AD1CHS123bits.CH123NA = 0; /* Select AN2 for CH3 +ve input
    AD1CHS123bits.CH123NA = 0; /* Select Vref- for CH1/CH2/CH3 -ve inputs
    AD1CON1bits.ADON = 1;
    Delay_us(20);
}

void Delay_us(unsigned int delay)
{
    for (i = 0; i < delay; i++)
    {
        __asm__ volatile ("repeat #39");
        __asm__ volatile ("nop");
    }
}
```

16.6.2 Alternate Input Selection Mode

In an Alternate Input Selection mode, the MUXA and MUXB control bits select the channel for conversion. Table 16-10 lists the analog inputs and control bits for selecting the channel. The ADC completes one sweep using the MUXA selection, and then another sweep using the MUXB selection, and then another sweep using the MUXA selection, and so on. The Alternate Input Selection mode is enabled by setting the Alternate Sample bit (ALTS) in the ADC Control Register 2 (ADxCON2<0>).

The analog input multiplexer is controlled by the AD1CHS123 and AD1CHS0 registers. There are two sets of control bits designated as MUXA (CHySA/CHyNA) and MUXB (CHySB/CHyNB) to select a particular input source for conversion. The MUXB control bits are used in Alternate Input Selection mode.

Table 16-10: Analog Input Selection

		MUXA		MUXB	
		Control Bits	Analog Inputs	Control Bits	Analog Inputs
CH0	+ve	CH0SA<5:0>	AN0 to AN48	CH0SB<5:0>	AN0 to AN48
	-ve	CH0NA	VREF-, AN1	CH0NB	AN0 to AN12
CH1	+ve	CH123SA	AN0, AN3	CH123SB	AN0, AN3
	-ve	CH123NA<1:0>	AN6, AN9, VREF-	CH123NB<1:0>	AN6, AN9, VREF-
CH2	+ve	CH123SA	AN1, AN4, AN0, AN25	CH123SB	AN1, AN4, AN0, AN25
	-ve	CH123NA<1:0>	AN7, AN10, VREF-	CH123NB<1:0>	AN7, AN10, VREF-
CH3	+ve	CH123SA	AN2, AN5, AN6, AN25	CH123SB	AN2, AN5, AN6, AN25
	-ve	CH123NA<1:0>	AN8, AN11, VREF-	CH123NB<1:0>	AN8, AN11, VREF-

Note: Availability and configuration of inputs varies by device. Refer to the “Analog-to-Digital Converter (ADC)” chapter in the specific device data sheet for availability.

For Alternate Input Selection mode in devices without DMA or with the ADC DMA Enable bit (ADDMAEN) clear, an ADC interrupt must be generated after an even number of sample/conversion sequences by programming the Samples Convert Sequences Per Interrupt bits (SMPI<4:0>). Table 16-11 lists the valid SMPIx values for Alternate Input Selection mode in different ADC configurations.

Table 16-11: Valid SMPIx Values for Alternate Input Selection Mode

CHPS<1:0>	SIMSAM	SMPI<4:0> (Decimal)	Conversions/ Interrupt	Description
00	x	1,3,5,7,9,11,13,15	2,4,6,8,10,12,14,16	1-Channel mode
01	0	3,7,11,15	4,8,12,16	2-Channel Sequential Sampling mode
1x	0	7,15	8,16	4-Channel Sequential Sampling mode
01	1	1,3,5,7	4,8,12,16	2-Channel Simultaneous Sampling mode
1x	1	1,3	8,16	4-Channel Simultaneous Sampling mode

Example 16-4 shows the code sequence to set up the ADC module for Alternate Input Selection mode for devices without DMA in the 4-Channel Simultaneous Sampling configuration. Figure 16-15 illustrates the ADC module operation sequence.

Note: On ADC interrupt, the ADC internal logic is initialized to restart the conversion sequence from the beginning.

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Example 16-4: ADC Code Sequence Setup for Alternate Input Selection Mode for 4-Channel Simultaneous Sampling (Devices without DMA or with the ADC DMA Enable Bit (ADDMAEN) Clear)

```
#include <p33Exxxx.h>

/** CONFIGURATION *****/
_FOSCSEL(FNOSC_FRC);
_FOSC(FCKSM_CSECMD & POSCMD_XT & OSCIOFNC_OFF & IOL1WAY_OFF);
_FWDT(FWDTEN_OFF);
_FPOR(FPWRT_PWR128 & BOREN_ON & ALTI2C1_ON & ALTI2C2_ON);
_FICD(ICS_PGD1 & RSTPRI_PF & JTAGEN_OFF);

void initAdcl(void);
void Delay_us(unsigned int);
int ADCValues[8] = {0, 0, 0, 0, 0, 0, 0, 0};
int i;

int main(void)
{
    // Configure the device PLL to obtain 40 MIPS operation. The crystal frequency is 8 MHz.
    // Divide 8MHz by 2, multiply by 40 and divide by 2. This results in Fosc of 80 MHz.
    // The CPU clock frequency is Fcy = Fosc/2 = 40 MHz.
    PLLFBD = 38;          /* M = 40 */
    CLKDIVbits.PLLPOST = 0; /* N1 = 2 */
    CLKDIVbits.PLLPRE = 0; /* N2 = 2 */
    OSCTUN = 0;

    /* Initiate Clock Switch to Primary Oscillator with PLL (NOSC = 0x3) */
    __builtin_write_OSCCONH(0x03);
    __builtin_write_OSCCONL(0x01);
    while (OSCCONbits.COSC != 0x3);
    while (_LOCK == 0); /* Wait for PLL lock at 40 MIPS */

    initAdcl();

    while(1)
    {
        while (!_AD1IF); /* Wait for all 8 conversions to complete */
        _AD1IF = 0;      /* Clear conversion done status bit */
        ADCValues[0] = ADC1BUF0; /* Read the AN8 conversion result */
        ADCValues[1] = ADC1BUF1; /* Read the AN0 conversion result */
        ADCValues[2] = ADC1BUF2; /* Read the AN1 conversion result */
        ADCValues[3] = ADC1BUF3; /* Read the AN2 conversion result */
        ADCValues[4] = ADC1BUF4; /* Read the AN9 conversion result */
        ADCValues[5] = ADC1BUF5; /* Read the AN3 conversion result */
        ADCValues[6] = ADC1BUF6; /* Read the AN4 conversion result */
        ADCValues[7] = ADC1BUF7; /* Read the AN5 conversion result */
    }
}

void initAdcl(void)
{
    /* Set port configuration */
    ANSELA = ANSELC = ANSELD = ANSELE = ANSELG = 0x0000;
    ANSELB = 0x033F; /* Ensure AN0 - AN5, AN8 and AN9 are analog */

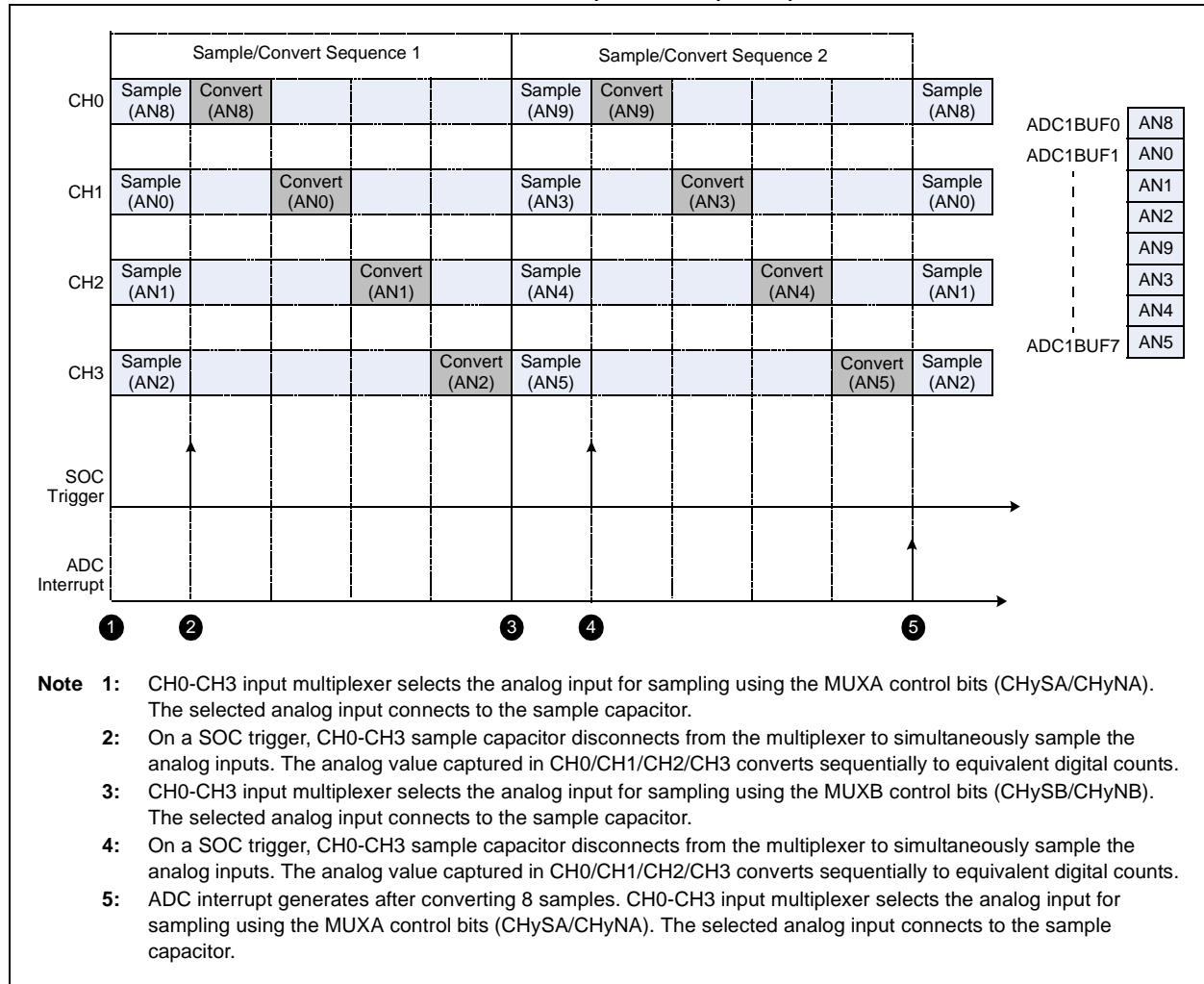
    /* Initialize ADC module */
    AD1CON1 = 0x00EC; /* Enable simultaneous sampling, auto-sample and auto-conversion */
    AD1CON2 = 0x0305; /* Sample 4 channels at a time, with alternate sampling enabled */
    AD1CON3 = 0x0F0F; /* Sample for 15*Tad before triggering conversion */
    AD1CON4 = 0x0000;
    AD1CSSH = 0x0000;
    AD1CSSL = 0x0000;

    /* Assign MUXA inputs */
    AD1CHS0bits.CH0SA = 8; /* Select AN8 for CH0 +ve input */
    AD1CHS0bits.CH0NA = 0; /* Select VREF- for CH0 -ve input */
    AD1CHS123bits.CH123SA = 0; /* Select AN0 for CH1 +ve input */
    AD1CHS123bits.CH123NA = 0; /* Select AN1 for CH2 +ve input */
    AD1CHS123bits.CH123NA = 0; /* Select AN2 for CH3 +ve input */
    AD1CHS123bits.CH123NA = 0; /* Select VREF- for CH1/CH2/CH3 -ve inputs */

    /* Assign MUXB inputs */
    AD1CHS0bits.CH0SB = 9; /* Select AN9 for CH0 +ve input */
    AD1CHS0bits.CH0NB = 0; /* Select VREF- for CH0 -ve input */
    AD1CHS123bits.CH123SB = 1; /* Select AN3 for CH1 +ve input */
    AD1CHS123bits.CH123NB = 0; /* Select AN4 for CH2 +ve input */
    AD1CHS123bits.CH123NB = 0; /* Select AN5 for CH3 +ve input */
    AD1CHS123bits.CH123NB = 0; /* Select VREF- for CH1/CH2/CH3 -ve inputs */
    /* Enable ADC module and provide ADC stabilization delay */
    AD1CON1bits.ADON = 1;
    Delay_us(20);
}

void Delay_us(unsigned int delay)
{
    for (i = 0; i < delay; i++)
    {
        __asm__ volatile ("repeat #39");
        __asm__ volatile ("nop");
    }
}
```


Figure 16-15: Alternate Input Selection in 4-Channel Simultaneous Sampling Configuration (Devices without DMA or with the ADC DMA Enable Bit (ADDMAEN) Clear)



Example 16-5 shows the code sequence to set up the ADC module for Alternate Input Selection mode in a 2-channel sequential sampling configuration for devices without DMA. Figure 16-16 shows the ADC operation sequence.

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Example 16-5: ADC Code Sequence Setup for Alternate Input Selection for 2-Channel Sequential Sampling (Devices without DMA or with the ADC DMA Enable Bit (ADDMAEN) Clear)

```
#include <p33Exxxx.h>

/** CONFIGURATION *****/
_FOSCSEL(FNOSC_FRC);
_FOSC(FCKSM_CSECMD & POSCMD_XT & OSCIOFNC_OFF & IOL1WAY_OFF);
_FWDT(FWDTEN_OFF);
_FPOR(FPWRT_PWR128 & BOREN_ON & ALTI2C1_ON & ALTI2C2_ON);
_FICD(ICS_PGD1 & RSTPRI_PF & JTAGEN_OFF);

void initAdcl(void);
void Delay_us(unsigned int);
int ADCValues[4] = {0, 0, 0, 0};
int i;

int main(void)
{
    // Configure the device PLL to obtain 40 MIPS operation. The crystal
    // frequency is 8MHz. Divide 8MHz by 2, multiply by 40 and divide by
    // 2. This results in Fosc of 80MHz. The CPU clock frequency is
    // Fcy = Fosc/2 = 40MHz.
    PLLFBD = 38;          /* M = 40 */
    CLKDIVbits.PLLPOST = 0; /* N1 = 2 */
    CLKDIVbits.PLLPRE = 0; /* N2 = 2 */
    OSCTUN = 0;

    /* Initiate Clock Switch to Primary
    * Oscillator with PLL (NOSC= 0x3)*/
    __builtin_write_OSCCONH(0x03);
    __builtin_write_OSCCONL(0x01);
    while (OSCCONbits.COSC != 0x3);
    while (_LOCK == 0); /* Wait for PLL lock at 40 MIPS */

    initAdcl();

    while(1)
    {
        while (!AD1IF); /* Wait for all 4 conversions to complete */
        AD1IF = 0; /* Clear conversion done status bit */
        ADCValues[0] = ADC1BUF0; /* Read the AN8 conversion result */
        ADCValues[1] = ADC1BUF1; /* Read the AN0 conversion result */
        ADCValues[2] = ADC1BUF2; /* Read the AN9 conversion result */
        ADCValues[3] = ADC1BUF3; /* Read the AN3 conversion result */
    }
}

void initAdcl(void)
{
    /* Set port configuration */
    ANSELA = ANSELC = ANSELD = ANSELE = ANSELG = 0x0000;
    ANSELB = 0x0309; /* Ensure AN0, AN3, AN8 and AN9 are analog */

    /* Initialize ADC module */
    AD1CON1 = 0x00E4; /* Enable sequential sampling, auto-sample and auto-conversion */
    AD1CON2 = 0x010D; /* Sample 2 channels, with alternate sampling enabled */
    AD1CON3 = 0x0F0F; /* Sample for 15*Tad before triggering conversion */
    AD1CON4 = 0x0000;
    AD1CSSH = 0x0000;
    AD1CSSL = 0x0000;

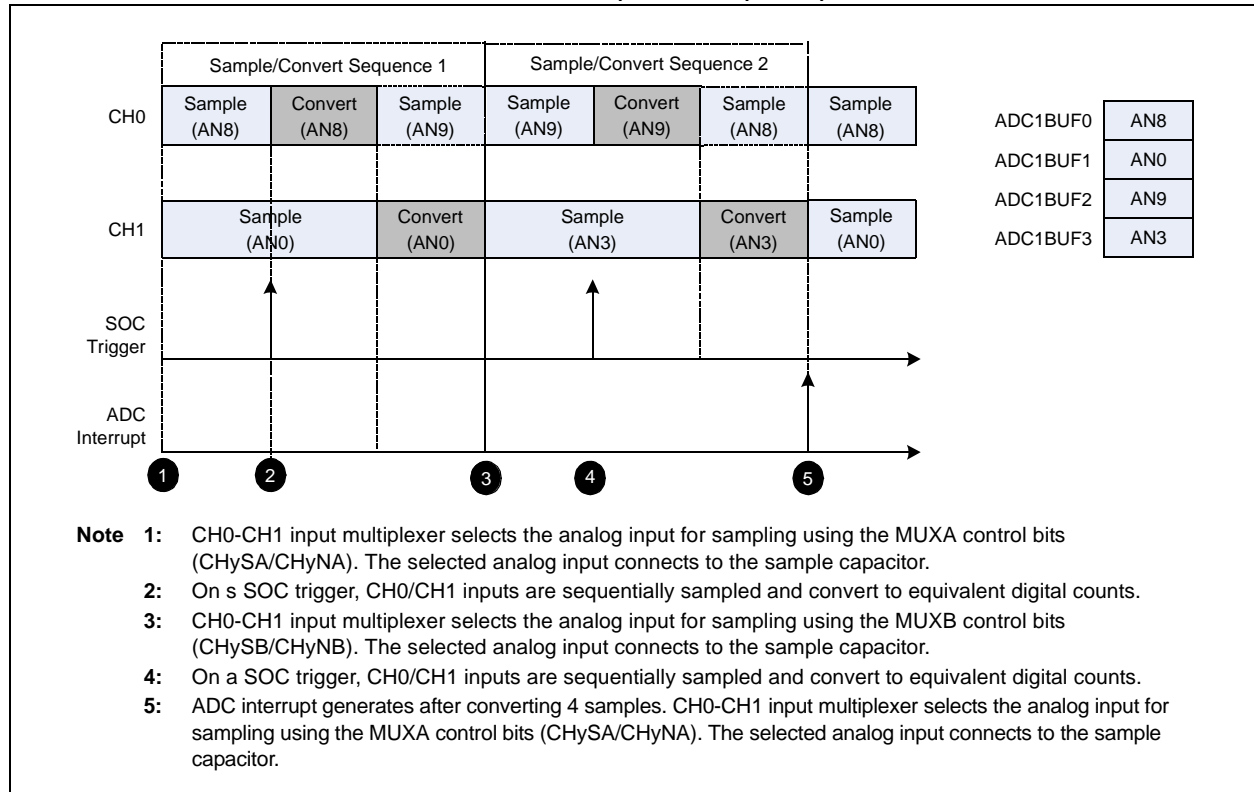
    /* Assign MUXA inputs */
    AD1CHS0bits.CH0SA = 8; /* Select AN8 for CH0 +ve input */
    AD1CHS0bits.CH0NA = 0; /* Select Vref- for CH0 -ve input */
    AD1CHS123bits.CH123SA = 0; /* Select AN0 for CH1 +ve input */
    AD1CHS123bits.CH123NA = 0; /* Select Vref- for CH1/CH2/CH3 -ve inputs */

    /* Assign MUXB inputs */
    AD1CHS0bits.CH0SB = 9; /* Select AN9 for CH0 +ve input */
    AD1CHS0bits.CH0NB = 0; /* Select Vref- for CH0 -ve input */
    AD1CHS123bits.CH123SB = 1; /* Select AN3 for CH1 +ve input */
    AD1CHS123bits.CH123NB = 0; /* Select Vref- for CH1/CH2/CH3 -ve inputs */

    /* Enable ADC module and provide ADC stabilization delay */
    AD1CON1bits.ADON = 1;
    Delay_us(20);
}

void Delay_us(unsigned int delay)
{
    for (i = 0; i < delay; i++)
    {
        __asm__ volatile ("repeat #39");
        __asm__ volatile ("nop");
    }
}
```

Figure 16-16: Alternate Input Selection in 2-Channel Sequential Sampling Configuration (Devices without DMA or with the ADC DMA Enable Bit (ADDMAEN) Clear)



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For devices with DMA and with the ADC DMA Enable bit (ADDMAEN) set, when Alternate Input Selection mode is enabled, set SMPI<4:0> = 00001 to allow two samples per DMA address point increment.

Figure 16-17: Alternate Input Selection in 4-Channel Simultaneous Sampling Configuration (Devices with DMA and with the ADC DMA Enable Bit (ADDMAEN) Set)

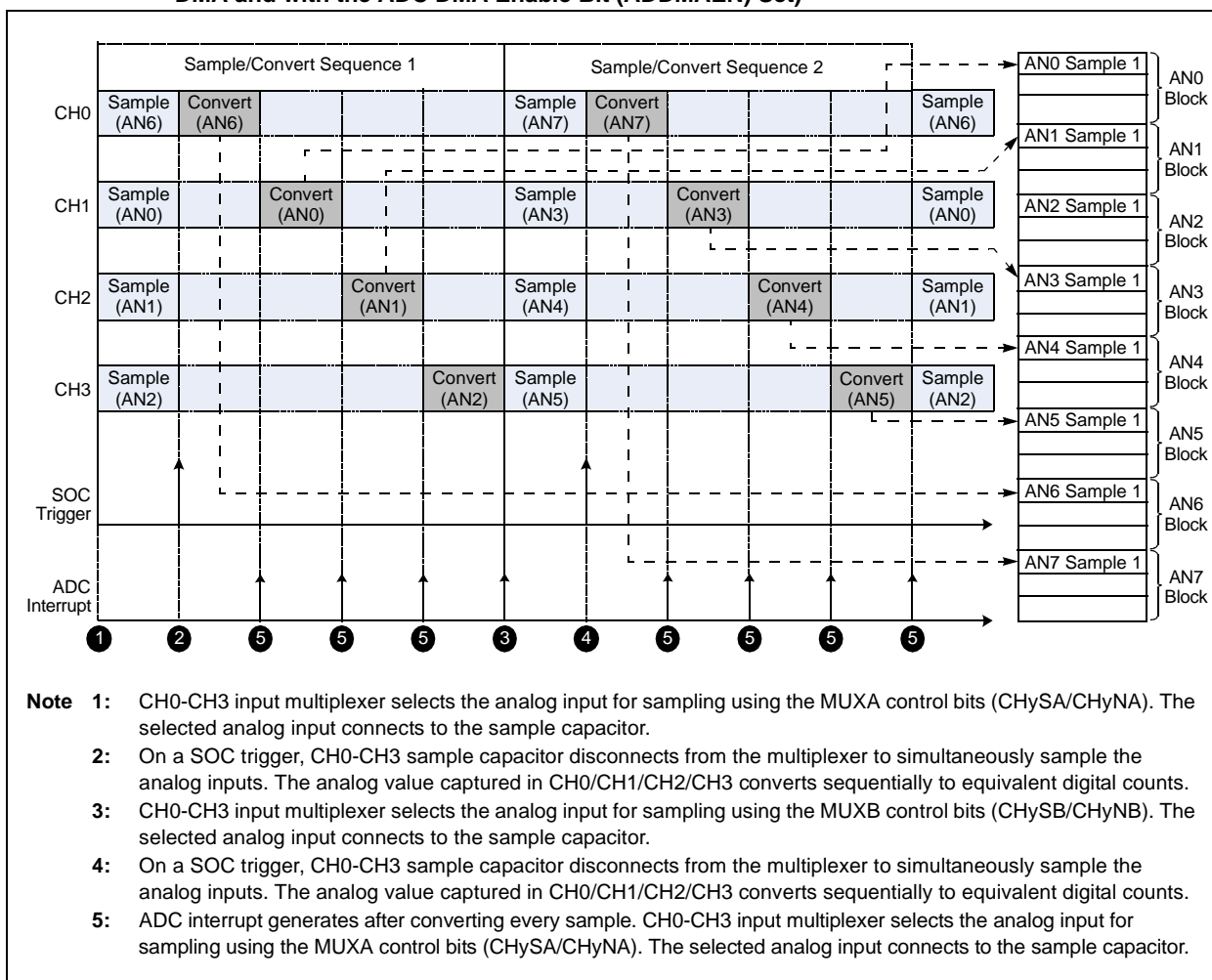
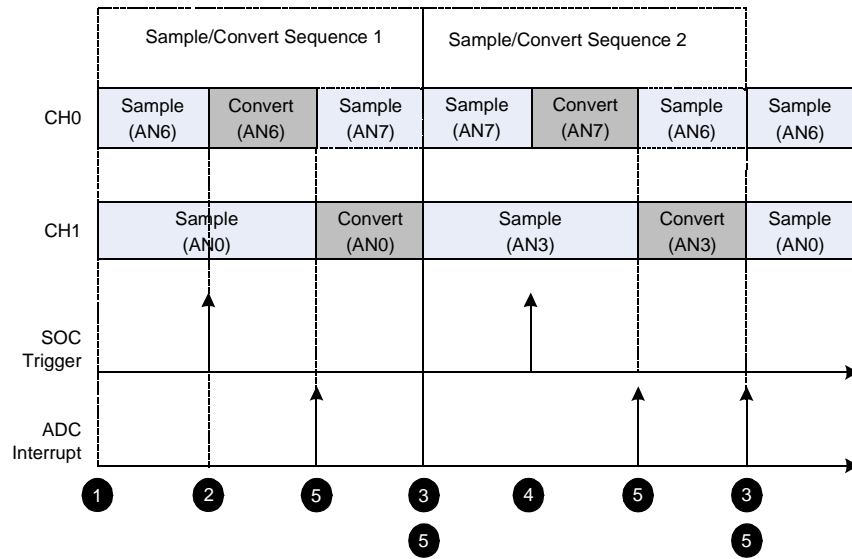


Figure 16-18: Alternate Input Selection in 2-Channel Sequential Sampling Configuration (Devices with DMA and with the ADC DMA Enable Bit (ADDMAEN) Set)



- Note 1:** CH0-CH1 input multiplexer selects the analog input for sampling using the MUXA control bits (CHySA/CHyNA). The selected analog input connects to the sample capacitor.
- 2:** On a SOC trigger, CH0/CH1 inputs are sequentially sampled and convert to equivalent digital counts.
- 3:** CH0-CH1 input multiplexer selects the analog input for sampling using the MUXB control bits (CHySB/CHyNB). The selected analog input connects to the sample capacitor.
- 4:** On a SOC trigger, CH0/CH1 inputs are sequentially sampled and convert to equivalent digital counts.
- 5:** ADC interrupt generates after every conversion.

16.6.3 Channel Scanning

The ADC module supports the Channel Scanning mode using CH0 (S&H Channel 0). The number of inputs scanned is software-selectable. Any subset of the analog inputs, from AN0 to AN31 (depending on the number of analog inputs present on a specific device), can be selected for conversion. The selected inputs are converted in ascending order. For example, if the input selection includes AN4, AN1 and AN3, the conversion sequence is AN1, AN3 and AN4. The conversion sequence selection is made by programming the ADCx Channel Select register (ADxCSSL). A logic '1' in the ADCx Channel Select register marks the associated analog input channel for inclusion in the conversion sequence. The Channel Scanning mode is enabled by setting the Channel Scan bit (CSCNA) in ADCx Control Register 2 (ADxCON2<10>). In Channel Scanning mode, MUXA software control is ignored and the ADC module sequences through the enabled channels.

In devices without DMA or with the ADC DMA Enable bit (ADDMAEN) clear, for every sample/convert sequence, one analog input is scanned. The ADC interrupt must be generated after all selected channels are scanned. If "N" inputs are enabled for channel scan, an interrupt must be generated after the "N" sample/convert sequence. [Table 16-12](#) lists the SMP1x values to scan "N" analog inputs using CH0 in different ADC configurations.

Note: A maximum of 32 ADC inputs (any) can be configured to be scanned at a time.

Table 16-12: Conversions Per Interrupt in Channel Scanning Mode (Devices without DMA or with the ADC DMA Enable Bit (ADDMAEN) Clear)

CHPS<1:0>	SIMSAM	SMP1<4:0> (Decimal)	Conversions/ Interrupt	Description
00	x	N – 1	N	1-Channel mode
01	0	2N – 1	2N	2-Channel Sequential Sampling mode
1x	0	4N – 1	4N	4-Channel Sequential Sampling mode
01	1	N – 1	2N	2-Channel Simultaneous Sampling mode
1x	1	N – 1	4N	4-Channel Simultaneous Sampling mode

[Example 16-6](#) shows the code sequence to scan four analog inputs using CH0 in devices without DMA or with the ADC DMA Enable bit (ADDMAEN) clear. [Figure 16-19](#) shows the ADC operation sequence.

Note: On ADC interrupt, the ADC internal logic is initialized to restart the conversion sequence from the beginning.

Example 16-6: Code Sequence to Scan Four Analog Inputs Using CH0 (Devices without DMA or with the ADC DMA Enable Bit (ADDMAEN) Clear)

```
#include <p33Exxxx.h>

/** CONFIGURATION *****/
_FOSCSEL(FNOSC_FRC);
_FOSC(FCKSM_CSECMD & POSCMD_XT & OSCIOFNC_OFF & IOL1WAY_OFF);
_FWDT(FWDTEN_OFF);
_FPOR(FPWRT_PWR128 & BOREN_ON & ALTI2C1_ON & ALTI2C2_ON);
_FICD(ICS_PGD1 & RSTPRI_PF & JTAGEN_OFF);

void initAdcl(void);
void Delay_us(unsigned int);
int ADCValues[4] = {0, 0, 0, 0};
int i;

int main(void)
{
    // Configure the device PLL to obtain 40 MIPS operation. The crystal frequency is 8 MHz.
    // Divide 8 MHz by 2, multiply by 40 and divide by 2. This results in Fosc of 80 MHz.
    // The CPU clock frequency is Fcy = Fosc/2 = 40 MHz.
    PLLFBD = 38;          /* M = 40 */
    CLKDIVbits.PLLPOST = 0; /* N1 = 2 */
    CLKDIVbits.PLLPRE = 0; /* N2 = 2 */
    OSCTUN = 0;

    /* Initiate Clock Switch to Primary Oscillator with PLL (NOSC = 0x3) */
    __builtin_write_OSCCONH(0x03);
    __builtin_write_OSCCONL(0x01);
    while (OSCCONbits.COSC != 0x3);
    while (_LOCK == 0); /* Wait for PLL lock at 40 MIPS */

    initAdcl();

    while(1)
    {
        while (!_AD1IF); /* Wait for all 4 conversions to complete */
        _AD1IF = 0;      /* Clear conversion done status bit */
        ADCValues[0] = ADC1BUF0; /* Read the AN2 conversion result */
        ADCValues[1] = ADC1BUF1; /* Read the AN3 conversion result */
        ADCValues[2] = ADC1BUF2; /* Read the AN5 conversion result */
        ADCValues[3] = ADC1BUF3; /* Read the AN8 conversion result */
    }
}

void initAdcl(void)
{
    /* Set port configuration */
    ANSELA = ANSELC = ANSELD = ANSELE = ANSELG = 0x0000;
    ANSELB = 0x012C; /* Ensure AN2, AN3, AN5 and AN8 are analog */

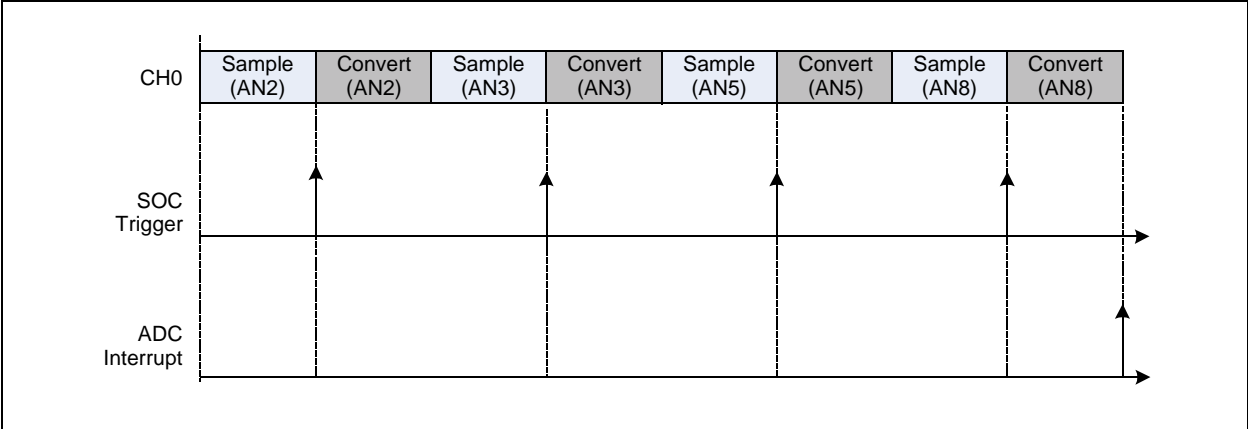
    /* Initialize ADC module */
    AD1CON1 = 0x04E4; /* Enable 12-bit mode, auto-sample and auto-conversion */
    AD1CON2 = 0x040C; /* Sample 4 channels alternately using channel scanning */
    AD1CON3 = 0x0F0F; /* Sample for 15*TAD before converting */
    AD1CON4 = 0x0000;
    AD1CSSH = 0x0000;
    AD1CSSL = 0x012C; /* Select AN2, AN3, AN5 and AN8 for scanning */

    /* Assign MUXA inputs */
    AD1CHS0bits.CH0SA = 0; /* CH0SA bits ignored for CH0 +ve input selection */
    AD1CHS0bits.CH0NA = 0; /* Select VREF- for CH0 -ve input */

    /* Enable ADC module and provide ADC stabilization delay */
    AD1CON1bits.ADON = 1;
    Delay_us(20);
}

void Delay_us(unsigned int delay)
{
    for (i = 0; i < delay; i++)
    {
        __asm__ volatile ("repeat #39");
        __asm__ volatile ("nop");
    }
}
```

Figure 16-19: Scan Four Analog Inputs Using CH0 (Devices without DMA or with the ADC DMA Enable Bit (ADDMAEN) Clear)



Example 16-7 shows the code sequence to scan two analog inputs using CH0 in a 2-channel alternate input selection configuration for devices without DMA. Figure 16-20 shows the ADC operation sequence.

Example 16-7: Code Sequence for Channel Scan with Alternate Input Selection (Devices without DMA or with the ADC DMA Enable Bit (ADDMAEN) Clear)

```
#include <p33Exxxx.h>

/** CONFIGURATION *****/
_FOSCSEL(FNOSC_FRC);
_FOSC(FCKSM_CSECMD & POSCMD_XT & OSCIOFNC_OFF & IOL1WAY_OFF);
_FWDT(FWDTEN_OFF);
_FPOR(FPWRT_PWR128 & BOREN_ON & ALTI2C1_ON & ALTI2C2_ON);
_FICD(ICS_PGD1 & RSTPRI_PF & JTAGEN_OFF);

void initAdcl(void);
void Delay_us(unsigned int);
int ADCValues[8] = {0, 0, 0, 0, 0, 0, 0, 0};
int i;

int main(void)
{
    // Configure the device PLL to obtain 40 MIPS operation. The crystal frequency is 8 MHz.
    // Divide 8 MHz by 2, multiply by 40 and divide by 2. This results in Fosc of 80 MHz.
    // The CPU clock frequency is Fcy = Fosc/2 = 40 MHz.
    PLLFBD = 38; // M = 40 */
    CLKDIVbits.PLLPOST = 0; // N1 = 2 */
    CLKDIVbits.PLLPRE = 0; // N2 = 2 */
    OSCTUN = 0;

    /*Initiate Clock Switch to Primary Oscillator with PLL (NOSC = 0x3) */
    __builtin_write_OSCCONH(0x03);
    __builtin_write_OSCCONL(0x01);
    while (OSCCONbits.COSC != 0x3);
    while (_LOCK == 0); // Wait for PLL lock at 40 MIPS */

    initAdcl();

    while(1)
    {
        while (!_AD1IF); // Wait for all 8 conversions to complete
        _AD1IF = 0; // Clear conversion done status bit
        ADCValues[0] = ADC1BUF0; // Read the AN2 conversion result
        ADCValues[1] = ADC1BUF1; // Read the first AN0 conversion result
        ADCValues[2] = ADC1BUF2; // Read the first AN8 conversion result
        ADCValues[3] = ADC1BUF3; // Read the first AN3 conversion result
        ADCValues[4] = ADC1BUF4; // Read the AN4 conversion result
        ADCValues[5] = ADC1BUF5; // Read the second AN0 conversion result
        ADCValues[6] = ADC1BUF6; // Read the second AN8 conversion result
        ADCValues[7] = ADC1BUF7; // Read the second AN3 conversion result
    }
}

void initAdcl(void)
{
    /* Set port configuration */
    ANSELA = ANSELC = ANSELD = ANSELE = ANSELG = 0x0000;
    ANSELB = 0x011D; // Ensure AN0, AN2, AN3, AN4 and AN8 are analog

    /* Initialize ADC module */
    AD1CON1 = 0x00E4; // Enable auto-sample and auto-conversion
    AD1CON2 = 0x051D; // Select 2-channel mode, enable both scanning and alternate sampling
    AD1CON3 = 0x0F0F; // Sample for 15 * Tad before converting
    AD1CON4 = 0x0000;
    AD1CSSH = 0x0000;
    AD1CSSL = 0x0014; // Select AN2 and AN4 for scanning

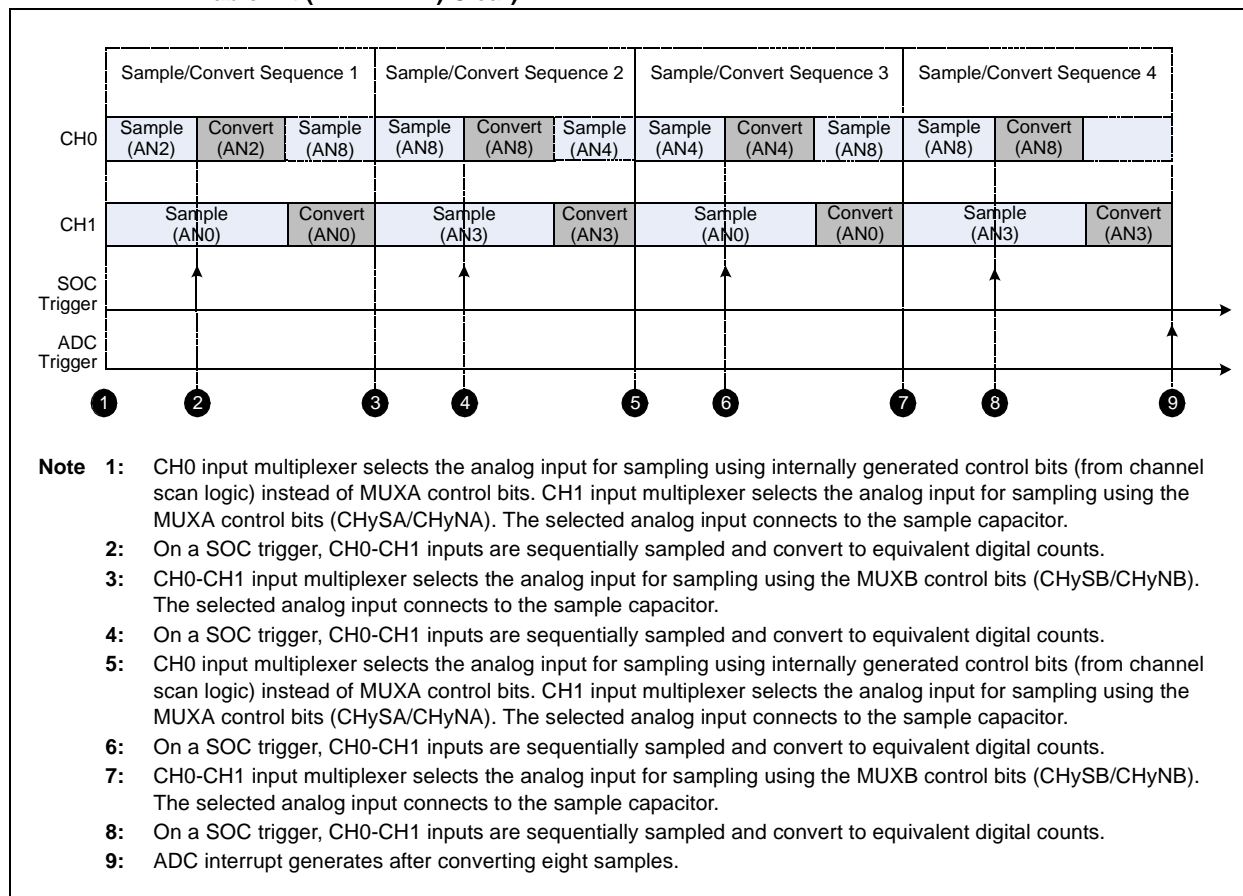
    /* Assign MUXA inputs */
    AD1CHS0bits.CH0SA = 0; // CH0SA bits ignored for CH0 +ve input selection
    AD1CHS0bits.CH0NA = 0; // Select VREF- for CH0 -ve input
    AD1CHS123bits.CH123SA = 0; // Select AN0 for CH1 +ve input
    AD1CHS123bits.CH123NA = 0; // Select VREF- for CH1 -ve input

    /* Assign MUXB inputs */
    AD1CHS0bits.CH0SB = 8; // Select AN8 for CH0 +ve input
    AD1CHS0bits.CH0NB = 0; // Select VREF- for CH0 -ve input
    AD1CHS123bits.CH123SB = 1; // Select AN3 for CH1 +ve input
    AD1CHS123bits.CH123NB = 0; // Select VREF- for CH1 -ve input

    /* Enable ADC module and provide ADC stabilization delay */
    AD1CON1bits.ADON = 1;
    Delay_us(20);
}

void Delay_us(unsigned int delay)
{
    for (i = 0; i < delay; i++)
    {
        __asm__ volatile ("repeat #39");
        __asm__ volatile ("nop");
    }
}
```

Figure 16-20: Channel Scan with Alternate Input Selection (Devices without DMA or with the ADC DMA Enable Bit (ADDMAEN) Clear)



For devices with DMA and with the ADDMAEN bit set, when channel scanning is used and only CH0 is active (ALTS = 0), the SMPI<4:0> bits must be set to the number of inputs being scanned minus one (i.e., SMPI<4:0> = N – 1).

Figure 16-21: Scan Four Analog Inputs Using CH0 (Devices with DMA and with the ADC DMA Enable Bit (ADDMAEN) Set)

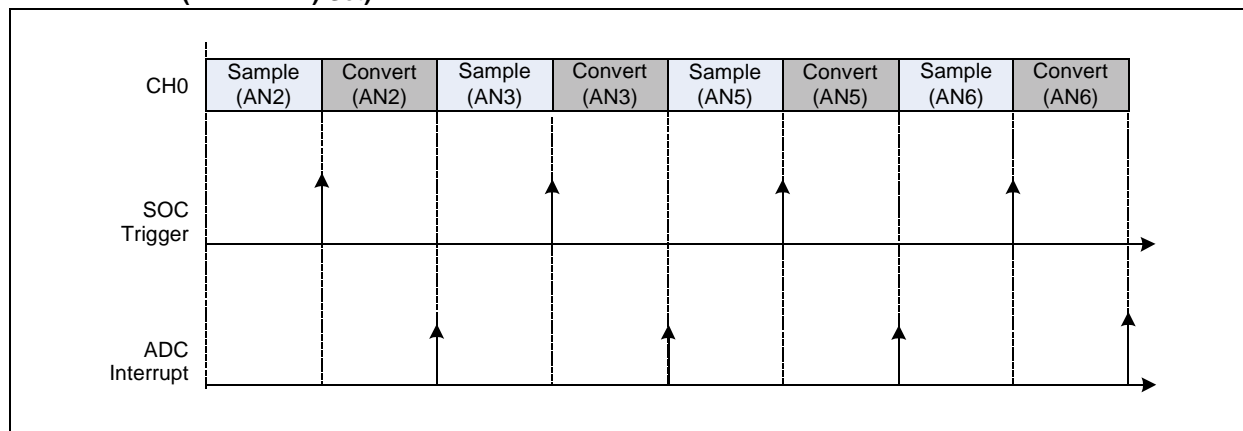
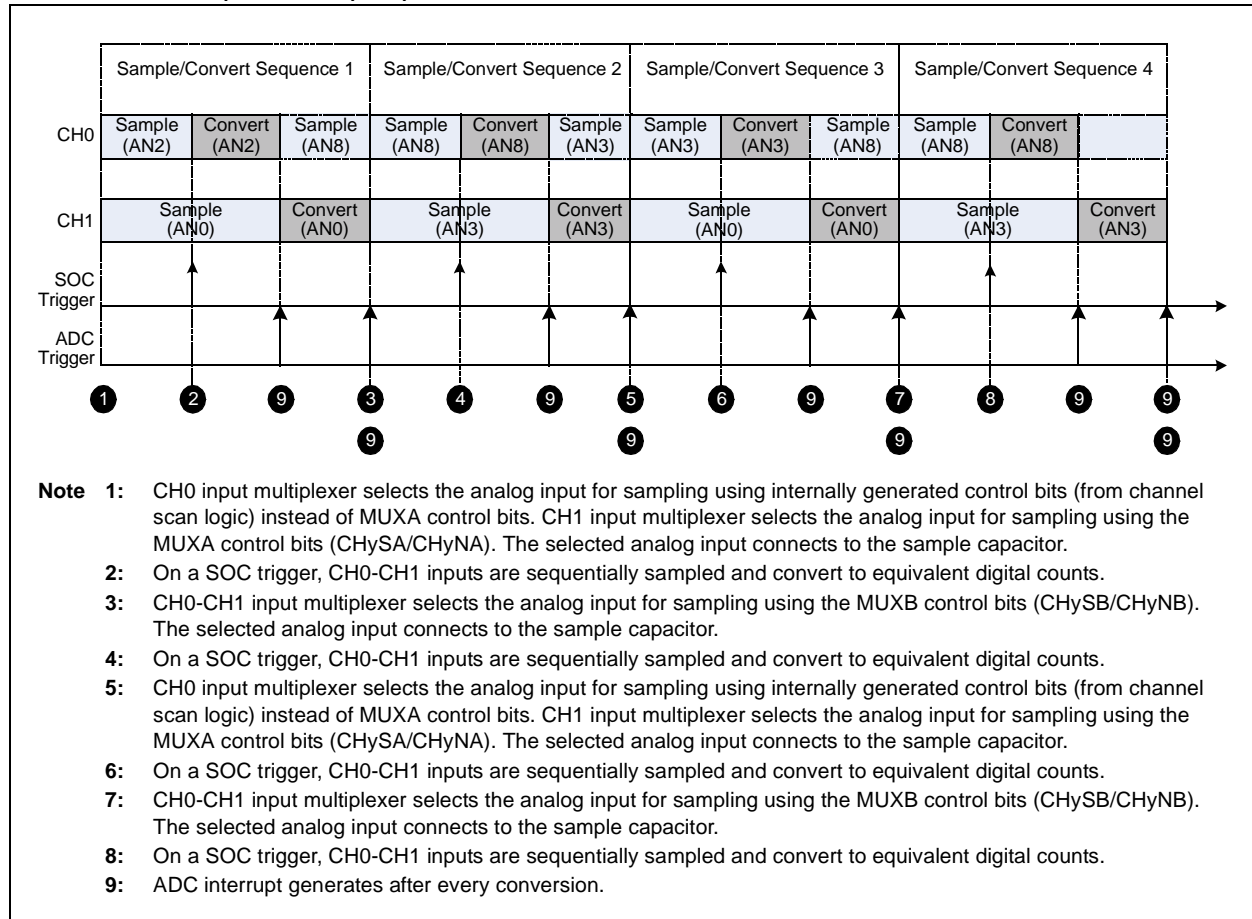


Figure 16-22: Channel Scan with Alternate Input Selection (Devices with DMA and with the ADC DMA Enable Bit (ADDMAEN) Set)



16.7 SPECIFYING CONVERSION RESULTS BUFFERING FOR DEVICES WITH DMA AND WITH ADC DMA ENABLE BIT (ADDMAEN) SET

The ADC module contains a single-word, read-only, dual port register (ADCxBUF0), which stores the Analog-to-Digital conversion result. If more than one conversion result needs to be buffered before triggering an interrupt, DMA data transfers can be used. Both ADC channels (ADC1 and ADC2) can trigger a DMA data transfer. Ensure that the ADDMAEN bit is set to use DMA with the ADC module. Depending on which ADC channel is selected as the DMA IRQ source, a DMA transfer occurs when the ADCx Interrupt Flag Status bit (AD1IF or AD2IF) in the Interrupt Flag Status Register x (IFS0 or IFS1, respectively) in the interrupt module gets set as a result of a sample conversion sequence.

The result of every Analog-to-Digital conversion is stored in the ADCxBUF0 register. If a DMA channel is not enabled for the ADC module, each result must be read by the user application before it gets overwritten by the next conversion result. However, if DMA is enabled, multiple conversion results can be automatically transferred from ADCxBUF0 to a user-defined buffer in the DMA RAM area. Thus, the application can process several conversion results with minimal software overhead.

<p>Note: For more information on how to configure a DMA channel to transfer data from the ADC buffer and define a corresponding DMA buffer area from where the data can be accessed by the application, please refer to Section 22. “Direct Memory Access (DMA)” (DS70182). For specific information on Interrupt registers, please refer to Section 6. “Interrupts” (DS70184).</p>
--

The DMA Buffer Build Mode bit (ADDMABM) in ADCx Control Register 1 (ADxCON1<12>) determines how the conversion results are filled in the DMA RAM buffer area being used for the ADC. If this bit is set (ADDMABM = 1), DMA buffers are written in the order of conversion. The ADC module provides an address to the DMA channel that is the same as the address used for the non-DMA stand-alone buffer. If the ADDMABM bit is cleared, then DMA buffers are written in Scatter/Gather mode. The ADC module provides a Scatter/Gather mode address to the DMA channel, based on the index of the analog input and the size of the DMA buffer.

When the SIMSAM bit specifies simultaneous sampling, the number of data samples in the buffer is related to the CHPS<1:0> bits. Algorithmically, the Channels per Sample (CH/S) times the number of samples results in the number of data sample entries in the buffer. To avoid loss of data in the buffer due to overruns, the DMAxCNT register must be set to the desired buffer size.

16.7.1 Using DMA in the Scatter/Gather Mode

When the ADDMABM bit is '0', the Scatter/Gather mode is enabled. In this mode, the DMA channel must be configured for Peripheral Indirect Addressing. The DMA buffer is divided into consecutive memory blocks corresponding to all available analog inputs (out of AN0-AN31). Each conversion result for a particular analog input is automatically transferred by the ADC module to the corresponding block within the user-defined DMA buffer area. Successive samples for the same analog input are stored in sequence within the block assigned to that input.

The number of samples that need to be stored in the DMA buffer for each analog input is specified by the DMABL<2:0> bits (ADxCON4<2:0>).

The buffer locations within each block are accessed by the ADC module using an internal pointer, which is initialized to '0' when the ADC module is enabled. When this internal pointer reaches the value defined by the DMABL<2:0> bits, it gets reset to '0'. This ensures that the conversion results of one analog input do not corrupt the conversion results of other analog inputs. The rate at which this internal pointer is incremented when data is written to the DMA buffer is specified by the SMPI<4:0> bits.

When no channel scanning or alternate sampling is required, SMPI<4:0> must be cleared, implying that the pointer increments on every sample per channel. Thus, it is theoretically possible to use every location in the DMA buffer for the blocks assigned to the analog inputs being sampled.

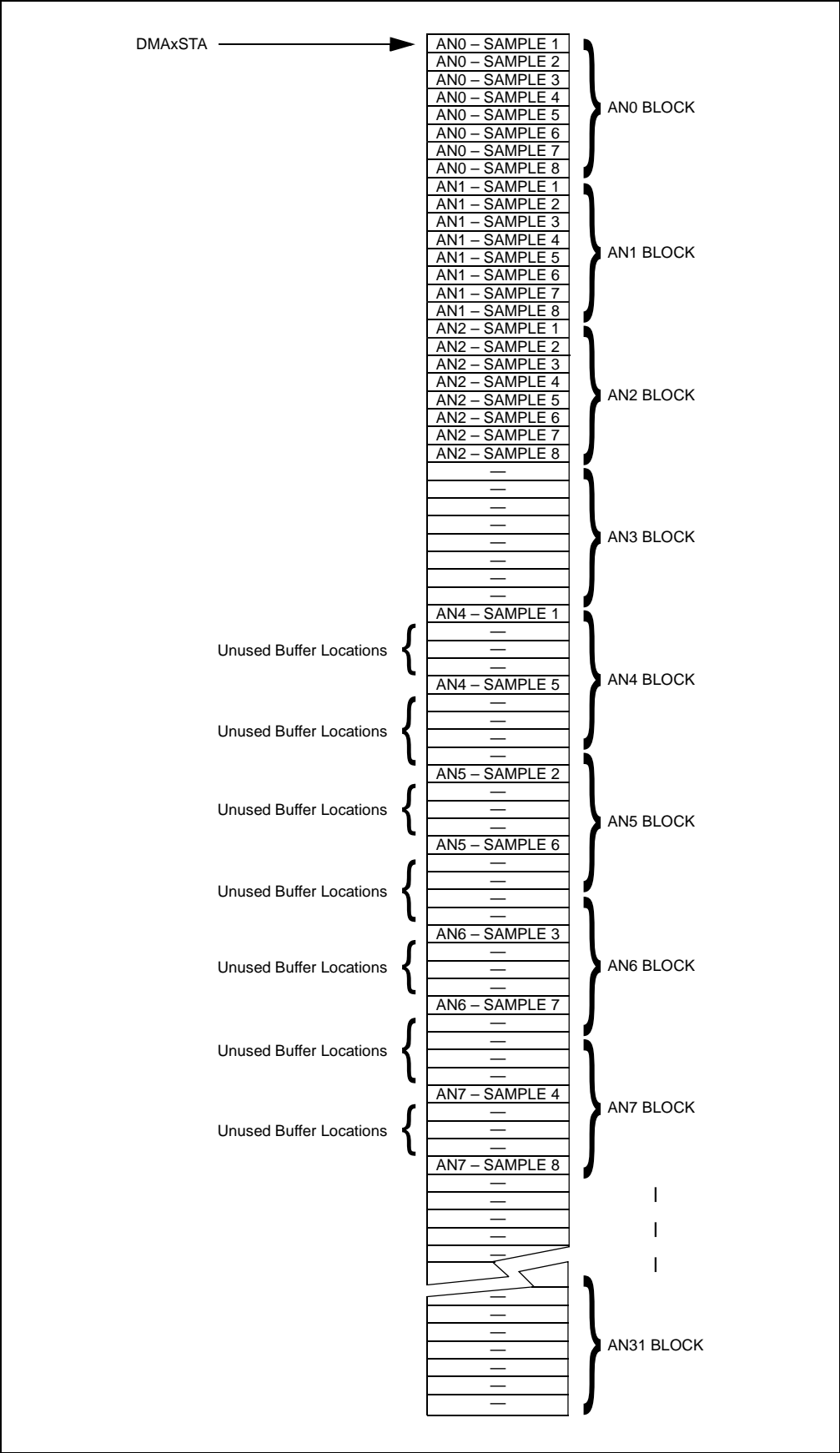
In the example illustrated in [Figure 16-23](#), it can be observed that the conversion results for the AN0, AN1 and AN2 inputs are stored in sequence, leaving no unused locations in their corresponding memory blocks. However, for the four analog inputs (AN4, AN5, AN6 and AN7), which are scanned by CH0, the first location in the AN5 block, the first two locations in the AN6 block and the first three locations in the AN7 block are unused, resulting in a relatively inefficient arrangement of data in the DMA buffer.

When scanning is used, and no simultaneous sampling is performed (SIMSAM = 0), SMPI<4:0> must be set to one less than the number of inputs being scanned. For example, if CHPS<1:0> = 00 (only one S&H channel is used), and AD1CSSL = 0xFFFF, indicating that AN0-AN15 are being scanned, then set SMPI<4:0> = 01111 so that the internal pointer is incremented only after every sixteenth sample/conversion sequence. This avoids unused locations in the blocks corresponding to the analog inputs being scanned.

Similarly, if ALTS = 1, indicating that alternating analog input selections are used, then SMPI<4:0> is set to '00001', thereby incrementing the internal pointer after every second sample.

Note: The ADC module does not perform limit checks on the generated buffer addresses. For example, you must ensure that the Least Significant bits (LSBs) of the DMAxSTA or DMAxSTB register used are indeed '0'. Also, the number of potential analog inputs multiplied by the buffer size, specified by DMABL<2:0>, must not exceed the total length of the DMA buffer.

Figure 16-23: DMA Buffer in Scatter/Gather Mode



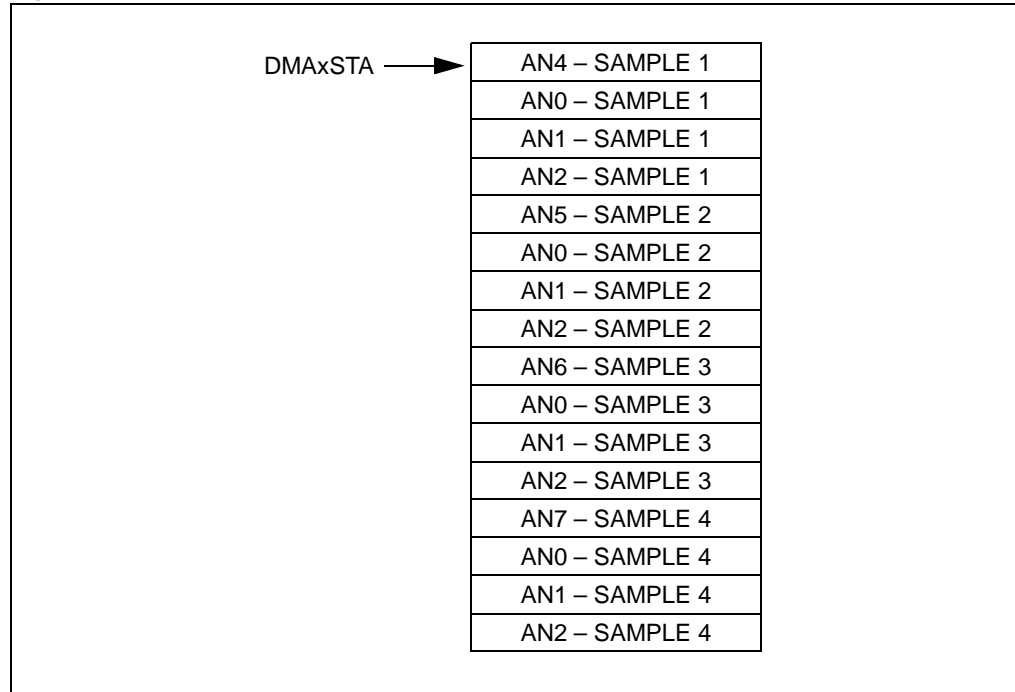
16.7.2 Using DMA in the Conversion Order Mode

When the ADDMABM bit (ADxCON1<12>) = 1, the Conversion Order mode is enabled. In this mode, the DMA channel can be configured for Register Indirect or Peripheral Indirect Addressing mode. All conversion results are stored in the user-specified DMA buffer area in the same order in which the conversions are performed by the ADC module. In this mode, the buffer is not divided into blocks allocated to different analog inputs; rather, the conversion results from different inputs are interleaved according to the specific Buffer Fill modes being used.

In this configuration, the Buffer Pointer is always incremented by one word. In this case, the SMP1<4:0> bits (ADxCON2<6:2>) must be cleared and the DMABL<2:0> bits (ADxCON4<2:0>) are ignored.

Figure 16-24 illustrates an example identical to the configuration in Figure 16-23, but using the Conversion Order mode. In this example, the DMAxCNT register has been configured to generate the DMA interrupt after 16 conversion results have been obtained.

Figure 16-24: DMA Buffer in Conversion Order Mode



16.8 ADC CONFIGURATION EXAMPLE

The following steps are used for performing an Analog-to-Digital conversion:

1. Select 10-bit or 12-bit mode (ADxCON1<10>).
2. Select the voltage reference source to match the expected range on the analog inputs (ADxCON2<15:13>).
3. Select the analog conversion clock to match the desired data rate with the processor clock (ADxCON3<7:0>).
4. Determine how inputs must be allocated to S&H channels (ADxCHS0<15:0> and ADxCHS123<15:0>).
5. Determine how many S&H channels must be used (ADxCON2<9:8>).
6. Determine how sampling must occur (ADxCON1<3>, ADxCSSH<15:0> and ADxCSSL<15:0>).
7. Select manual or auto-sampling.
8. Select the conversion trigger and sampling time.
9. Select how the data format for the conversion results must be stored in the buffer (ADxCON1<9:8>).
10. Set the ADDMAEN bit to configure the ADC module to use DMA.
11. Select the interrupt rate or DMA Buffer Pointer increment rate (ADxCON2<9:5>).
12. Select the number of samples in the DMA buffer for each ADC module input (ADxCON4<2:0>).
13. Configure the ADC interrupt (if required):
 - a) Clear the ADxIF bit
 - b) Select the interrupt priority (ADxIP<2:0>)
 - c) Set the ADxIE bit
14. Configure the DMA channel (if needed).
15. Enable the DMA channel.
16. Turn on the ADC module (ADxCON1<15>).

The options for these configuration steps are described in subsequent sections.

16.9 ADC CONFIGURATION FOR 1.1 Msps

When the device is running at an operating frequency of 40 MIPS, for example, the ADC module can be configured to sample at a 1.1 Msps throughput rate with 10-bit resolution.

The ADC module is set to 10-bit operation by setting the AD12B bit to '0' (ADxCON1<10>). The ASAM bit (ADxCON1<2>) is set to '1' to begin sampling automatically after the conversion completes. The internal counter, which ends sampling and starts conversion, is set as the sample clock source by setting SSRCG (ADxCON1<4>) = 0 and the SSRC<2:0> bits (ADxCON1<7:5>) = 111. The system clock is selected to be the ADC conversion clock by setting the ADRC bit (ADxCON3<15>) to '0'. The automatic sample time bit is set to less than 12 TAD. The ADC conversion clock is configured to 75 ns by setting the ADCS<7:0> bits (ADxCON3<7:0>) to '00000010', as calculated in Equation 16-7.

Equation 16-7: ADC Conversion Clock

$$T_{AD} = T_{CY} \cdot (ADCS<7:0> + 1) = (1/40M) \cdot 3 = 75 \text{ ns (13.3 MHz)}$$

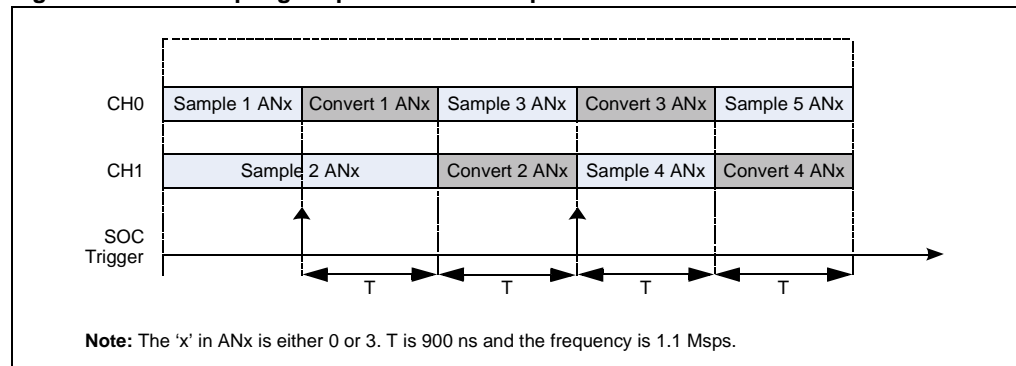
The ADC conversion time will be 12 TAD since the ADC module is configured for 10-bit operation, as calculated in Equation 16-8.

Equation 16-8: ADC Conversion Time

$$T_{CONV} = 12 \cdot T_{AD} = 900 \text{ ns (1.1 MHz)}$$

The ADC channels, CH0 and CH1 (CHPS<1:0> = 01), are set up to convert analog input, AN0 or AN3 (only one at any time), in Sequential mode (SIMSAM = 0). Figure 16-25 illustrates the sampling sequence.

Figure 16-25: Sampling Sequence for 1.1 Msps



For devices with DMA, the DMA channel can be configured in Ping-Pong mode to move the converted data from the ADC to the DMA RAM. See the ADC and DMA configuration code in Example 16-8.

For devices without DMA, the ADC configuration remains the same. The samples are transferred to ADC1BUF0-ADC1BUFF at a rate of 1.1 Msps. The data can be processed by accessing half of the buffers at a time by setting the BUFS bit.

Note: The ADC module cannot achieve maximum throughput of 1.1 Msps at the maximum operating frequency of 60 MIPS.

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Example 16-8: ADC Configuration Code for 1.1 Msps

```
#include <p33Exxxx.h>

/** CONFIGURATION *****/
_FOSCSEL(FNOSC_FRC);
_FOSC(FCKSM_CSECMD & POSCMD_XT & OSCIOFNC_OFF & IOL1WAY_OFF);
_FWDT(FWDTEN_OFF);
_FPOR(FPWRT_PWR128 & BOREN_ON & ALTI2C1_ON & ALTI2C2_ON);
_FICD(ICS_PGD1 & RSTPRI_PF & JTAGEN_OFF);

void initAdcl(void);
void initDma0(void);
void Delay_us(unsigned int);
int BufferA[8] = {0, 0, 0, 0, 0, 0, 0, 0};
int BufferB[8] = {0, 0, 0, 0, 0, 0, 0, 0};
int i;

int main(void)
{
    // Configure the device PLL to obtain 40 MIPS operation. The crystal frequency is 8 MHz.
    // Divide 8 MHz by 2, multiply by 40 and divide by 2. This results in Fosc of 80 MHz.
    // The CPU clock frequency is Fcy = Fosc/2 = 40 MHz.
    PLLFBD = 38;          /* M = 40 */
    CLKDIVbits.PLLPOST = 0; /* N1 = 2 */
    CLKDIVbits.PLLPRE = 0; /* N2 = 2 */
    OSCSTUN = 0;

    /* Initiate Clock Switch to Primary Oscillator with PLL (NOSC = 0x3) */
    __builtin_write_OSCCONH(0x03);
    __builtin_write_OSCCONL(0x01);
    while (OSCCONbits.COSC != 0x3);
    while (_LOCK == 0); /* Wait for PLL lock at 40 MIPS */

    initAdcl();
    initDma0();

    while(1); /* Wait for DMA interrupts to occur */
}

void initAdcl(void)
{
    /* Set port configuration */
    ANSELA = ANSELC = ANSELD = ANSELE = ANSELG = 0x0000;
    ANSELB = 0x0001; /* Ensure AN0 is analog */

    /* Initialize ADC module */
    AD1CON1 = 0x13E4; /* DMA Conversion Order, sequential sampling, 10-bit, Signed Fractional */
    AD1CON2 = 0x0100; /* Select 2-channel mode, increment DMA pointer after every sample */
    AD1CON3bits.ADC = 0; /* ADC Clock is derived from System Clock */
    AD1CON3bits.SAMC = 2; /* Sample for 2 * Tad before converting */
    AD1CON3bits.ADCS = 2; /* TAD = Tcy * (ADCS + 1) = (1 / 40MHz) * 3 = 75 ns (13.3 MHz) */
    AD1CON4 = 0x0100; /* ADC conversion time for 10-bit Tconv = 12 * Tad = 900 ns (1.1 Msps) */
    AD1CSSH = 0x0000; /* Use DMA to store conversion results */
    AD1CSSL = 0x0000;

    /* Assign MUXA inputs */
    AD1CHS0bits.CH0SA = 0; /* Select AN0 for CH0 +ve input */
    AD1CHS0bits.CH0NA = 0; /* Select VREF- for CH0 -ve input */
    AD1CHS123bits.CH123SA = 0; /* Select AN0 for CH1 +ve input */
    AD1CHS123bits.CH123NA = 0; /* Select VREF- for CH1 -ve input */

    /* Enable ADC module and provide ADC stabilization delay */
    AD1CON1bits.ADON = 1;
    Delay_us(20);
}

void __attribute__((interrupt, auto_psv)) _DMA0Interrupt(void)
{
    _DMA0IF = 0; /* Clear DMA interrupt flag to prepare for next block */
}

void Delay_us(unsigned int delay)
{
    for (i = 0; i < delay; i++)
    {
        __asm__ volatile ("repeat #39");
        __asm__ volatile ("nop");
    }
}
```

16.10 SAMPLE AND CONVERSION SEQUENCE EXAMPLES FOR DEVICES WITHOUT DMA AND FOR DEVICES WITH DMA BUT WITH ADC DMA ENABLE BIT (ADDMAEN) CLEAR

The following configuration examples show the Analog-to-Digital operation in different sampling and buffering configurations. In each example, setting the ASAM bit starts automatic sampling. A conversion trigger ends sampling and starts conversion.

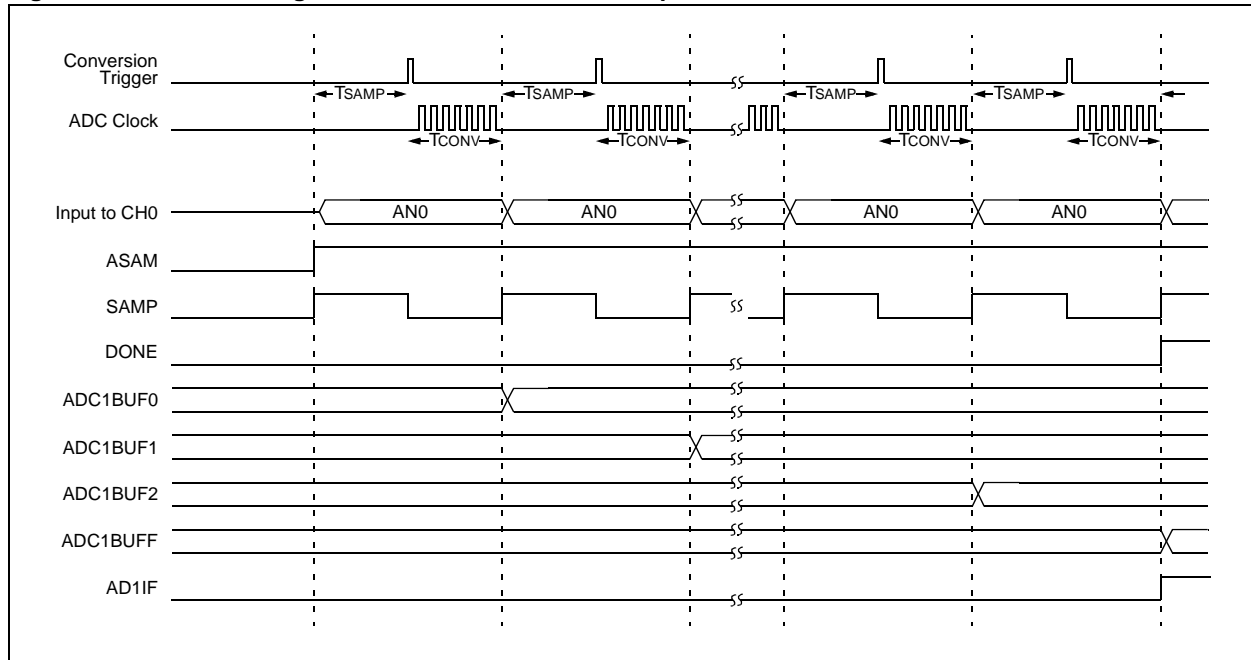
Note: These examples are based on devices without op amps. Availability and configuration of inputs varies by device. Refer to the “Op Amp/Comparator” chapter in the specific device data sheet to determine availability.

16.10.1 Sampling and Converting a Single Channel Multiple Times

Figure 16-26 and Table 16-13 illustrate a basic configuration of the ADC. In this case, one ADC input, AN0, is sampled by one S&H channel, CH0, and converted. The results are stored in the ADC buffer (ADC1BUF0-ADC1BUFF). This process repeats 16 times until the buffer is full and then the ADC module generates an interrupt. The entire process then repeats.

The CHPSx bits specify that only S&H CH0 is active. With ALTS clear, only the MUXA inputs are active. The CH0SAx and CH0NA bits are specified (AN0-VREF-) as the input to the S&H channel. All other input selection bits are not used.

Figure 16-26: Converting One Channel, 16 Times/Interrupt



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Table 16-13: Converting One Channel, 16 Times per ADC Interrupt

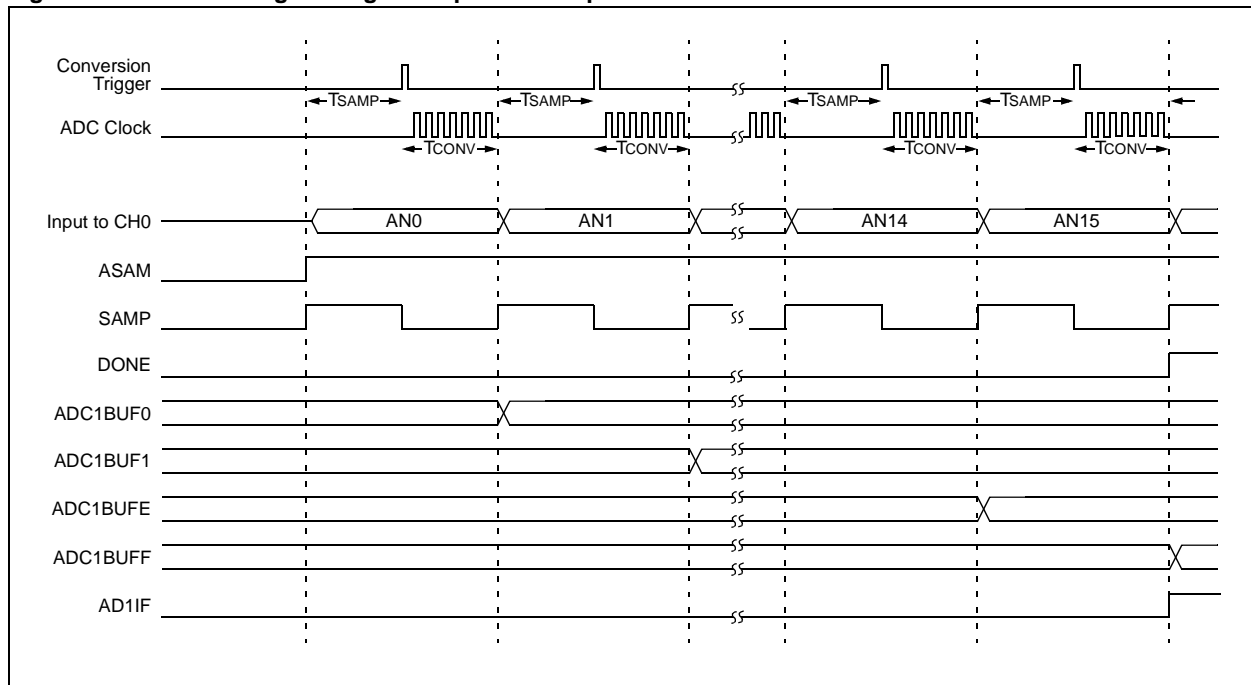
CONTROL BITS		OPERATION SEQUENCE	
Sequence Select			
SMPI<4:0> = 01111	Interrupt on 16th Sample	Sample MUXA Inputs: AN0 ≥ CH0	
CHPS<1:0> = 00	Sample Channel CH0	Convert CH0, Write ADC1BUF0	
SIMSAM = n/a	Not Applicable for Single Channel Sample	Sample MUXA Inputs: AN0 ≥ CH0	
BUFM = 0	Single 16-Word Result Buffer	Convert CH0, Write ADC1BUF1	
ALTS = 0	Always Use MUXA Input Select	Sample MUXA Inputs: AN0 ≥ CH0	
ADDMAEN = 0	Do Not Use DMA with ADC	Convert CH0, Write ADC1BUF2	
MUXA Input Select		Sample MUXA Inputs: AN0 ≥ CH0	
CH0SA<5:0> = 000000	Select AN0 for CH0+ Input	Convert CH0, Write ADC1BUF3	
CH0NA = 0	Select VREF- for CH0- Input	Sample MUXA Inputs: AN0 ≥ CH0	
CSCNA = 0	No Input Scan	Convert CH0, Write ADC1BUF4	
CSS<15:0> = n/a	Scan Input Select Unused	Sample MUXA Inputs: AN0 ≥ CH0	
CH123SA<2:0> = n/a	Channels CH1, CH2, CH3+ Inputs Unused	Convert CH0, Write ADC1BUF5	
CH123NA<1:0> = n/a	Channels CH1, CH2, CH3- Inputs Unused	Sample MUXA Inputs: AN0 ≥ CH0	
MUXB Input Select		Convert CH0, Write ADC1BUF6	
CH0SB<5:0> = n/a	Channel CH0+ Input Unused	Sample MUXA Inputs: AN0 ≥ CH0	
CH0NB = n/a	Channel CH0- Input Unused	Convert CH0, Write ADC1BUF7	
CH123SB<2:0> = n/a	Channels CH1, CH2, CH3+ Inputs Unused	Sample MUXA Inputs: AN0 ≥ CH0	
CH123NB<1:0> = n/a	Channels CH1, CH2, CH3- Inputs Unused	Convert CH0, Write ADC1BUF8	
ADC Buffer @ First ADC Interrupt		Sample MUXA Inputs: AN0 ≥ CH0	
ADC1BUF0	AN0 Sample 1	Convert CH0, Write ADC1BUF9	
ADC1BUF1	AN0 Sample 2	Sample MUXA Inputs: AN0 ≥ CH0	
ADC1BUF2	AN0 Sample 3	Convert CH0, Write ADC1BUFA	
ADC1BUF3	AN0 Sample 4	Sample MUXA Inputs: AN0 ≥ CH0	
ADC1BUF4	AN0 Sample 5	Convert CH0, Write ADC1BUFB	
ADC1BUF5	AN0 Sample 6	Sample MUXA Inputs: AN0 ≥ CH0	
ADC1BUF6	AN0 Sample 7	Convert CH0, Write ADC1BUFC	
ADC1BUF7	AN0 Sample 8	Sample MUXA Inputs: AN0 ≥ CH0	
ADC1BUF8	AN0 Sample 9	Convert CH0, Write ADC1BUFD	
ADC1BUF9	AN0 Sample 10	Sample MUXA Inputs: AN0 ≥ CH0	
ADC1BUFA	AN0 Sample 11	Convert CH0, Write ADC1BUFE	
ADC1BUFB	AN0 Sample 12	Sample MUXA Inputs: AN0 ≥ CH0	
ADC1BUFC	AN0 Sample 13	Convert CH0, Write ADC1BUFF	
ADC1BUFD	AN0 Sample 14	ADC Interrupt	
ADC1BUFE	AN0 Sample 15	Repeat	
ADC1BUFF	AN0 Sample 16		
ADC Buffer @ Second ADC Interrupt			
		AN0 Sample 17	
		AN0 Sample 18	
		AN0 Sample 19	
		AN0 Sample 20	
		AN0 Sample 21	
		AN0 Sample 22	
		AN0 Sample 23	
		AN0 Sample 24	
		AN0 Sample 25	
		AN0 Sample 26	
		AN0 Sample 27	
		AN0 Sample 28	
		AN0 Sample 29	
		AN0 Sample 30	
		AN0 Sample 31	
		AN0 Sample 32	

16.10.2 Analog-to-Digital Conversions While Scanning Through 16 Analog Inputs

Figure 16-27 and Table 16-14 illustrate a typical setup where all available analog input channels are sampled by one S&H channel, CH0, and converted. The Set Scan Input Selection bit (CSCNA) in the ADC Control Register 2 (ADxCON2<10>) specifies scanning of the ADC inputs to the CH0 positive input. Other conditions are similar to those described in [Section 16.10.1 “Sampling and Converting a Single Channel Multiple Times”](#).

Initially, the AN0 input is sampled by CH0 and converted, and then the AN1 input is sampled and converted. This process of scanning the inputs repeats 16 times until the buffer is full. The result is stored in the ADC buffer (ADC1BUF0-ADC1BUFF). Then, the ADC module generates an interrupt. The entire process then repeats.

Figure 16-27: Scanning Through 16 Inputs/Interrupt



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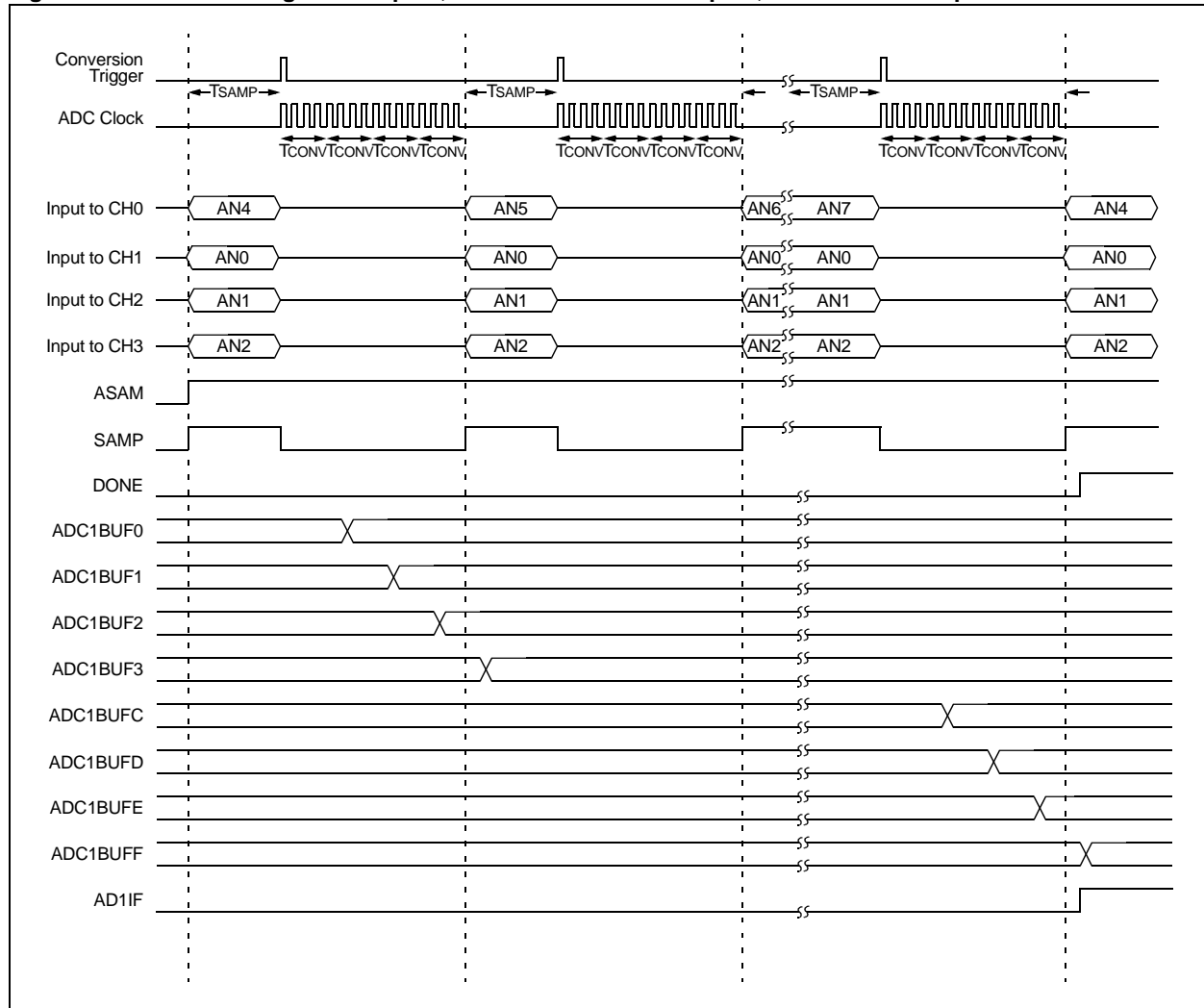
Table 16-14: Scanning Through 16 Inputs per ADC Interrupt

CONTROL BITS		OPERATION SEQUENCE	
Sequence Select			
SMPI<4:0> = 01111	Interrupt on 16th Sample	Sample MUXA Inputs: AN0 ≥ CH0	Convert CH0, Write ADC1BUF0
CHPS<1:0> = 00	Sample Channel CH0	Sample MUXA Inputs: AN1 ≥ CH0	Convert CH0, Write ADC1BUF1
SIMSAM = n/a	Not Applicable for Single Channel Sample	Sample MUXA Inputs: AN2 ≥ CH0	Convert CH0, Write ADC1BUF2
BUFM = 0	Single 16-Word Result Buffer	Sample MUXA Inputs: AN3 ≥ CH0	Convert CH0, Write ADC1BUF3
ALTS = 0	Always Use MUXA Input Select	Sample MUXA Inputs: AN4 ≥ CH0	Convert CH0, Write ADC1BUF4
ADDMAEN = 0	Do Not Use DMA with ADC	Sample MUXA Inputs: AN5 ≥ CH0	Convert CH0, Write ADC1BUF5
MUXA Input Select		Sample MUXA Inputs: AN6 ≥ CH0	Convert CH0, Write ADC1BUF6
CH0SA<5:0> = n/a	Override by CSCNA	Sample MUXA Inputs: AN7 ≥ CH0	Convert CH0, Write ADC1BUF7
CH0NA = 0	Select VREF- for CH0- Input	Sample MUXA Inputs: AN8 ≥ CH0	Convert CH0, Write ADC1BUF8
CSCNA = 1	Scan CH0+ Inputs	Sample MUXA Inputs: AN9 ≥ CH0	Convert CH0, Write ADC1BUF9
CSS<15:0> = 1111 1111 1111 1111	Scan Input Select Unused	Sample MUXA Inputs: AN10 ≥ CH0	Convert CH0, Write ADC1BUFA
CH123SA<2:0> = n/a	Channels CH1, CH2, CH3+ Inputs Unused	Sample MUXA Inputs: AN11 ≥ CH0	Convert CH0, Write ADC1BUFB
CH123NA<1:0> = n/a	Channels CH1, CH2, CH3- Inputs Unused	Sample MUXA Inputs: AN12 ≥ CH0	Convert CH0, Write ADC1BUFC
MUXB Input Select		Sample MUXA Inputs: AN13 ≥ CH0	Convert CH0, Write ADC1BUFD
CH0SB<5:0> = n/a	Channel CH0+ Input Unused	Sample MUXA Inputs: AN14 ≥ CH0	Convert CH0, Write ADC1BUFE
CH0NB = n/a	Channel CH0- Input Unused	Sample MUXA Inputs: AN15 ≥ CH0	Convert CH0, Write ADC1BUFF
CH123SB<2:0> = n/a	Channels CH1, CH2, CH3+ Inputs Unused	ADC Interrupt	
CH123NB<1:0> = n/a	Channels CH1, CH2, CH3- Inputs Unused	Repeat	
ADC Buffer @ First ADC Interrupt		ADC Buffer @ Second ADC Interrupt	
ADC1BUF0	AN0 Sample 1		AN0 Sample 17
ADC1BUF1	AN1 Sample 2		AN1 Sample 18
ADC1BUF2	AN2 Sample 3		AN2 Sample 19
ADC1BUF3	AN3 Sample 4		AN3 Sample 20
ADC1BUF4	AN4 Sample 5		AN4 Sample 21
ADC1BUF5	AN5 Sample 6		AN5 Sample 22
ADC1BUF6	AN6 Sample 7		AN6 Sample 23
ADC1BUF7	AN7 Sample 8		AN7 Sample 24
ADC1BUF8	AN8 Sample 9		AN8 Sample 25
ADC1BUF9	AN9 Sample 10		AN9 Sample 26
ADC1BUFA	AN10 Sample 11		AN10 Sample 27
ADC1BUFB	AN11 Sample 12		AN11 Sample 28
ADC1BUFC	AN12 Sample 13		AN12 Sample 29
ADC1BUFD	AN13 Sample 14		AN13 Sample 30
ADC1BUFE	AN14 Sample 15		AN14 Sample 31
ADC1BUFF	AN15 Sample 16		AN15 Sample 32

16.10.3 Sampling Three Inputs Frequently While Scanning Four Other Inputs

Figure 16-28 and Table 16-15 illustrate how the ADC module could be configured to sample three inputs frequently, using S&H channels, CH1, CH2 and CH3; while four other inputs are sampled less frequently by scanning them, using S&H channel, CH0. In this case, only MUXA inputs are used and all four channels are sampled simultaneously. Four different inputs (AN4, AN5, AN6, AN7) are scanned in CH0, whereas AN0, AN1 and AN2 are the fixed inputs for CH1, CH2 and CH3, respectively. Thus, in every set of 16 samples, AN0, AN1 and AN2 are sampled four times, while AN4, AN5, AN6 and AN7 are sampled only once each.

Figure 16-28: Converting Three Inputs, Four Times and Four Inputs, One Time/Interrupt



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Table 16-15: Converting Three Inputs, Four Times and Four Inputs, One Time per ADC Interrupt

CONTROL BITS		OPERATION SEQUENCE	
Sequence Select			
SMPI<4:0> = 00011	Interrupt on 4th Sample ⁽¹⁾	Sample MUXA Inputs: AN4 ≥ CH0, AN0 ≥ CH1, AN1 ≥ CH2, AN2 ≥ CH3	
CHPS<1:0> = 1x	Sample Channels CH0, CH1, CH2, CH3	Convert CH0, Write ADC1BUF0	
SIMSAM = 1	Sample All Channels Simultaneously	Convert CH1, Write ADC1BUF1	
BUFM = 0	Single 16-Word Result Buffer	Convert CH2, Write ADC1BUF2	
ALTS = 0	Always Use MUXA Input Select	Convert CH3, Write ADC1BUF3	
ADDMAEN = 0	Do Not Use DMA with ADC	Sample MUXA Inputs: AN5 ≥ CH0, AN0 ≥ CH1, AN1 ≥ CH2, AN2 ≥ CH3	
MUXA Input Select		Convert CH0, Write ADC1BUF4	
CH0SA<5:0> = n/a	Override by CSCNA	Convert CH1, Write ADC1BUF5	
CH0NA = 0	Select VREF- for CH0- Input	Convert CH2, Write ADC1BUF6	
CSCNA = 1	Scan CH0+ Inputs	Convert CH3, Write ADC1BUF7	
CSS<15:0> = 0000 0000 1111 0000	Scan AN4, AN5, AN6, AN7	Sample MUXA Inputs: AN6 ≥ CH0, AN0 ≥ CH1, AN1 ≥ CH2, AN2 ≥ CH3	
CH123SA<2:0> = 000	CH1+ = AN0, CH2+ = AN1, CH3+ = AN2	Convert CH0, Write ADC1BUF8	
CH123NA<1:0> = 0x	CH1-, CH2-, CH3- = VREF-	Convert CH1, Write ADC1BUF9	
MUXB Input Select		Convert CH2, Write ADC1BUFA	
CH0SB<5:0> = n/a	Channel CH0+ Input Unused	Convert CH3, Write ADC1BUFB	
CH0NB = n/a	Channel CH0- Input Unused	Sample MUXA Inputs: AN7 ≥ CH0, AN0 ≥ CH1, AN1 ≥ CH2, AN2 ≥ CH3	
CH123SB<2:0> = n/a	Channels CH1, CH2, CH3+ Inputs Unused	Convert CH0, Write ADC1BUFC	
CH123NB<1:0> = n/a	Channels CH1, CH2, CH3- Inputs Unused	Convert CH1, Write ADC1BUFD	
ADC Buffer @ First ADC Interrupt		Convert CH2, Write ADC1BUFE	
ADC1BUF0	AN4 Sample 1	Convert CH3, Write ADC1BUFF	
ADC1BUF1	AN0 Sample 1	ADC Interrupt	
ADC1BUF2	AN1 Sample 1	Repeat	
ADC1BUF3	AN2 Sample 1		
ADC1BUF4	AN5 Sample 1		
ADC1BUF5	AN0 Sample 2		
ADC1BUF6	AN1 Sample 2		
ADC1BUF7	AN2 Sample 2		
ADC1BUF8	AN6 Sample 1		
ADC1BUF9	AN0 Sample 3		
ADC1BUFA	AN1 Sample 3		
ADC1BUFB	AN2 Sample 3		
ADC1BUFC	AN7 Sample 1		
ADC1BUFD	AN0 Sample 4		
ADC1BUFE	AN1 Sample 4		
ADC1BUFF	AN2 Sample 4		
ADC Buffer @ Second ADC Interrupt			
		AN4 Sample 2	
		AN0 Sample 5	
		AN1 Sample 5	
		AN2 Sample 5	
		AN5 Sample 2	
		AN0 Sample 6	
		AN1 Sample 6	
		AN2 Sample 6	
		AN6 Sample 2	
		AN0 Sample 7	
		AN1 Sample 7	
		AN2 Sample 7	
		AN7 Sample 2	
		AN0 Sample 8	
		AN1 Sample 8	
		AN2 Sample 8	

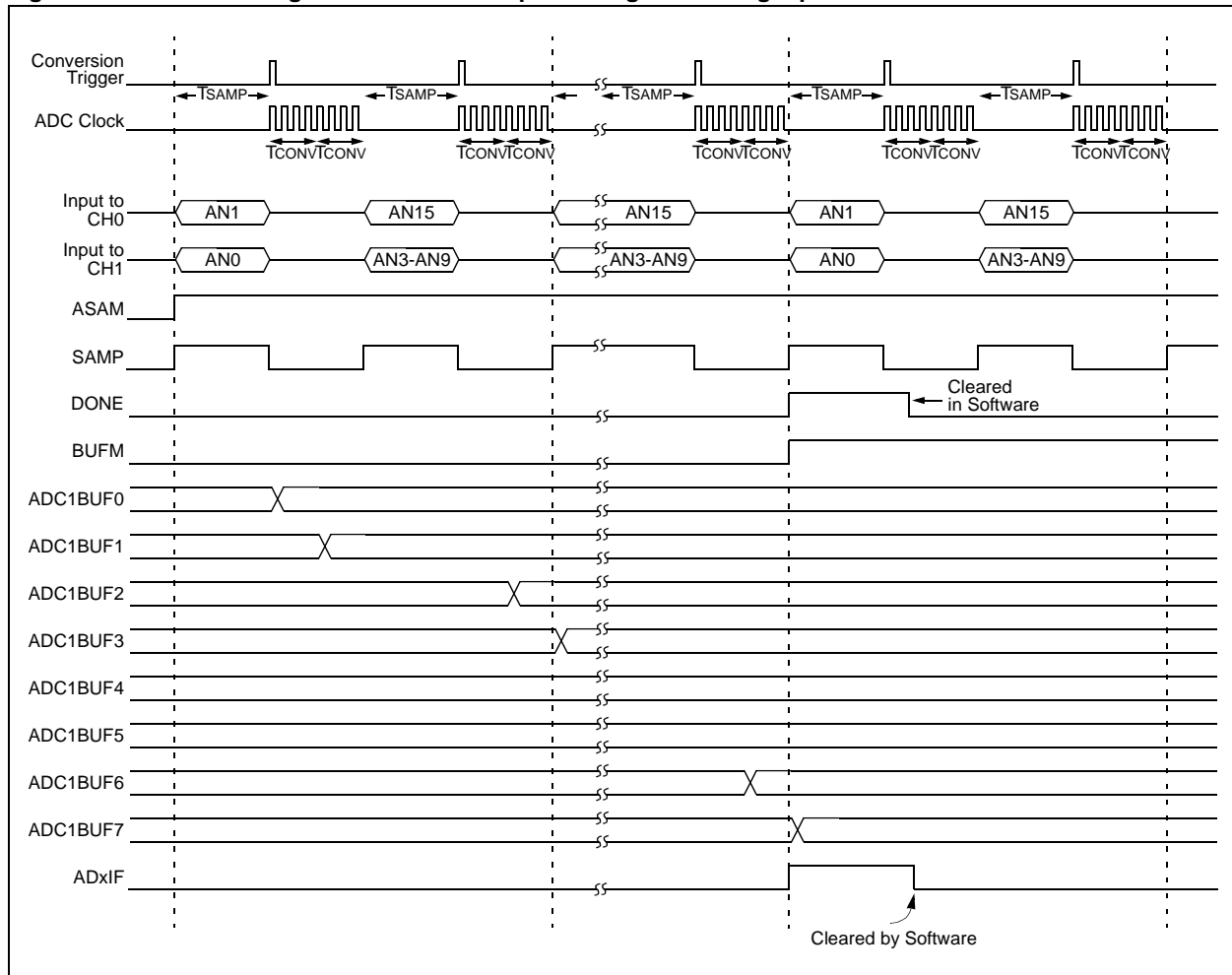
Note 1: During this simultaneous sampling, one sample and four conversions are treated as one sample and convert sequence. Therefore, when SMPI<4:0> = 00011, an ADC interrupt is generated after 16 samples are converted and buffered in ADC1BUF0-ADC1BUFF.

16.10.4 Using Alternating MUXA, MUXB Input Selections

Figure 16-29 and Table 16-16 demonstrate alternate sampling of the inputs assigned to MUXA and MUXB. In this example, two channels are enabled to sample simultaneously. Setting the ALTS bit (ADCxCON2<0>) enables alternating input selections. The first sample uses the MUXA inputs specified by the CH0SA<5:0>, CH0NA, CH123SA<2:0> and CH123NA<1:0> bits. The next sample uses the MUXB inputs specified by the CH0SB<5:0>, CH0NB, CH123SB<2:0> and CH123NB<1:0> bits. In this example, one of the MUXB input specifications uses two analog inputs as a differential source to the S&H, sampling (AN3-AN9).

Using four S&H channels without alternating input selections results in the same number of conversions as this example, using two channels with alternating input selections. However, because the CH1, CH2 and CH3 channels are more limited in the selection of the analog inputs, this example method provides more flexibility of input selection than using four channels.

Figure 16-29: Converting Two Sets of Two Inputs Using Alternating Input Selections



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Table 16-16: Converting Two Sets of Two Inputs Using Alternating Input Selections

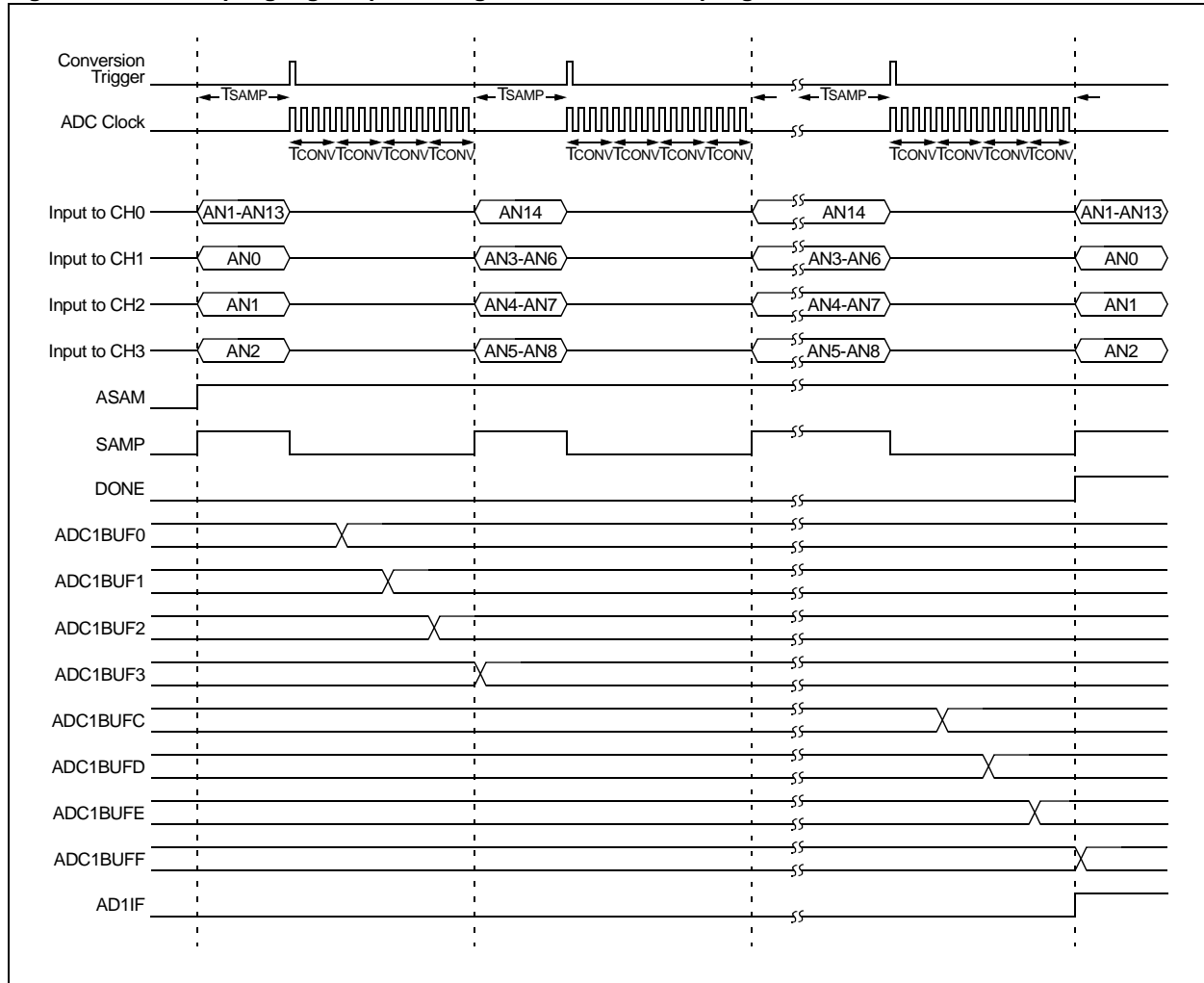
CONTROL BITS		OPERATION SEQUENCE	
Sequence Select			
SMPI<4:0> = 00011	Interrupt on 4th Sample	Sample MUXA Inputs: AN1 ≥ CH0, AN0 ≥ CH1	Convert CH0, Write ADC1BUF0
CHPS<1:0> = 01	Sample Channels CH0, CH1		Convert CH1, Write ADC1BUF1
SIMSAM = 1	Sample All Channels Simultaneously	Sample MUXB Inputs: AN15 ≥ CH0, (AN3-AN9) ≥ CH1	Convert CH0, Write ADC1BUF2
BUFM = 1	Dual 8-Word Result Buffers		Convert CH1, Write ADC1BUF3
ALTS = 1	Alternate MUXA/B Input Select	Sample MUXA Inputs: AN1 ≥ CH0, AN0 ≥ CH1	Convert CH0, Write ADC1BUF4
ADDMAEN = 0	Do Not Use DMA with ADC		Convert CH1, Write ADC1BUF5
MUXA Input Select			Interrupt; Change Buffer
CH0SA<5:0> = 000001	Select AN1 for CH0+ Input	Sample MUXA Inputs: AN1 ≥ CH0, AN0 ≥ CH1	Convert CH0, Write ADC1BUF8
CH0NA = 0	Select VREF- for CH0- Input		Convert CH1, Write ADC1BUF9
CSCNA = 0	No Input Scan	Sample MUXB Inputs: AN15 ≥ CH0, (AN3-AN9) ≥ CH1	Convert CH0, Write ADC1BUFA
CSS<15:0> = n/a	Scan Input Select Unused		Convert CH1, Write ADC1BUFB
CH123SA<2:0> = 000	CH1+ = AN0, CH2+ = AN1, CH3+ = AN2	Sample MUXA Inputs: AN1 ≥ CH0, AN0 ≥ CH1	Convert CH0, Write ADC1BUFC
CH123NA<1:0> = 0x	CH1-, CH2-, CH3- = VREF-		Convert CH1, Write ADC1BUFD
MUXB Input Select		Sample MUXB Inputs: AN15 ≥ CH0, (AN3-AN9) ≥ CH1	Convert CH0, Write ADC1BUFE
CH0SB<5:0> = 111111	Select AN15 for CH0+ Input		Convert CH1, Write ADC1BUFF
CH0NB = 0	Select VREF- for CH0- Input		ADC Interrupt; Change Buffer
CH123SB<2:0> = 111	CH1+ = AN3, CH2+ = AN4, CH3+ = AN5		Repeat
CH123NB<1:0> = 11	CH1- = AN9, CH2- = AN10, CH3- = AN11		
ADC Buffer @ First ADC Interrupt		ADC Buffer @ Second ADC Interrupt	
ADC1BUF0	AN1 Sample 1		
ADC1BUF1	AN0 Sample 1		
ADC1BUF2	AN15 Sample 2		
ADC1BUF3	(AN3-AN9) Sample 2		
ADC1BUF4	AN1 Sample 3		
ADC1BUF5	AN0 Sample 3		
ADC1BUF6	AN15 Sample 4		
ADC1BUF7	(AN3-AN9) Sample 4		
ADC1BUF8			AN1 Sample 5
ADC1BUF9			AN0 Sample 5
ADC1BUFA			AN15 Sample 6
ADC1BUFB			(AN3-AN9) Sample 6
ADC1BUFC			AN1 Sample 7
ADC1BUFD			AN0 Sample 7
ADC1BUFE			AN15 Sample 8
ADC1BUFF			(AN3-AN9) Sample 8

16.10.5 Sampling Eight Inputs Using Simultaneous Sampling

Figure 16-30 and Table 16-17 demonstrate identical setups with the exception that this example uses simultaneous sampling ($SIMSAM = 1$), and Figure 16-31 uses sequential sampling ($SIMSAM = 0$). Both examples use alternating inputs and specify differential inputs to the S&H.

Figure 16-30 and Table 16-17 demonstrate simultaneous sampling. When converting more than one channel and selecting simultaneous sampling, the ADC module samples all channels, then performs the required conversions in sequence. In this example, with the ASAM bit set, sampling begins after the conversion is complete.

Figure 16-30: Sampling Eight Inputs Using Simultaneous Sampling



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Table 16-17: Sampling Eight Inputs Using Simultaneous Sampling

CONTROL BITS		OPERATION SEQUENCE	
Sequence Select			
SMPI<4:0> = 00011	Interrupt on 4th Sample	Sample MUXA Inputs: (AN1-AN13) ≥ CH0, AN0 ≥ CH1, AN1 ≥ CH2, AN2 ≥ CH3	
CHPS<1:0> = 1x	Sample Channels CH0, CH1, CH2, CH3	Convert CH0, Write ADC1BUF0	
SIMSAM = 1	Sample All Channels Simultaneously	Convert CH1, Write ADC1BUF1	
BUFM = 0	Single 16-Word Result Buffer	Convert CH2, Write ADC1BUF2	
ALTS = 1	Alternate MUXA/MUXB Input Select	Convert CH3, Write ADC1BUF3	
ADDMAEN = 0	Do Not Use DMA with ADC	Sample MUXB Inputs: AN14 ≥ CH0, (AN3-AN6) ≥ CH1, (AN4-AN7) ≥ CH2, (AN5-AN8) ≥ CH3	
MUXA Input Select		Convert CH0, Write ADC1BUF4	
CH0SA<5:0> = 111101	Select AN13 for CH0+ Input	Convert CH1, Write ADC1BUF5	
CH0NA = 1	Select AN1 for CH0- Input	Convert CH2, Write ADC1BUF6	
CSCNA = 0	No Input Scan	Convert CH3, Write ADC1BUF7	
CSS<15:0> = n/a	Scan Input Select Unused	Sample MUXA Inputs: (AN1-AN13) ≥ CH0, AN0 ≥ CH1, AN1 ≥ CH2, AN2 ≥ CH3	
CH123SA<2:0> = 000	CH1+ = AN0, CH2+ = AN1, CH3+ = AN2	Convert CH0, Write ADC1BUF8	
CH123NA<1:0> = 0x	CH1-, CH2-, CH3- = VREF-	Convert CH1, Write ADC1BUF9	
MUXB Input Select		Convert CH2, Write ADC1BUFA	
CH0SB<5:0> = 111110	Select AN14 for CH0+ Input	Convert CH3, Write ADC1BUFB	
CH0NB = 0	Select VREF- for CH0- Input	Sample MUXB Inputs: AN14 ≥ CH0, (AN3-AN6) ≥ CH1, (AN4-AN7) ≥ CH2, (AN5-AN8) ≥ CH3	
CH123SB<2:0> = 111	CH1+ = AN3, CH2+ = AN4, CH3+ = AN5	Convert CH0, Write ADC1BUFC	
CH123NB<1:0> = 10	CH1- = AN6, CH2- = AN7, CH3- = AN8	Convert CH1, Write ADC1BUFD	
ADC Buffer @ First ADC Interrupt		Convert CH2, Write ADC1BUFE	
ADC1BUF0	(AN1-AN13) Sample 1	Convert CH3, Write ADC1BUFF	
ADC1BUF1	AN0 Sample 1	ADC Interrupt	
ADC1BUF2	AN1 Sample 1	Repeat	
ADC1BUF3	AN2 Sample 1		
ADC1BUF4	AN14 Sample 1		
ADC1BUF5	(AN3-AN6) Sample 1		
ADC1BUF6	(AN4-AN7) Sample 1		
ADC1BUF7	(AN5-AN8) Sample 1		
ADC1BUF8	(AN1-AN13) Sample 1		
ADC1BUF9	AN0 Sample 2		
ADC1BUFA	AN1 Sample 2		
ADC1BUFB	AN2 Sample 2		
ADC1BUFC	AN14 Sample 2		
ADC1BUFD	(AN3-AN6) Sample 2		
ADC1BUFE	(AN4-AN7) Sample 2		
ADC1BUFF	(AN5-AN8) Sample 2		
ADC Buffer @ Second ADC Interrupt			
		(AN1-AN13) Sample 3	
		AN0 Sample 3	
		AN1 Sample 3	
		AN2 Sample 3	
		AN14 Sample 3	
		(AN3-AN6) Sample 3	
		(AN4-AN7) Sample 3	
		(AN5-AN8) Sample 3	
		(AN1-AN13) Sample 4	
		AN0 Sample 4	
		AN1 Sample 4	
		AN2 Sample 4	
		AN14 Sample 4	
		(AN3-AN6) Sample 4	
		(AN4-AN7) Sample 4	
		(AN5-AN8) Sample 4	

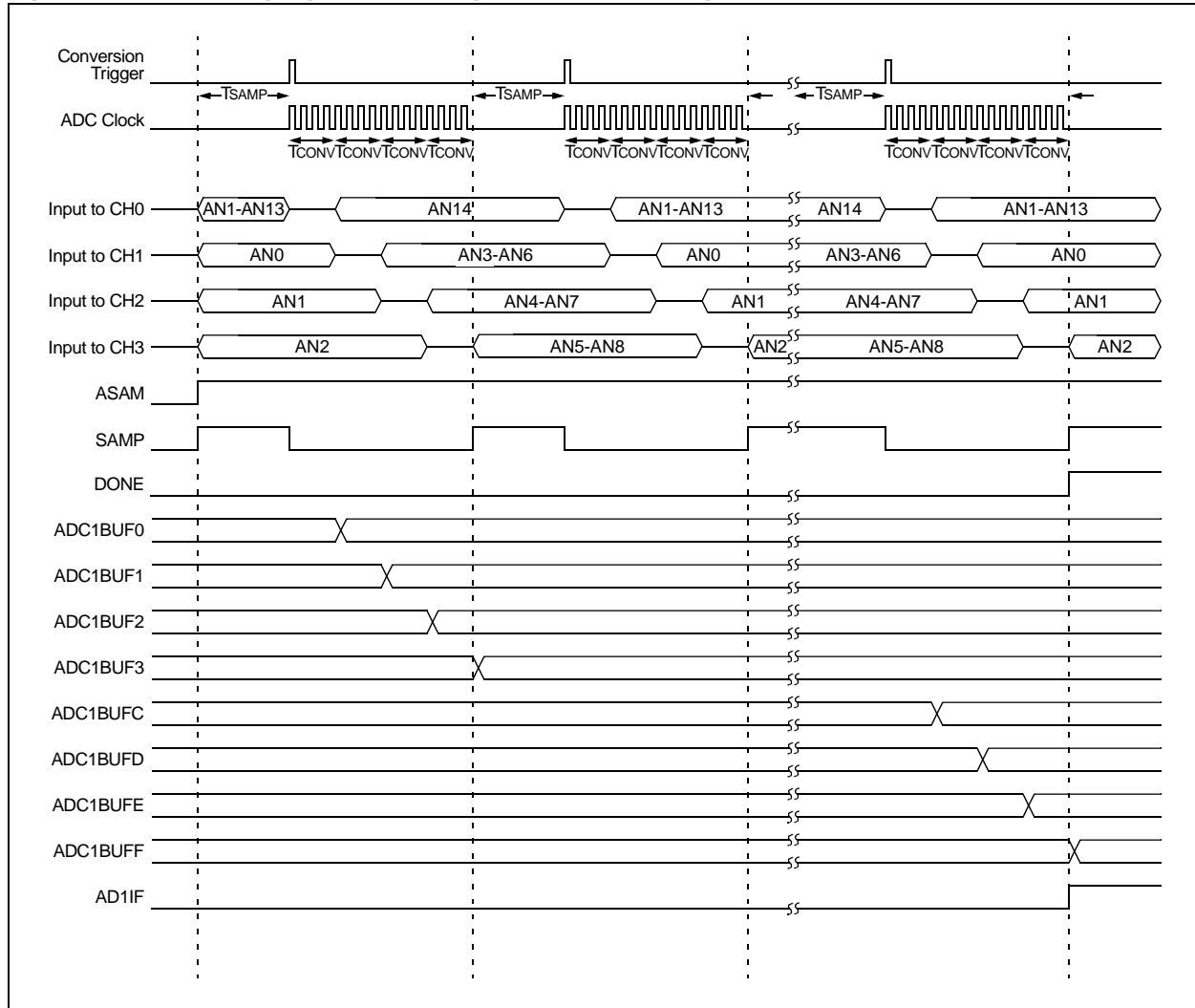
16.10.6 Sampling Eight Inputs Using Sequential Sampling

Figure 16-31 and Table 16-18 demonstrate sequential sampling. When converting more than one channel and selecting sequential sampling, the ADC module starts sampling a channel at the earliest opportunity, then performs the required conversions in sequence. In this example, with the ASAM bit set, sampling of a channel begins after the conversion of that channel completes.

When the ASAM bit is clear, sampling does not resume after conversion completion, but occurs when the SAMP bit (ADxCON1<1>) is set.

When utilizing more than one channel, sequential sampling provides more sampling time since a channel can be sampled while a conversion occurs on another.

Figure 16-31: Sampling Eight Inputs Using Sequential Sampling



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Table 16-18: Sampling Eight Inputs Using Sequential Sampling

CONTROL BITS		OPERATION SEQUENCE	
Sequence Select			
SMPI<4:0> = 01111	Interrupt on 16th Sample	Sample: (AN1-AN13) ≥ CH0	Convert CH0, Write ADC1BUF0
CHPS<1:0> = 1x	Sample Channels CH0, CH1, CH2, CH3	Sample: AN0 ≥ CH1	Convert CH1, Write ADC1BUF1
SIMSAM = 0	Sample All Channels Sequentially	Sample: AN1 ≥ CH2	Convert CH2, Write ADC1BUF2
BUFM = 0	Single 16-Word Result Buffer	Sample: AN2 ≥ CH3	Convert CH3, Write ADC1BUF3
ALTS = 1	Alternate MUXA/MUXB Input Select	Sample: AN14 ≥ CH0	Convert CH0, Write ADC1BUF4
ADDMAEN = 0	Do Not Use DMA with ADC	Sample: (AN3-AN6) ≥ CH1	Convert CH1, Write ADC1BUF5
MUXA Input Select		Sample: (AN4-AN7) ≥ CH2	Convert CH2, Write ADC1BUF6
CH0SA<5:0> = 111101	Select AN13 for CH0+ Input	Sample: (AN5-AN8) ≥ CH3	Convert CH3, Write ADC1BUF7
CH0NA = 1	Select AN1 for CH0- Input	Sample: (AN1-AN13) ≥ CH0	Convert CH0, Write ADC1BUF8
CSCNA = 0	No Input Scan	Sample: AN0 ≥ CH1	Convert CH1, Write ADC1BUF9
CSS<15:0> = n/a	Scan Input Select Unused	Sample: AN1 ≥ CH2	Convert CH2, Write ADC1BUFA
CH123SA<2:0> = 000	CH1+ = AN0, CH2+ = AN1, CH3+ = AN2	Sample: AN2 ≥ CH3	Convert CH3, Write ADC1BUFB
CH123NA<1:0> = 0x	CH1- = AN0, CH2- = AN1, CH3- = AN2	Sample: AN14 ≥ CH0	Convert CH0, Write ADC1BUFC
MUXB Input Select		Sample: (AN3-AN6) ≥ CH1	Convert CH1, Write ADC1BUFD
CH0SB<5:0> = 111110	Select AN14 for CH0+ Input	Sample: (AN4-AN7) ≥ CH2	Convert CH2, Write ADC1BUFE
CH0NB = 0	Select VREF- for CH0- Input	Sample: (AN5-AN8) ≥ CH3	Convert CH3, Write ADC1BUFF
CH123SB<2:0> = 111	CH1+ = AN3, CH2+ = AN4, CH3+ = AN5	ADC Interrupt	
CH123NB<1:0> = 10	CH1- = AN6, CH2- = AN7, CH3- = AN8	Repeat	
ADC Buffer @ First ADC Interrupt		ADC Buffer @ Second ADC Interrupt	
ADC1BUF0	(AN1-AN13) Sample 1	(AN1-AN13) Sample 3	
ADC1BUF1	AN0 Sample 1	AN0 Sample 3	
ADC1BUF2	AN1 Sample 1	AN1 Sample 3	
ADC1BUF3	AN2 Sample 1	AN2 Sample 3	
ADC1BUF4	AN14 Sample 1	AN14 Sample 3	
ADC1BUF5	(AN3-AN6) Sample 1	(AN3-AN6) Sample 3	
ADC1BUF6	(AN4-AN7) Sample 1	(AN4-AN7) Sample 3	
ADC1BUF7	(AN5-AN8) Sample 1	(AN5-AN8) Sample 3	
ADC1BUF8	(AN1-AN13) Sample 2	(AN1-AN13) Sample 4	
ADC1BUF9	AN0 Sample 2	AN0 Sample 4	
ADC1BUFA	AN1 Sample 2	AN1 Sample 4	
ADC1BUFB	AN2 Sample 2	AN2 Sample 28	
ADC1BUFC	AN14 Sample 2	AN14 Sample 4	
ADC1BUFD	(AN3-AN6) Sample 2	(AN3-AN6) Sample 4	
ADC1BUFE	(AN4-AN7) Sample 2	(AN4-AN7) Sample 4	
ADC1BUFF	(AN5-AN8) Sample 2	(AN5-AN8) Sample 4	

16.11 SAMPLE AND CONVERSION SEQUENCE EXAMPLES FOR DEVICES WITH DMA AND WITH ADDMAEN BIT SET

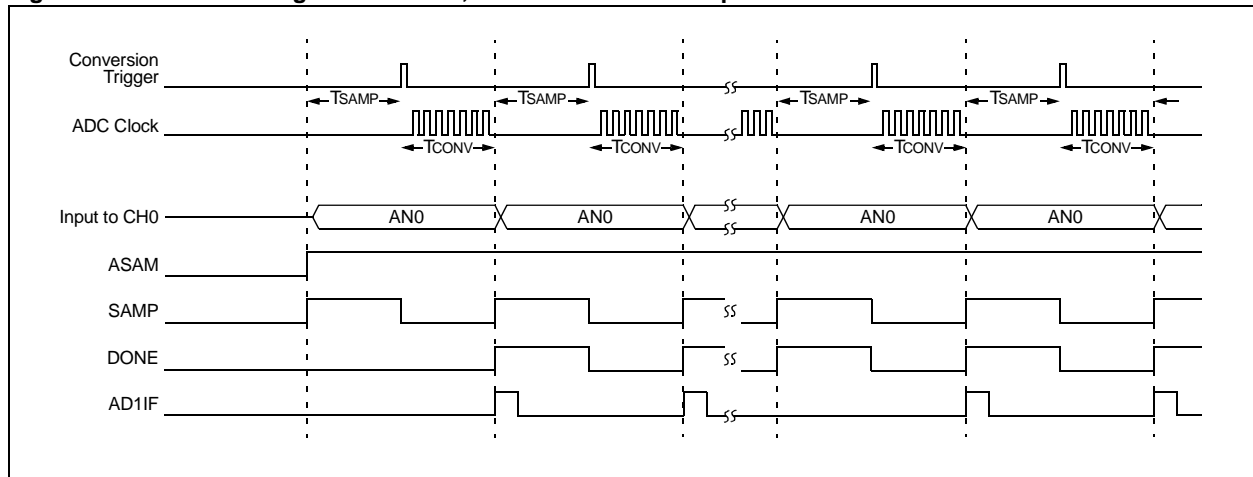
The following configuration examples show the Analog-to-Digital operation in different sampling and buffering configurations. In each example, setting the ASAM bit starts automatic sampling. A conversion trigger ends sampling and starts conversion.

16.11.1 Sampling and Converting a Single Channel, Multiple Times

Figure 16-32 and Table 16-19 illustrate a basic configuration of the ADC. In this case, one ADC input, AN0, is sampled by one S&H channel, CH0, and converted. The results are stored in the user-configured DMA RAM buffer. This process repeats 16 times until the buffer is full and then the DMA module generates an interrupt. The entire process then repeats.

The CHPS<1:0> bits specify that only S&H CH0 is active. With ALTS clear, only the MUXA inputs are active. The CH0SA<5:0> bits and CH0NA bit are specified (AN0-VREF-) as the input to the S&H channel. All other input selection bits are not used.

Figure 16-32: Converting One Channel, 16 Times/DMA Interrupt



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Table 16-19: Converting One Channel, 16 Times per DMA Interrupt

CONTROL BITS		OPERATION SEQUENCE	
Sequence Select			
SMPI<4:0> = 00000	DMA Address Increments After Every Sample/Conversion Operation	Sample MUXA Inputs: AN0 ≥ CH0	Convert CH0
CHPS<1:0> = 00	Sample Channel CH0	Sample MUXA Inputs: AN0 ≥ CH0	Convert CH0
SIMSAM = n/a	Not Applicable for Single Channel Sample	Sample MUXA Inputs: AN0 ≥ CH0	Convert CH0
ADDMABM = 1	DMA Buffer Written in Order of Conversion	Sample MUXA Inputs: AN0 ≥ CH0	Convert CH0
DMABL<2:0> = 100	16-Word Buffer Allocated to Analog Input	Sample MUXA Inputs: AN0 ≥ CH0	Convert CH0
ALTS = 0	Always Use MUXA Input Select	Sample MUXA Inputs: AN0 ≥ CH0	Convert CH0
ADDMAEN = 1	Use DMA with ADC	Sample MUXA Inputs: AN0 ≥ CH0	Convert CH0
MUXA Input Select		Sample MUXA Inputs: AN0 ≥ CH0	Convert CH0
CH0SA<5:0> = 000000	Select AN0 for CH0+ Input	Sample MUXA Inputs: AN0 ≥ CH0	Convert CH0
CH0NA = 0	Select VREF- for CH0- Input	Sample MUXA Inputs: AN0 ≥ CH0	Convert CH0
CSCNA = 0	No Input Scan	Sample MUXA Inputs: AN0 ≥ CH0	Convert CH0
CSS<15:0> = n/a	Scan Input Select Unused	Sample MUXA Inputs: AN0 ≥ CH0	Convert CH0
CH123SA<2:0> = n/a	Channels CH1, CH2, CH3+ Input Unused	Sample MUXA Inputs: AN0 ≥ CH0	Convert CH0
CH123NA<1:0> = n/a	Channels CH1, CH2, CH3- Input Unused	Sample MUXA Inputs: AN0 ≥ CH0	Convert CH0
MUXB Input Select		Sample MUXA Inputs: AN0 ≥ CH0	Convert CH0
CH0SB<5:0> = n/a	Channel CH0+ Input Unused	Sample MUXA Inputs: AN0 ≥ CH0	Convert CH0
CH0NB = n/a	Channel CH0- Input Unused		DMA Interrupt
CH123SB<2:0> = n/a	Channels CH1, CH2, CH3+ Input Unused		Repeat
CH123NB<1:0> = n/a	Channels CH1, CH2, CH3- Input Unused		
DMA Buffer @ First DMA Interrupt		DMA Buffer @ Second DMA Interrupt	
AN0 Sample 1		AN0 Sample 17	
AN0 Sample 2		AN0 Sample 18	
AN0 Sample 3		AN0 Sample 19	
AN0 Sample 4		AN0 Sample 20	
AN0 Sample 5		AN0 Sample 21	
AN0 Sample 6		AN0 Sample 22	
AN0 Sample 7		AN0 Sample 23	
AN0 Sample 8		AN0 Sample 24	
AN0 Sample 9		AN0 Sample 25	
AN0 Sample 10		AN0 Sample 26	
AN0 Sample 11		AN0 Sample 27	
AN0 Sample 12		AN0 Sample 28	
AN0 Sample 13		AN0 Sample 29	
AN0 Sample 14		AN0 Sample 30	
AN0 Sample 15		AN0 Sample 31	
AN0 Sample 16		AN0 Sample 32	

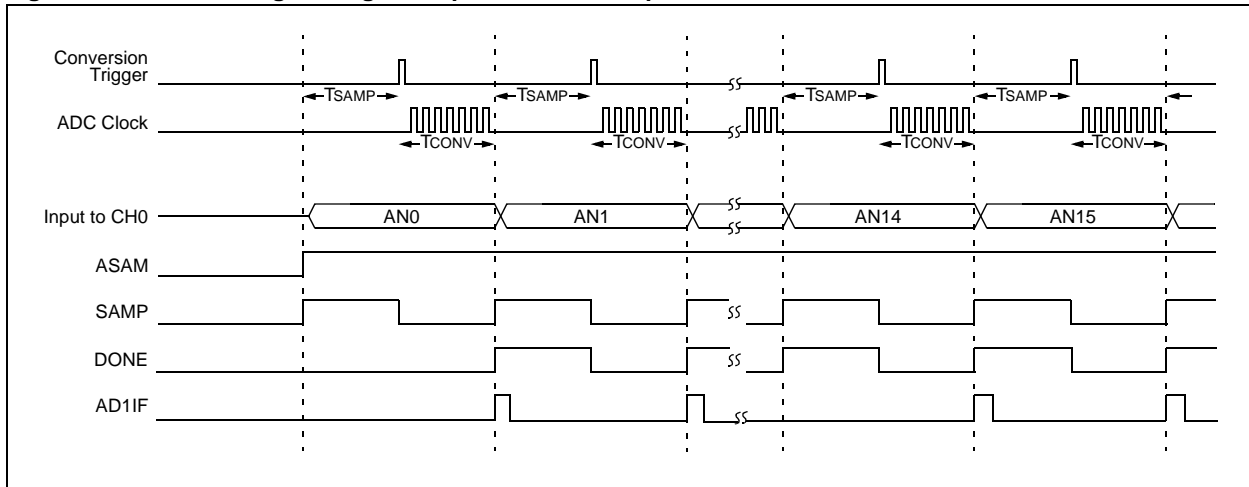
Note: The DMA module must be configured correctly to compliment the ADC module.

16.11.2 Analog-to-Digital Conversions While Scanning Through 16 Analog Inputs

Figure 16-33 and Table 16-20 illustrate a typical setup, where all available analog input channels are sampled by one S&H channel, CH0, and converted. The Set Scan Input Selection bit (CSCNA) in ADC Control Register 2 (ADxCON2<10>) specifies the scanning of the ADC inputs to the CH0 positive input. Other conditions are similar to those described in [Section 16.10.1 “Sampling and Converting a Single Channel Multiple Times”](#).

Initially, the AN0 input is sampled by CH0 and converted. The result is stored in the user-configured DMA buffer. Then, the AN1 input is sampled and converted. This process of scanning the inputs repeats 16 times until the buffer is full. Then the DMA module generates an interrupt. The entire process then repeats.

Figure 16-33: Scanning Through 16 Inputs/DMA Interrupt

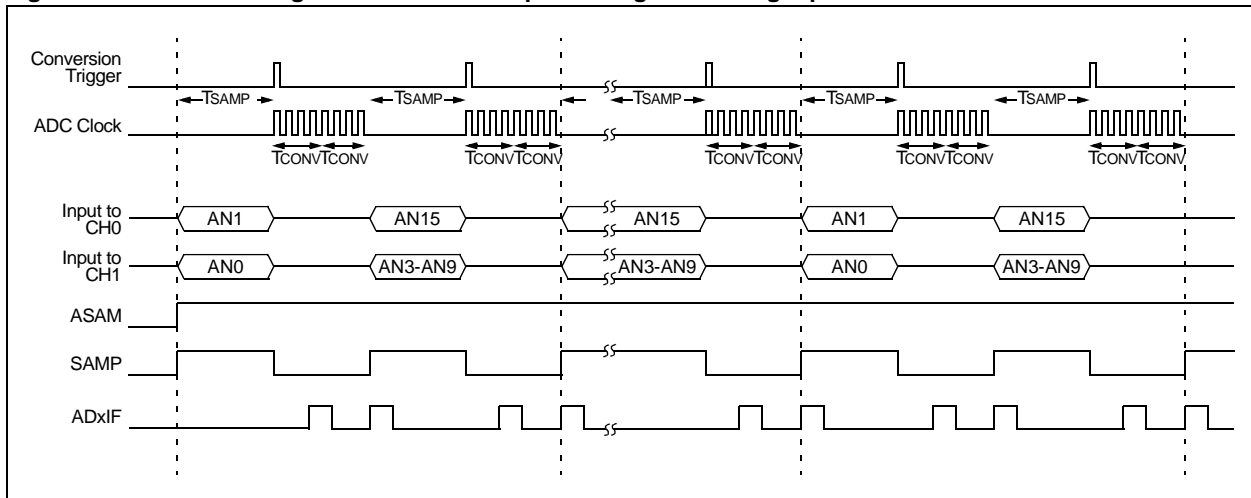


16.11.3 Using Alternating MUXA, MUXB Input Selections

Figure 16-34 and Table 16-21 demonstrate alternate sampling of the inputs assigned to MUXA and MUXB. In this example, two channels are enabled to sample simultaneously. Setting the ALTS bit (ADCxCON2<0>) enables alternating input selections. The first sample uses the MUXA inputs, specified by the CH0SA<5:0>, CH0NA, CH123SA<2:0> and CH123NA<1:0> bits. The next sample uses the MUXB inputs, specified by the CH0SB<5:0>, CH0NB, CH123SB<2:0> and CH123NB<1:0> bits. In this example, one of the MUXB input specifications uses two analog inputs as a differential source to the S&H, sampling (AN3-AN9).

Using four S&H channels without alternating input selections results in the same number of conversions as this example, using two channels with alternating input selections. However, because the CH1, CH2 and CH3 channels are more limited in the selectivity of the analog inputs, this example method provides more flexibility of input selection than using four channels.

Figure 16-34: Converting Two Sets of Two Inputs Using Alternating Input Selections



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Table 16-21: Converting Two Sets of Two Inputs Using Alternating Input Selections

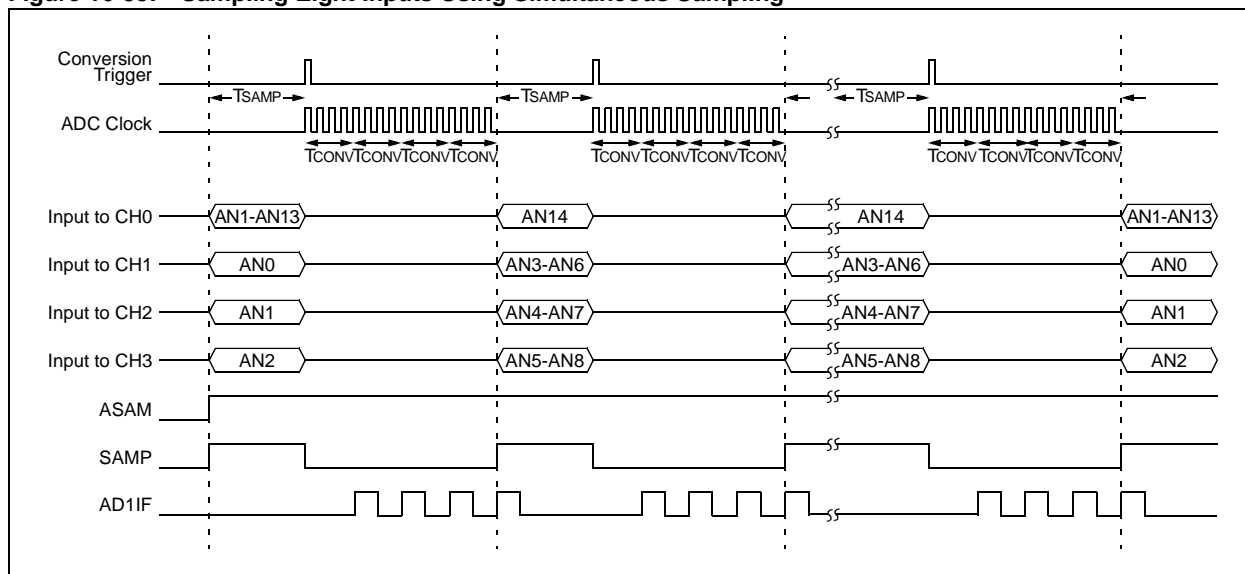
CONTROL BITS		OPERATION SEQUENCE	
Sequence Select			
SMPI<4:0> = 00001 DMA Address Increments After Every 2nd Sample/Conversion Operation		Sample MUXA Inputs: AN1 ≥ CH0, AN0 ≥ CH1	
		Convert CH0	
		Convert CH1	
CHPS<1:0> = 01 Sample Channels CH0, CH1		Sample MUXB Inputs: AN15 ≥ CH0, (AN3-AN9) ≥ CH1	
		Convert CH0	
		Convert CH1	
SIMSAM = 1 Sample All Channels Simultaneously		Sample MUXA Inputs: AN1 ≥ CH0, AN0 ≥ CH1	
		Convert CH0	
		Convert CH1	
ADDMABM = 1 DMA Buffer Written in Order of Conversion		Sample MUXB Inputs: AN15 ≥ CH0, (AN3-AN9) ≥ CH1	
		Convert CH0	
ALTS = 1 Alternate MUXA/MUXB Input Select		Convert CH1	
ADDMAEN = 1 Use DMA with ADC		DMA Interrupt	
		Sample MUXA Inputs: AN1 ≥ CH0, AN0 ≥ CH1	
		Convert CH0	
		Convert CH1	
		Sample MUXB Inputs: AN15 ≥ CH0, (AN3-AN9) ≥ CH1	
		Convert CH0	
		Convert CH1	
		Sample MUXA Inputs: AN1 ≥ CH0, AN0 ≥ CH1	
		Convert CH0	
		Convert CH1	
		Sample MUXB Inputs: AN15 ≥ CH0, (AN3-AN9) ≥ CH1	
		Convert CH0	
		Convert CH1	
		DMA Interrupt	
		Repeat	
MUXA Input Select			
CH0SA<5:0> = 000001 Select AN1 for CH0+ Input			
CH0NA = 0 Select VREF- for CH0- Input			
CSCNA = 0 No Input Scan			
CSS<15:0> = n/a Scan Input Select Unused			
CH123SA<2:0> = 000 CH1+ = AN0, CH2+ = AN1, CH3+ = AN2			
CH123NA<1:0> = 0x CH1-, CH2-, CH3- = VREF-			
MUXB Input Select			
CH0SB<5:0> = 111111 Select AN15 for CH0+ Input			
CH0NB = 0 Select VREF- for CH0- Input			
CH123SB<2:0> = 111 CH1+ = AN3, CH2+ = AN4, CH3+ = AN5			
CH123NB<1:0> = 11 CH1- = AN9, CH2- = AN10, CH3- = AN11			
DMA Buffer @ First DMA Interrupt		DMA Buffer @ Second DMA Interrupt	
AN1 Sample 1		AN1 Sample 3	
AN0 Sample 1		AN0 Sample 3	
AN15 Sample 1		AN15 Sample 3	
(AN3-AN9) Sample 1		(AN3-AN9) Sample 3	

16.11.4 Sampling Eight Inputs Using Simultaneous Sampling

Figure 16-35 and Table 16-22 demonstrate identical setups, with the exception that this example uses simultaneous sampling ($\text{SIMSAM} = 1$), and Figure 16-36 uses sequential sampling ($\text{SIMSAM} = 0$). Both examples use alternating inputs and specify differential inputs to the S&H.

Figure 16-35 and Table 16-22 demonstrate simultaneous sampling. When converting more than one channel, and selecting simultaneous sampling, the ADC module samples all channels, then performs the required conversions in sequence. In this example, with the ASAM bit set, sampling begins after the conversion is complete.

Figure 16-35: Sampling Eight Inputs Using Simultaneous Sampling



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Table 16-22: Sampling Eight Inputs Using Simultaneous Sampling

CONTROL BITS		OPERATION SEQUENCE	
Sequence Select			
SMPI<4:0> = 00001	DMA Address Increments After Every 2nd Sample/Conversion Operation	Sample MUXA Inputs: (AN1-AN13) ≥ CH0, AN0 ≥ CH1, AN1 ≥ CH2, AN2 ≥ CH3	
CHPS<1:0> = 1x	Sample Channels CH0, CH1, CH2, CH3	Convert CH0	
SIMSAM = 1	Sample All Channels Simultaneously	Convert CH1	
ADDMABM = 0	DMA Buffer Written in Order of Conversion	Convert CH2	
ALTS = 1	Alternate MUXA/MUXB Input Select	Convert CH3	
ADDMAEN = 1	Use DMA with ADC	Sample MUXB Inputs: AN14 ≥ CH0, (AN3-AN6) ≥ CH1, (AN4-AN7) ≥ CH2, (AN5-AN8) ≥ CH3	
MUXA Input Select		Convert CH0	
CH0SA<5:0> = 111101	Select AN13 for CH0+ Input	Convert CH1	
CH0NA = 1	Select AN1 for CH0- Input	Convert CH2	
CSCNA = 0	No Input Scan	Convert CH3	
CSS<15:0> = n/a	Scan Input Select Unused	Sample MUXB Inputs: AN14 ≥ CH0, (AN3-AN6) ≥ CH1, (AN4-AN7) ≥ CH2, (AN5-AN8) ≥ CH3	
CH123SA<2:0> = 000	CH1+ = AN0, CH2+ = AN1, CH3+ = AN2	Convert CH0	
CH123NA<1:0> = 0x	CH1-, CH2-, CH3- = VREF-	Convert CH1	
MUXB Input Select		Convert CH2	
CH0SB<5:0> = 111110	Select AN14 for CH0+ Input	Convert CH3	
CH0NB = 0	Select VREF- for CH0- Input	DMA Interrupt	
CH123SB<2:0> = 111	CH1+ = AN3, CH2+ = AN4, CH3+ = AN5	Repeat	
CH123NB<1:0> = 10	CH1- = AN6, CH2- = AN7, CH3- = AN8		
DMA Buffer @ First DMA Interrupt		DMA Buffer @ Second DMA Interrupt	
(AN1-AN13) Sample 1		(AN1-AN13) Sample 3	
AN0 Sample 1		AN0 Sample 3	
AN1 Sample 1		AN1 Sample 3	
AN2 Sample 1		AN2 Sample 3	
AN14 Sample 1		AN14 Sample 3	
(AN3-AN6) Sample 1		(AN3-AN6) Sample 3	
(AN4-AN7) Sample 1		(AN4-AN7) Sample 3	
(AN5-AN8) Sample 1		(AN5-AN8) Sample 3	
(AN1-AN13) Sample 1		(AN1-AN13) Sample 4	
AN0 Sample 2		AN0 Sample 4	
AN1 Sample 2		AN1 Sample 4	
AN2 Sample 2		AN2 Sample 4	
AN14 Sample 2		AN14 Sample 4	
(AN3-AN6) Sample 2		(AN3-AN6) Sample 4	
(AN4-AN7) Sample 2		(AN4-AN7) Sample 4	
(AN5-AN8) Sample 2		(AN5-AN8) Sample 4	

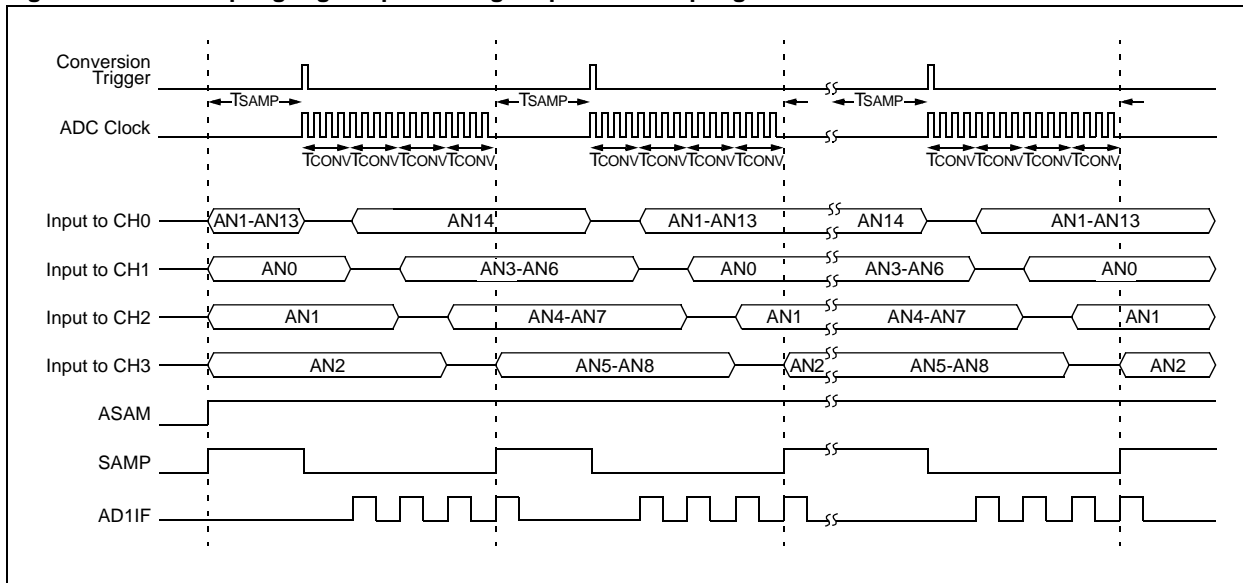
16.11.5 Sampling Eight Inputs Using Sequential Sampling

Figure 16-36 and Table 16-23 demonstrate sequential sampling. When converting more than one channel and selecting sequential sampling, the ADC module starts sampling a channel at the earliest opportunity, then performs the required conversions in sequence. In this example, with the ASAM bit set, sampling of a channel begins after the conversion of that channel completes.

When ASAM is clear, sampling does not resume after conversion completion, but occurs when the SAMP bit (ADxCON1<1>) is set.

When utilizing more than one channel, sequential sampling provides more sampling time since a channel can be sampled while a conversion occurs on another channel.

Figure 16-36: Sampling Eight Inputs Using Sequential Sampling



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Table 16-23: Sampling Eight Inputs Using Sequential Sampling

CONTROL BITS		OPERATION SEQUENCE	
Sequence Select		Sample: (AN1-AN13) ≥ CH0	
SMPI<4:0> = 00001	DMA Address Increments After Every 2nd Sample/Conversion Operation		Convert CH0
CHPS<1:0> = 1x	Sample Channels CH0, CH1, CH2, CH3	Sample: AN0 ≥ CH1	
SIMSAM = 0	Sample All Channels Sequentially		Convert CH1
ADDMABM = 1	DMA Buffer Written in Order of Conversion	Sample: AN1 ≥ CH2	
ALTS = 1	Alternate MUXA/MUXB Input Select		Convert CH2
ADDMAEN = 1	Use DMA with ADC	Sample: AN2 ≥ CH3	
			Convert CH3
		Sample: AN14 ≥ CH0	
			Convert CH0
		Sample: (AN3-AN6) ≥ CH1	
			Convert CH1
		Sample: (AN4-AN7) ≥ CH2	
			Convert CH2
		Sample: (AN5-AN8) ≥ CH3	
			Convert CH3
		Sample: (AN1-AN13) ≥ CH0	
			Convert CH0
		Sample: AN0 ≥ CH1	
			Convert CH1
		Sample: AN1 ≥ CH2	
			Convert CH2
		Sample: AN2 ≥ CH3	
			Convert CH3
		Sample: AN14 ≥ CH0	
			Convert CH0
		Sample: (AN3-AN6) ≥ CH1	
			Convert CH1
		Sample: (AN4-AN7) ≥ CH2	
			Convert CH2
		Sample: (AN5-AN8) ≥ CH3	
			Convert CH3
		DMA Interrupt	
		Repeat	
MUXA Input Select			
CH0SA<5:0> = 011110	Select AN6 for CH0+ Input		
CH0NA = 0	Select VREF- for CH0- Input		
CSCNA = 0	No Input Scan		
CSS<15:0> = n/a	Scan Input Select Unused		
CH123SA<2:0> = 000	CH1+ = AN0, CH2+ = AN1, CH3+ = AN2		
CH123NA<1:0> = 0x	CH1-, CH2-, CH3- = VREF-		
MUXB Input Select			
CH0SB<5:0> = 011111	Select AN7 for CH0+ Input		
CH0NB = 0	Select VREF- for CH0- Input		
CH123SB<2:0> = 111	CH1+ = AN3, CH2+ = AN4, CH3+ = AN5		
CH123NB<1:0> = 0x	CH1-, CH2-, CH3- = VREF-		
DMA Buffer @ First DMA Interrupt		DMA Buffer @ Second DMA Interrupt	
(AN1-AN13) Sample 1		(AN1-AN13) Sample 3	
AN0 Sample 1		AN0 Sample 3	
AN1 Sample 1		AN1 Sample 3	
AN2 Sample 1		AN2 Sample 3	
AN14 Sample 1		AN14 Sample 3	
(AN3-AN6) Sample 1		(AN3-AN6) Sample 3	
(AN4-AN7) Sample 1		(AN4-AN7) Sample 3	
(AN5-AN8) Sample 1		(AN5-AN8) Sample 3	
(AN1-AN13) Sample 2		(AN1-AN13) Sample 4	
AN0 Sample 2		AN0 Sample 4	
AN1 Sample 2		AN1 Sample 4	
AN2 Sample 2		AN2 Sample 28	
AN14 Sample 2		AN14 Sample 4	
(AN3-AN6) Sample 2		(AN3-AN6) Sample 4	
(AN4-AN7) Sample 2		(AN4-AN7) Sample 4	
(AN5-AN8) Sample 2		(AN5-AN8) Sample 4	

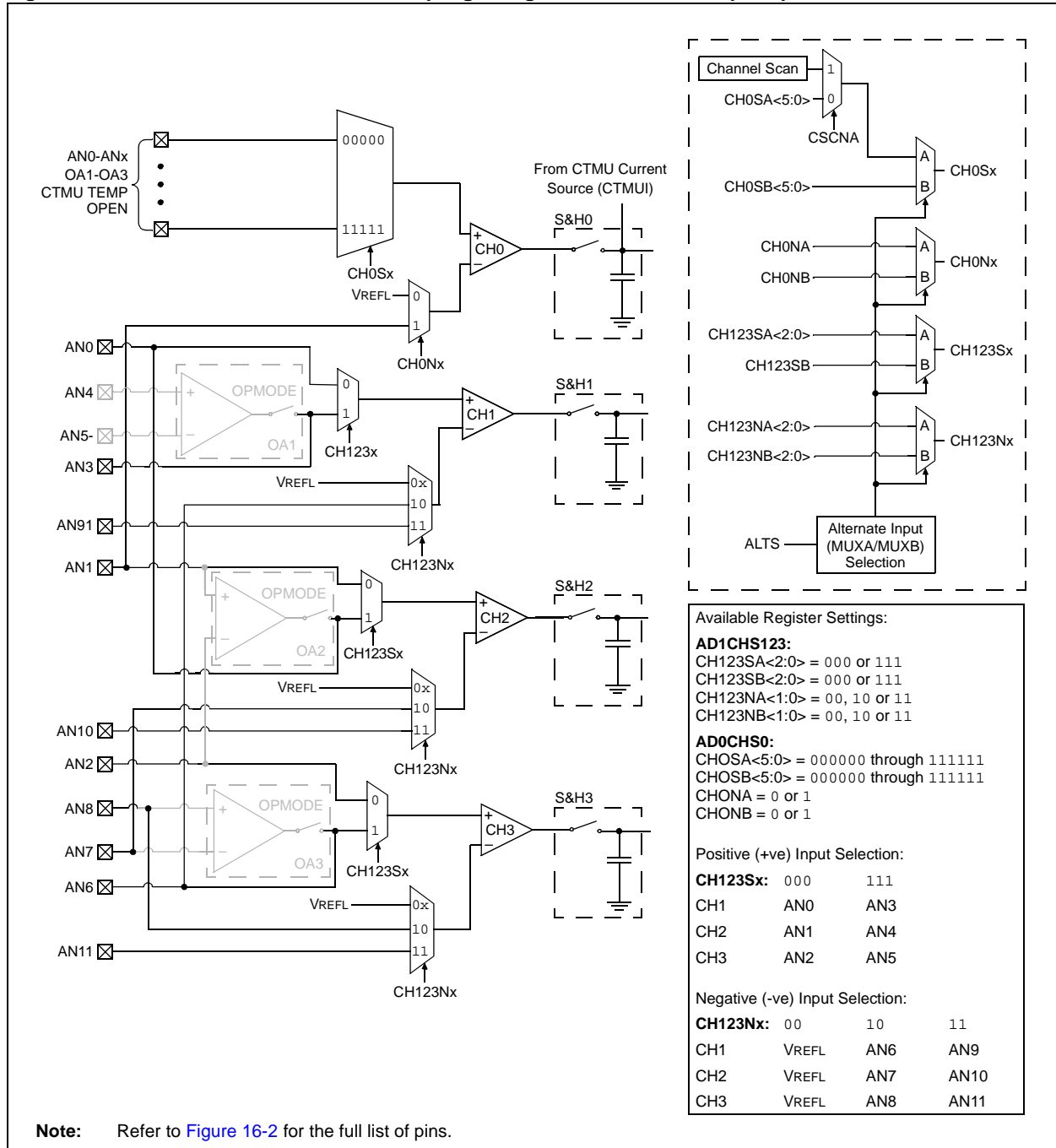
16.12 CONFIGURATION EXAMPLES FOR DEVICES WITH INTERNAL OP AMPS

The block diagram in Figure 16-2 depicts all of the available connection options to the four Sample-and-Hold (S&H) amplifiers (CH0-CH3) for devices that include internal op amps. Depending on the particular device pinout, the ADC module can have up to 16 analog input pins, designated AN0 through AN15, which are shared with op amps pins.

The following three examples (Figure 16-37, Figure 16-38 and Figure 16-39) illustrate the effects of internal op amp use on the ability of the device to simultaneously sample. These three examples show the use of no op amps, all three op amps and two op amps.

Figure 16-37 shows the use of no op amps, with all of the ANx inputs available to sample external voltages in MUXA/MUXB and alternate simultaneous sampling schemes.

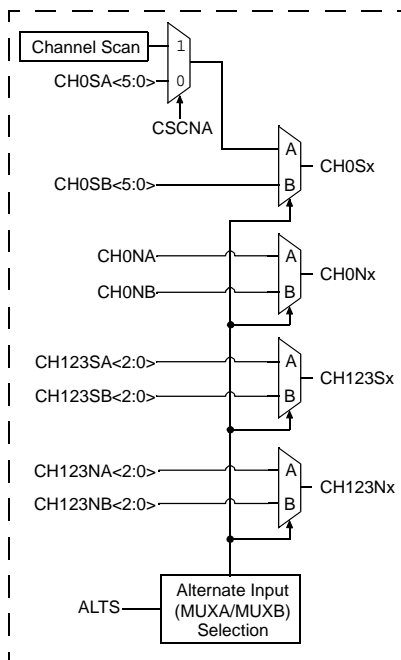
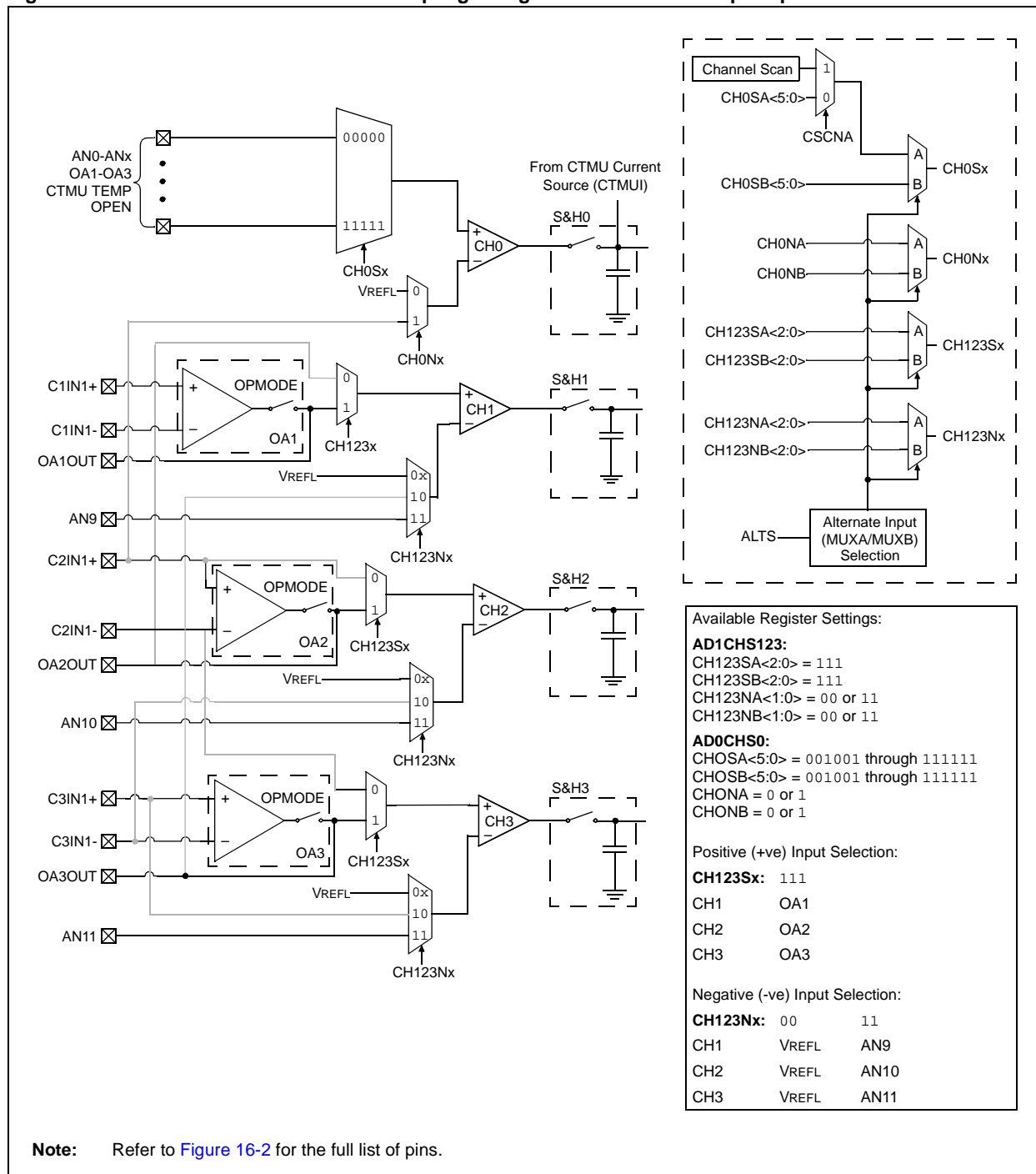
Figure 16-37: Simultaneous/Alternate Sampling Using ANx Pins with All Op Amps Disabled



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It is important to note that in Figure 16-38, where all three op amps (Op Amp 1, Op Amp 2 and Op Amp 3) are used, all of the analog channels for MUXA sampling are used for op amp functionality. This limits the usefulness of the alternate MUXA/MUXB sampling scheme.

Figure 16-38: Simultaneous/Alternate Sampling Using ANx Pins and Two Op Amps



Available Register Settings:

AD1CHS123:

CH123SA<2:0> = 111

CH123SB<2:0> = 111

CH123NA<1:0> = 00 or 11

CH123NB<1:0> = 00 or 11

AD0CHS0:

CH0SA<5:0> = 001001 through 111111

CH0SB<5:0> = 001001 through 111111

CH0NA = 0 or 1

CH0NB = 0 or 1

Positive (+ve) Input Selection:

CH123Sx: 111

CH1 OA1

CH2 OA2

CH3 OA3

Negative (-ve) Input Selection:

CH123Nx: 00 11

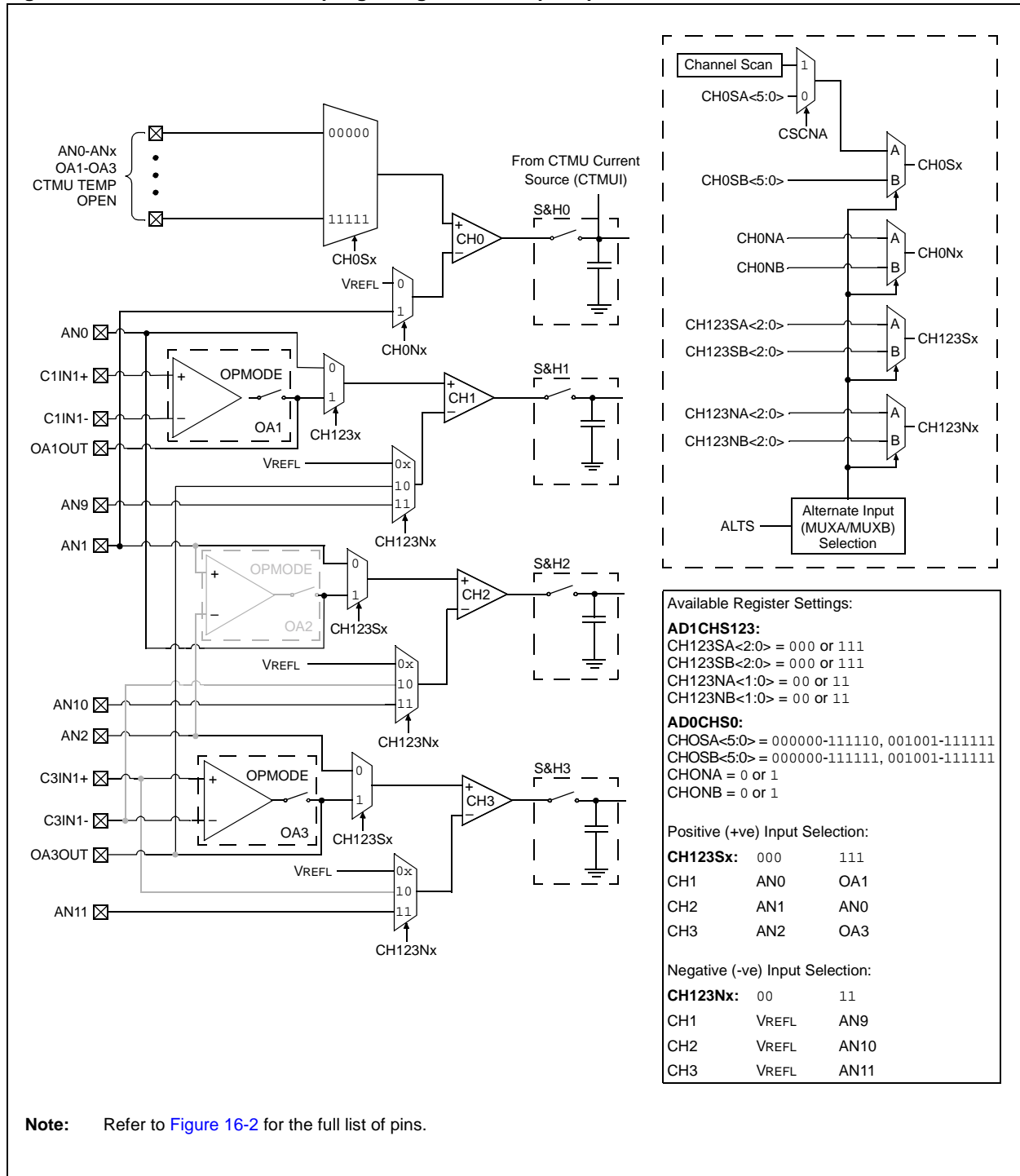
CH1 VREFL AN9

CH2 VREFL AN10

CH3 VREFL AN11

In [Figure 16-39](#), Op Amp 1 and Op Amp 3 are used, while Op Amp 2 remains disabled. This frees AN0, AN1 and AN2 to be used for sampling external voltages. This configuration enables alternate MUXA/MUX B sampling of up to four channels on MUXA, and two op amps and two ANx channels on MUXB. Note that AN0 is duplicated on each sampling.

Figure 16-39: Simultaneous Sampling Using All Three Op Amps



16.13 ANALOG-TO-DIGITAL SAMPLING REQUIREMENTS

The analog input models of the 10-bit and 12-bit ADC modes are shown in [Figure 16-40](#) and [Figure 16-41](#). The total sampling time for the Analog-to-Digital conversion is a function of the internal amplifier settling time and the holding capacitor charge time.

For the ADC module to meet its specified accuracy, the Charge Holding Capacitor (CHOLD) must be allowed to fully charge to the voltage level on the analog input pin. The Analog Output Source (Rs) impedance, the Interconnect Resistance (RIC) impedance and the internal Sampling Switch Resistance (RSS) impedance combine to directly affect the time required to charge the capacitor, CHOLD. Therefore, the combined impedance must be small enough to fully charge the holding capacitor within the chosen sample time. To minimize the effects of pin leakage currents on the accuracy of the ADC module, the maximum recommended source impedance, Rs, is 200Ω. After the analog input channel is selected, this sampling function must be completed prior to starting the conversion. The internal holding capacitor is in a discharged state prior to each sample operation.

A minimum time period must be enabled between conversions for the sample time. For more information on the minimum sampling time for a device, refer to the “**Electrical Characteristics**” chapter in the specific device data sheet.

Figure 16-40: Analog Input Model (10-Bit Mode)

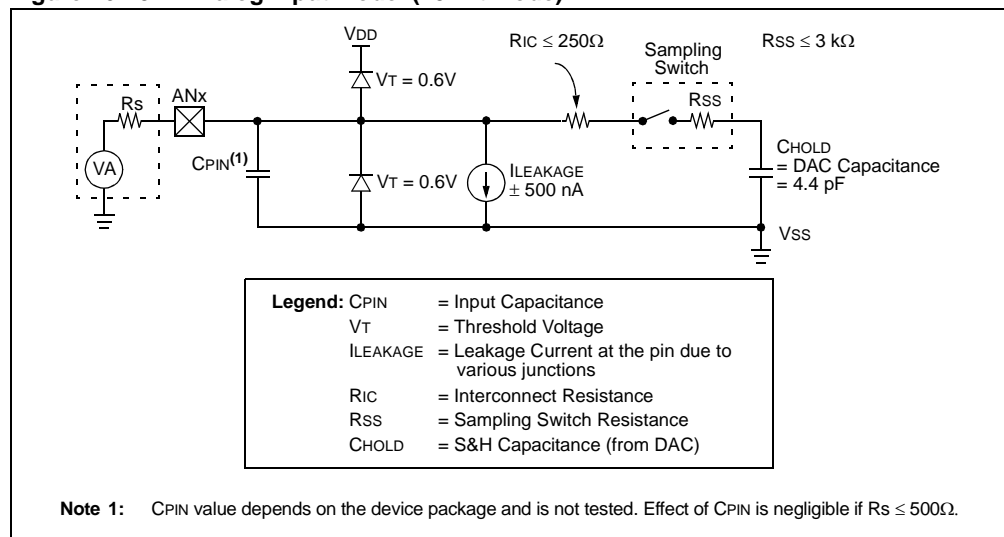
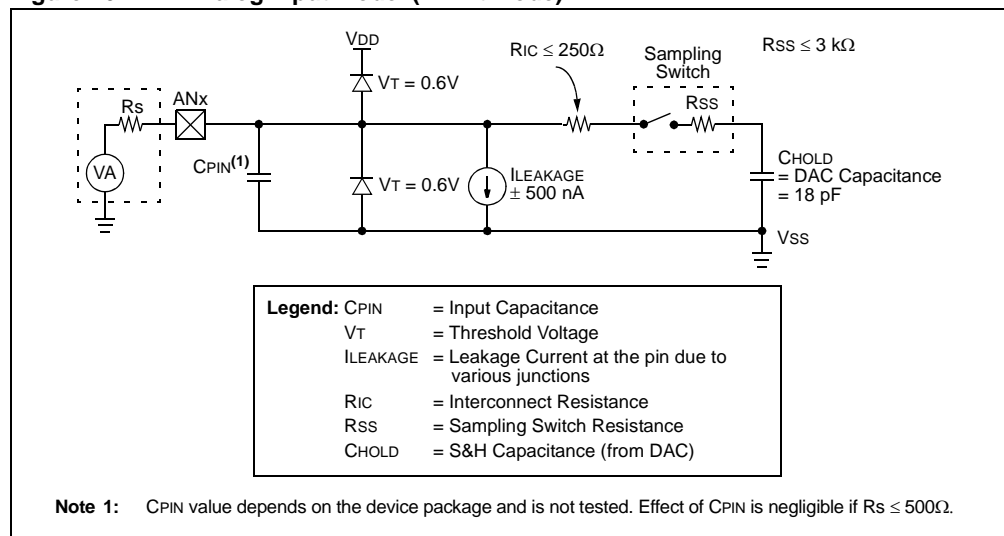


Figure 16-41: Analog Input Model (12-Bit Mode)



16.14 READING THE ADC RESULT BUFFER

The RAM is 10 bits or 12 bits wide, but the data is automatically formatted to one of four selectable formats when the buffer is read. The FORM<1:0> bits (ADxCON1<9:8>) select the format. The formatting hardware provides a 16-bit result on the data bus for all of the data formats. Figure 16-42 and Figure 16-43 illustrate the data output formats that can be selected using the FORM<1:0> control bits.

Figure 16-42: Analog-to-Digital Output Data Formats (10-Bit Mode)

RAM Contents:	<table><tr><td>d09</td><td>d08</td><td>d07</td><td>d06</td><td>d05</td><td>d04</td><td>d03</td><td>d02</td><td>d01</td><td>d00</td></tr></table>										d09	d08	d07	d06	d05	d04	d03	d02	d01	d00
d09	d08	d07	d06	d05	d04	d03	d02	d01	d00											
Read to Bus:																				
Unsigned Integer	<table><tr><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>d09</td><td>d08</td><td>d07</td><td>d06</td><td>d05</td><td>d04</td><td>d03</td><td>d02</td><td>d01</td><td>d00</td></tr></table>	0	0	0	0	0	0	d09	d08	d07	d06	d05	d04	d03	d02	d01	d00			
0	0	0	0	0	0	d09	d08	d07	d06	d05	d04	d03	d02	d01	d00					
Signed Integer	<table><tr><td>$\overline{\text{d09}}$</td><td>$\overline{\text{d09}}$</td><td>$\overline{\text{d09}}$</td><td>$\overline{\text{d09}}$</td><td>$\overline{\text{d09}}$</td><td>$\overline{\text{d09}}$</td><td>$\overline{\text{d09}}$</td><td>d08</td><td>d07</td><td>d06</td><td>d05</td><td>d04</td><td>d03</td><td>d02</td><td>d01</td><td>d00</td></tr></table>	$\overline{\text{d09}}$	$\overline{\text{d09}}$	$\overline{\text{d09}}$	$\overline{\text{d09}}$	$\overline{\text{d09}}$	$\overline{\text{d09}}$	$\overline{\text{d09}}$	d08	d07	d06	d05	d04	d03	d02	d01	d00			
$\overline{\text{d09}}$	$\overline{\text{d09}}$	$\overline{\text{d09}}$	$\overline{\text{d09}}$	$\overline{\text{d09}}$	$\overline{\text{d09}}$	$\overline{\text{d09}}$	d08	d07	d06	d05	d04	d03	d02	d01	d00					
Unsigned Fractional (1.15)	<table><tr><td>d09</td><td>d08</td><td>d07</td><td>d06</td><td>d05</td><td>d04</td><td>d03</td><td>d02</td><td>d01</td><td>d00</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr></table>	d09	d08	d07	d06	d05	d04	d03	d02	d01	d00	0	0	0	0	0	0			
d09	d08	d07	d06	d05	d04	d03	d02	d01	d00	0	0	0	0	0	0					
Signed Fractional (1.15)	<table><tr><td>$\overline{\text{d09}}$</td><td>d08</td><td>d07</td><td>d06</td><td>d05</td><td>d04</td><td>d03</td><td>d02</td><td>d01</td><td>d00</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr></table>	$\overline{\text{d09}}$	d08	d07	d06	d05	d04	d03	d02	d01	d00	0	0	0	0	0	0			
$\overline{\text{d09}}$	d08	d07	d06	d05	d04	d03	d02	d01	d00	0	0	0	0	0	0					

Figure 16-43: Analog-to-Digital Output Data Formats (12-Bit Mode)

RAM Contents:	<table><tr><td>d11</td><td>d10</td><td>d09</td><td>d08</td><td>d07</td><td>d06</td><td>d05</td><td>d04</td><td>d03</td><td>d02</td><td>d01</td><td>d00</td></tr></table>																d11	d10	d09	d08	d07	d06	d05	d04	d03	d02	d01	d00				
d11	d10	d09	d08	d07	d06	d05	d04	d03	d02	d01	d00																					
Read to Bus:																																
Unsigned Integer	<table><tr><td>0</td><td>0</td><td>0</td><td>0</td><td>d11</td><td>d10</td><td>d09</td><td>d08</td><td>d07</td><td>d06</td><td>d05</td><td>d04</td><td>d03</td><td>d02</td><td>d01</td><td>d00</td></tr></table>																0	0	0	0	d11	d10	d09	d08	d07	d06	d05	d04	d03	d02	d01	d00
0	0	0	0	d11	d10	d09	d08	d07	d06	d05	d04	d03	d02	d01	d00																	
Signed Integer	<table><tr><td>$\overline{\text{d11}}$</td><td>$\overline{\text{d11}}$</td><td>$\overline{\text{d11}}$</td><td>$\overline{\text{d11}}$</td><td>$\overline{\text{d11}}$</td><td>d10</td><td>d09</td><td>d08</td><td>d07</td><td>d06</td><td>d05</td><td>d04</td><td>d03</td><td>d02</td><td>d01</td><td>d00</td></tr></table>																$\overline{\text{d11}}$	$\overline{\text{d11}}$	$\overline{\text{d11}}$	$\overline{\text{d11}}$	$\overline{\text{d11}}$	d10	d09	d08	d07	d06	d05	d04	d03	d02	d01	d00
$\overline{\text{d11}}$	$\overline{\text{d11}}$	$\overline{\text{d11}}$	$\overline{\text{d11}}$	$\overline{\text{d11}}$	d10	d09	d08	d07	d06	d05	d04	d03	d02	d01	d00																	
Unsigned Fractional	<table><tr><td>d11</td><td>d10</td><td>d09</td><td>d08</td><td>d07</td><td>d06</td><td>d05</td><td>d04</td><td>d03</td><td>d02</td><td>d01</td><td>d00</td><td>0</td><td>0</td><td>0</td><td>0</td></tr></table>																d11	d10	d09	d08	d07	d06	d05	d04	d03	d02	d01	d00	0	0	0	0
d11	d10	d09	d08	d07	d06	d05	d04	d03	d02	d01	d00	0	0	0	0																	
Signed Fractional (1.15)	<table><tr><td>$\overline{\text{d11}}$</td><td>d10</td><td>d09</td><td>d08</td><td>d07</td><td>d06</td><td>d05</td><td>d04</td><td>d03</td><td>d02</td><td>d01</td><td>d00</td><td>0</td><td>0</td><td>0</td><td>0</td></tr></table>																$\overline{\text{d11}}$	d10	d09	d08	d07	d06	d05	d04	d03	d02	d01	d00	0	0	0	0
$\overline{\text{d11}}$	d10	d09	d08	d07	d06	d05	d04	d03	d02	d01	d00	0	0	0	0																	

Table 16-24 and Table 16-25 list the numerical equivalents of various result codes for 10-bit and 12-bit modes, respectively.

Table 16-24: Numerical Equivalents of Various Result Codes (10-Bit Mode)

VIN/VREF	10-Bit Output Code	16-Bit Integer Format	16-Bit Signed Integer Format	16-Bit Fractional Format	16-Bit Signed Fractional Format
1023/1024	11 1111 1111	0000 0011 1111 1111 = 1023	0000 0001 1111 1111 = 511	1111 1111 1100 0000 = 0.999	0111 1111 1100 0000 = 0.99804
1022/1024	11 1111 1110	0000 0011 1111 1110 = 1022	0000 0001 1111 1110 = 510	1111 1111 1000 0000 = 0.998	0111 1111 1000 0000 = 0.499609
⋮					
513/1024	10 0000 0001	0000 0010 0000 0001 = 513	0000 0000 0000 0001 = 1	1000 0000 0100 0000 = 0.501	0000 0000 0100 0000 = 0.00195
512/1024	10 0000 0000	0000 0010 0000 0000 = 512	0000 0000 0000 0000 = 0	1000 0000 0000 0000 = 0.500	0000 0000 0000 0000 = 0
511/1024	01 1111 1111	0000 0001 1111 1111 = 511	1111 1111 1111 1111 = -1	0111 1111 1100 0000 = .499	1111 1111 1100 0000 = -0.00195
⋮					
1/1024	00 0000 0001	0000 0000 0000 0001 = 1	1111 1110 0000 0001 = -511	0000 0000 0100 0000 = 0.001	1000 0000 0100 0000 = -0.99804
0/1024	00 0000 0000	0000 0000 0000 0000 = 0	1111 1110 0000 0000 = -512	0000 0000 0000 0000 = 0	1000 0000 0000 0000 = -1

Table 16-25: Numerical Equivalents of Various Result Codes (12-Bit Mode)

VIN/VREF	12-Bit Output Code	16-Bit Unsigned Integer Format	16-Bit Signed Integer Format	16-Bit Unsigned Fractional Format	16-Bit Signed Fractional Format
4095/4096	1111 1111 1111	0000 1111 1111 1111 = 4095	0000 0111 1111 1111 = 2047	1111 1111 1111 0000 = 0.9998	0111 1111 1111 0000 = 0.9995
4094/4096	1111 1111 1110	0000 1111 1111 1110 = 4094	0000 0111 1111 1110 = 2046	1111 1111 1110 0000 = 0.9995	0111 1111 1110 0000 = 0.9990
⋮					
2049/4096	1000 0000 0001	0000 1000 0000 0001 = 2049	0000 0000 0000 0001 = 1	1000 0000 0001 0000 = 0.5002	0000 0000 0001 0000 = 0.0005
2048/4096	1000 0000 0000	0000 1000 0000 0000 = 2048	0000 0000 0000 0000 = 0	1000 0000 0000 0000 = 0.500	0000 0000 0000 0000 = 0.000
2047/4096	0111 1111 1111	0000 0111 1111 1111 = 2047	1111 1111 1111 1111 = -1	0111 1111 1111 0000 = 0.4998	1111 1111 1111 0000 = -0.0005
⋮					
1/4096	0000 0000 0001	0000 0000 0000 0001 = 1	1111 1000 0000 0001 = -2047	0000 0000 0001 0000 = 0.0002	1000 0000 0001 0000 = -0.9995
0/4096	0000 0000 0000	0000 0000 0000 0000 = 0	1111 1000 0000 0000 = -2048	0000 0000 0000 0000 = 0	1000 0000 0000 0000 = -1.000

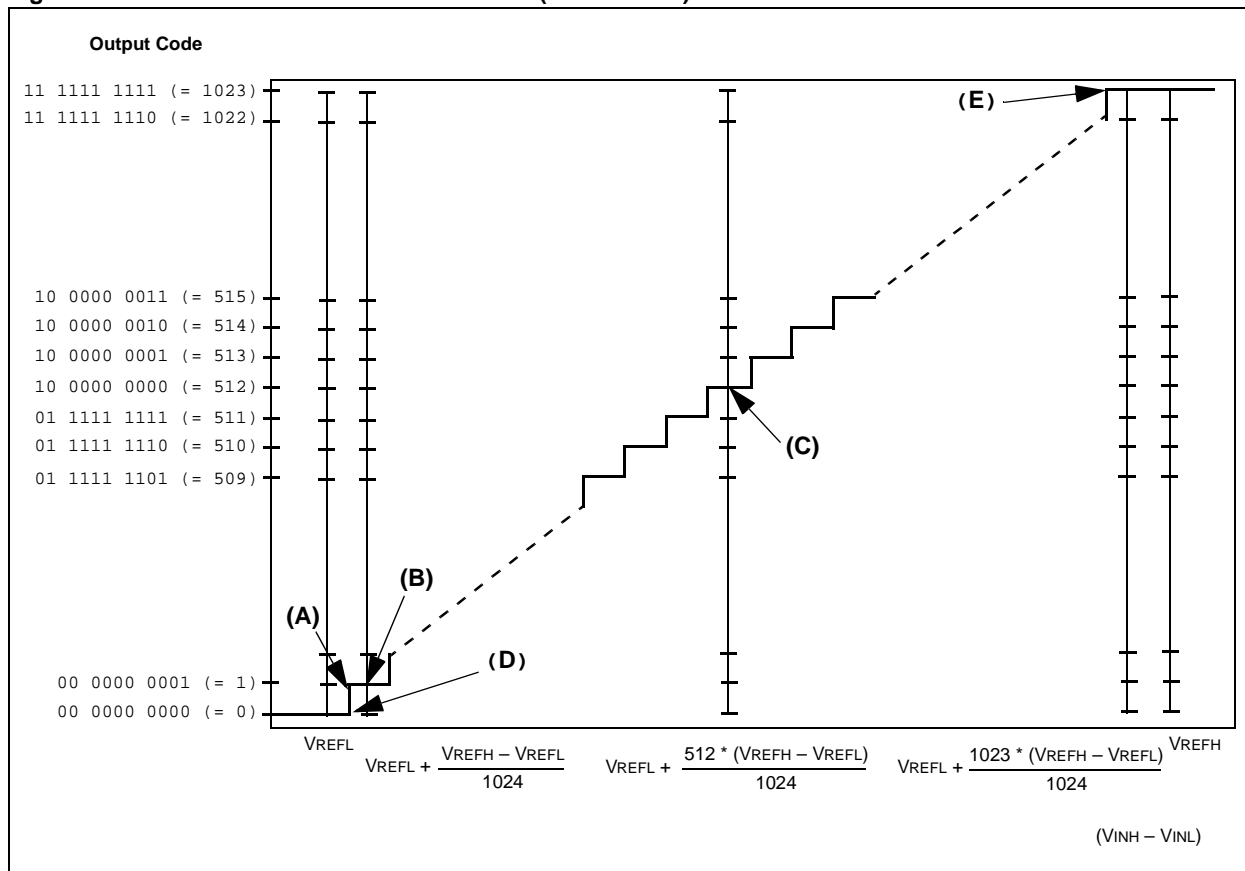
16.15 TRANSFER FUNCTIONS

16.15.1 10-Bit Mode

The ideal transfer function of the ADC module is shown in [Figure 16-44](#). The difference of the input voltages, ($V_{INH} - V_{INL}$), is compared to the reference voltages, ($V_{REFH} - V_{REFL}$).

- The first code transition (A) occurs when the input voltage is ($V_{REFH} - V_{REFL}/2048$) or 0.5 LSB
- The '00 0000 0001' code is centered at ($V_{REFH} - V_{REFL}/1024$) or 1.0 LSB (B)
- The '10 0000 0000' code is centered at ($512 * (V_{REFH} - V_{REFL})/1024$) (C)
- An input voltage less than ($1 * (V_{REFH} - V_{REFL})/2048$) converts as '00 0000 0000' (D)
- An input greater than ($2045 * (V_{REFH} - V_{REFL})/2048$) converts as '11 1111 1111' (E)

Figure 16-44: ADC Module Transfer Function (10-Bit Mode)

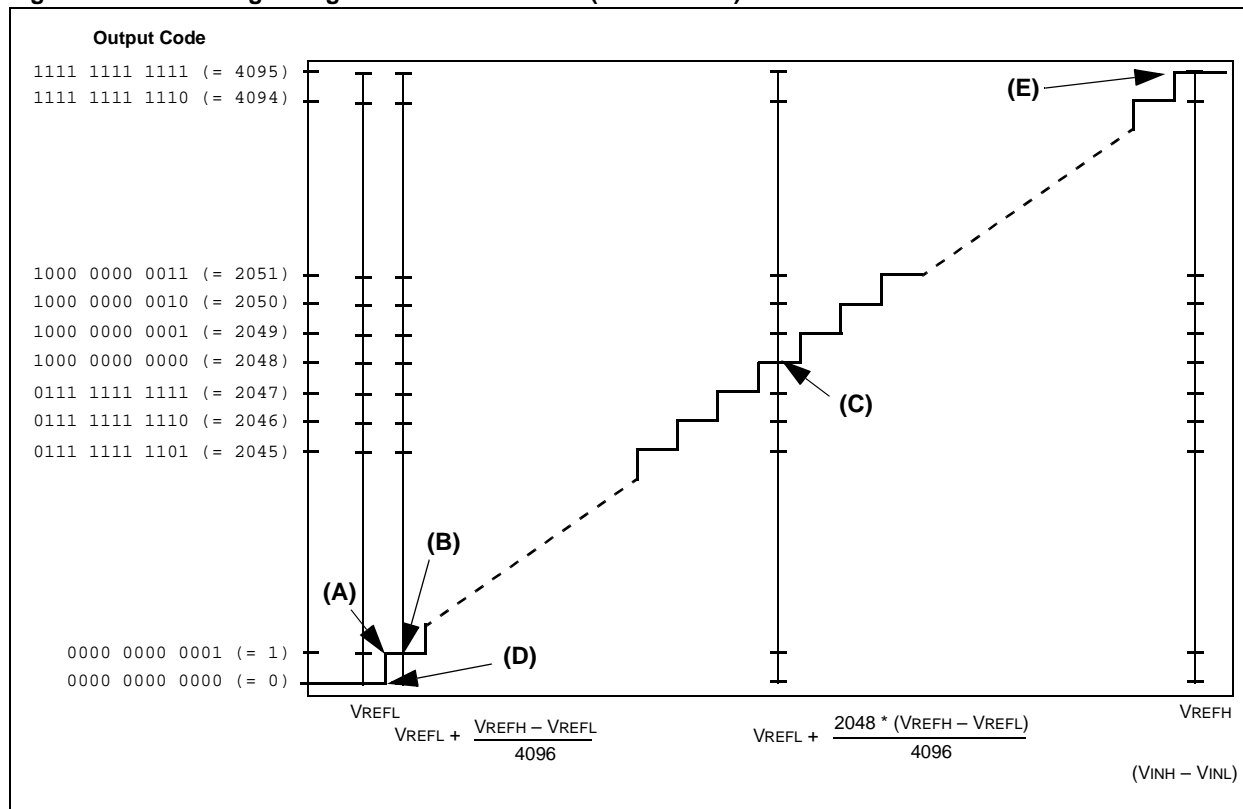


16.15.2 12-Bit Mode

The ideal transfer function of the ADC is shown in [Figure 16-45](#). The difference of the input voltages, $(V_{INH} - V_{INL})$, is compared to the reference voltages, $(V_{REFH} - V_{REFL})$.

- The first code transition (A) occurs when the input voltage is $(V_{REFH} - V_{REFL}/8192)$ or 0.5 LSb
- The '00 0000 0001' code is centered at $(V_{REFH} - V_{REFL}/4096)$ or 1.0 LSb (B)
- The '10 0000 0000' code is centered at $(2048 * (V_{REFH} - V_{REFL})/4096)$ (C)
- An input voltage less than $(1 * (V_{REFH} - V_{REFL})/8192)$ converts as '00 0000 0000' (D)
- An input greater than $(8192 * (V_{REFH} - V_{REFL})/8192)$ converts as '11 1111 1111' (E)

Figure 16-45: Analog-to-Digital Transfer Function (12-Bit Mode)



16.16 ADC ACCURACY/ERROR

Refer to the “**Electrical Characteristics**” chapter of the specific device data sheet for more information on the INL, DNL, gain and offset errors. In addition, see [Section 16.21 “Related Application Notes”](#) for a list of documents that discuss ADC accuracy.

16.17 CONNECTION CONSIDERATIONS

Since the analog inputs employ ESD protection, they have diodes to VDD and VSS. As a result, the analog input must be between VDD and VSS. If the input voltage exceeds this range by greater than 0.3V (either direction), one of the diodes becomes forward biased and it may damage the device if the input current specification is exceeded.

An external RC filter is sometimes added for anti-aliasing of the input signal. The R component must be selected to ensure that the sampling time requirements are satisfied. Any external components connected (via high-impedance) to an analog input pin (capacitor, Zener diode, etc.) must have very little leakage current at the pin.

16.18 OPERATION DURING SLEEP AND IDLE MODES

Sleep and Idle modes are useful for minimizing conversion noise because the digital activity of the CPU, buses, and other peripherals, is minimized.

16.18.1 CPU Sleep Mode without RC Analog-to-Digital Clock

When the device enters Sleep mode, all clock sources to the ADC module are shut down and stay at logic ‘0’.

If Sleep occurs in the middle of a conversion, the conversion is aborted unless the ADC is clocked from its internal RC clock generator. The converter does not resume a partially completed conversion on exiting from Sleep mode.

Register contents are not affected by the device entering or leaving Sleep mode.

16.18.2 CPU Sleep Mode with RC Analog-to-Digital Clock

The ADC module can operate during Sleep mode if the Analog-to-Digital clock source is set to the internal Analog-to-Digital RC oscillator (ADRC = 1). This eliminates digital switching noise from the conversion. When the conversion is completed, the DONE bit is set and the result is loaded into the ADC result buffer, ADCxBUF0.

If the ADC interrupt is enabled (ADxIE = 1), the device wakes up from Sleep when the ADC interrupt occurs. Program execution resumes at the ADC Interrupt Service Routine (ISR) if the ADC interrupt is greater than the current CPU priority. Otherwise, execution continues from the instruction after the PWRSAV instruction that placed the device in Sleep mode.

If the ADC interrupt is not enabled, the ADC module is turned off, although the ADON bit remains set.

To minimize the effects of digital noise on the ADC module operation, the user must select a conversion trigger source that ensures the Analog-to-Digital conversion takes place in Sleep mode. The automatic conversion trigger option can be used for sampling and conversion in Sleep (SSRCG = 0 and SSRC<2:0> = 111). To use the automatic conversion option, the ADON bit must be set in the instruction before the PWRSAV instruction.

Note: For the ADC module to operate in Sleep, the ADC clock source must be set to RC (ADRC = 1).

16.18.3 ADC Operation During CPU Idle Mode

For the Analog-to-Digital conversion, the ADSIDL bit (ADxCON1<13>) selects if the ADC module stops or continues on Idle. If ADSIDL = 0, the ADC module continues normal operation when the device enters Idle mode. If the ADC interrupt is enabled (ADxIE = 1), the device wakes up from Idle mode when the ADC interrupt occurs. Program execution resumes at the ADC Interrupt Service Routine if the ADC interrupt is greater than the current CPU priority. Otherwise, execution continues from the instruction after the *PWRSV* instruction that placed the device in Idle mode.

If ADSIDL = 1, the ADC module stops in Idle. If the device enters Idle mode in the middle of a conversion, the conversion is aborted. The converter does not resume a partially completed conversion on exiting from Idle mode.

16.19 EFFECTS OF A RESET

A device Reset forces all registers to their Reset state. This forces the ADC module to be turned off and any conversion in progress to be aborted. All pins that are multiplexed with analog inputs are configured as analog inputs. The corresponding TRIS bits are set.

The ADCxBUF0 through ADCxBUFF registers are not initialized during a Reset and contain unknown data.

16.20 DESIGN TIPS

Question 1: *How can I optimize the system performance of the ADC module?*

Answer: Here are three suggestions for optimizing performance:

1. Make sure you meet all of the timing specifications. If you are turning the ADC module off and on, there is a minimum delay you must wait before taking a sample. If you are changing input channels, there is a minimum delay you must wait for this as well. Finally, there is TAD, which is the time selected for each bit conversion. TAD is selected in ADxCON3 and must be within a range, as specified in the “**Electrical Characteristics**” chapter of the specific device data sheet. If TAD is too short, the result may not be fully converted before the conversion is terminated. If TAD is too long, the voltage on the sampling capacitor can decay before the conversion is complete. These timing specifications are provided in the “**Electrical Characteristics**” chapter of the specific device data sheet.
2. Often, the source impedance of the analog signal is high (greater than 10 k Ω), so the current drawn from the source to charge the sample capacitor can affect accuracy. If the input signal does not change too quickly, try putting a 0.1 μ F capacitor on the analog input. This capacitor charges to the analog voltage being sampled and supplies the instantaneous current needed to charge the 4.4 pF internal holding capacitor.
3. Put the device into Sleep mode before the start of the Analog-to-Digital conversion. The RC clock source selection is required for conversions in Sleep mode. This technique increases accuracy because digital noise from the CPU and other peripherals is minimized.

Question 2: *Do you know of a good reference on ADCs?*

Answer: A good reference for understanding Analog-to-Digital conversions is the “*Analog-Digital Conversion Handbook*” third edition, published by Prentice Hall (ISBN 0-13-03-2848-0).

Question 3: *My combination of channels/sample and samples/interrupt is greater than the size of the buffer. What will happen to the buffer?*

Answer: This configuration is not recommended. The buffer will contain unknown results.

16.21 RELATED APPLICATION NOTES

This section lists application notes that are related to this section of the manual. These application notes may not be written specifically for the dsPIC33E/PIC24E product family, but the concepts are pertinent and can be used with modification and possible limitations. The current application notes related to the Analog-to-Digital Converter (ADC) module are:

Title	Application Note #
Using the Analog-to-Digital (A/D) Converter	AN546
Four-Channel Digital Voltmeter with Display and Keyboard	AN557
Understanding A/D Converter Performance Specifications	AN693
Using the dsPIC30F for Sensorless BLDC Control	AN901
Using the dsPIC30F for Vector Control of an ACIM	AN908
Sensored BLDC Motor Control Using the dsPIC30F2010	AN957
An Introduction to AC Induction Motor Control Using the dsPIC30F MCU	AN984
Achieving Higher ADC Resolution Using Oversampling	AN1152

Note: Please visit the Microchip web site (www.microchip.com) for additional application notes and code examples for the dsPIC33E/PIC24E family of devices.

16.22 REVISION HISTORY

Revision A (January 2010)

This is the initial released version of this document.

Revision B (March 2011)

This revision includes the following updates:

- All code examples have been revised (see Example 16-1 through Example 16-8)
- Distinctions regarding devices *without* DMA, and for devices *with* DMA that have the ADC DMA Enable bit (ADDMAEN) **clear** have been added throughout the document. Affected content includes:
 - Third and last paragraphs of [Section 16.1 “Introduction”](#)
 - Title of Figure 16-1 (**Figure 16-2** was removed)
 - First paragraph of [Section 16.2.1 “ADC Result Buffer”](#)
 - Note 3 and bits 6-2 in the ADCx Control Register (see [Register 16-2](#))
 - [Section 16.10 “Sample and Conversion Sequence Examples for Devices without DMA and for Devices with DMA but with ADC DMA Enable Bit \(ADDMAEN\) Clear”](#) title
- Distinctions regarding devices *without* DMA, and for devices *with* DMA that have the ADC DMA Enable bit (ADDMAEN) **set** have been added throughout the document. Affected content includes:
 - First paragraph of [Section 16.4.7 “Sample and Conversion Operation \(SMPI\) Bits”](#)
 - Added a note box to [Section 16.7.1 “Using DMA in the Scatter/Gather Mode”](#)
 - Fourth paragraph of [Section 16.6.1 “Fixed Input Selection”](#)
 - Fourth paragraph of [Section 16.6.3 “Channel Scanning”](#)
 - [Section 16.11 “Sample and Conversion Sequence Examples for Devices with DMA and with ADDMAEN Bit Set”](#) title
- Added Note 4 to the ADCx Control Register 3 (see [Register 16-3](#))
- Updated the Automatic Sample and Manual Conversion Sequence (see [Figure 16-5](#))
- Updated the second paragraph to clarify stabilization of ADC results in [Section 16.3.5.2 “External Conversion Trigger”](#)
- Updated CH3 Sample/Convert in 4-Channel Sequential Sampling (see [Figure 16-12](#))
- Added a note regarding TAD specifications to [Section 16.4.5 “ADC Clock Selection”](#)
- Updated [Section 16.4.8.2 “Timer Interrupt Trigger”](#)
- Updated the first paragraph and changed the number of ADC inputs from 16 to 32 in the first note of [Section 16.6.3 “Channel Scanning”](#)
- Updated the Analog-to-Digital conversion process steps in [Section 16.8 “ADC Configuration Example”](#)
- Updated the Sequence Select bit value and description for ADDMAEN (see [Table 16-13](#), [Table 16-14](#), [Table 16-15](#), [Table 16-16](#), [Table 16-17](#), and [Table 16-18](#))
- Updated the Sequence Select bit value for SMPI<4:0> (see [Table 16-15](#), [Table 16-16](#), and [Table 16-17](#))
- Updated the MUXA Input Select bit value and description for CHOSA<3:0> and CHONA, and the MUXB Input Select bit value and description for CHOSB<3:0> and CH123NB<1:0> (see [Table 16-18](#))
- Changed ADC1BUF2 to ADC1BUFE (see [Figure 16-27](#))
- Removed ADC1BUF8 from Converting Two Sets of Two Inputs Using Alternating Input Selections (see [Figure 16-29](#))
- Changed the ADCxBUF0 register reference to ADCxBUF0-ADCxBUFF in [Section 16.19 “Effects of a Reset”](#)
- Updated the SMPI bit range from <4:0> to <3:0> for AD2CON2 in the ADC1 and ADC2 Register Map (see [Table 16-27](#))
- Updates to formatting and minor typographical changes were incorporated throughout the document

Revision C (May 2013)

This revision includes the following updates:

- Figures:
 - Updated [Figure 16-1](#), [Figure 16-2](#) and [Figure 16-13](#)
 - Updated the Channel Scan numbers in [Figure 16-37](#) through [Figure 16-39](#)
 - Updated the available register settings in [Figure 16-37](#) through [Figure 16-39](#)
- Notes:
 - Updated the pin numbers and the number of op amp outputs in Note 2, in [Section 16.1 “Introduction”](#)
 - Added Note 4 in [Figure 16-2](#)
 - Updated the Notes in [Register 16-1](#) through [Register 16-9](#)
 - Updated the Note in [Table 16-9](#) and [Table 16-10](#)
- Registers:
 - Updated the bit setting descriptions for bit 7-5 and bit 3 in [Register 16-1](#)
 - Updated [Register 16-5](#) and [Register 16-6](#)
- Sections:
 - Updated the features list in [Section 16.1 “Introduction”](#)
 - Updated the pin numbers and the number of op amp outputs in the last paragraph on page 16-2 in [Section 16.1 “Introduction”](#)
 - Added PTG Trigger as a source in the list of sources that the ADC module can use as a conversion trigger, in [Section 16.4.8 “Conversion Trigger Sources”](#)
 - Added [Section 16.4.8.4 “PTG Trigger”](#)
 - Added [Section 16.12 “Configuration Examples for Devices with Internal Op Amps”](#)
 - Removed [Section 16.19 “Special Function Registers”](#)
- Tables:
 - Removed [Table 16-2: SOC Trigger Selection](#)
 - Updated the following in [Table 16-9](#):
 - Updated the CH0 +ve Control bits, CHOSA<4:0> to CHOSA<5:0>
 - Updated the CH0 +ve Analog Inputs, AN0 to AN12 as AN0 to AN48
 - Added AN0 and AN25 to the CH2 +ve CH123SA Analog Inputs
 - Added AN6 and AN25 to the CH3 +ve CH123SA Analog Inputs
 - Updated the following in [Table 16-10](#):
 - Updated the CH0 +ve Control bits, CHOSB<4:0> to CHOSB<5:0>
 - Updated the CH0 +ve Analog Inputs, AN0 to AN12 as AN0 to AN48
 - Added AN0 and AN25 to the CH2 +ve CH123SB Analog Inputs
 - Added AN6 and AN25 to the CH3 +ve CH123SB Analog Inputs
 - Updated the following in [Table 16-13](#) through [Table 16-19](#) and [Table 16-21](#) through [Table 16-23](#):
 - Updated CH0SA<3:0> to CH0SA<5:0> in the MUXA Input Select table
 - Updated CH123SA to CH123SA<2:0> in the MUXA Input Select table
 - Updated CH0SB<3:0> to CH0SB<5:0> in the MUXB Input Select table
 - Updated CH123SB to CH123SB<2:0> in the MUXB Input Select table
- Updates to formatting and minor typographical changes were incorporated throughout the document

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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.

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