
5-Bit Digital-to-Analog Converter

Introduction

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The Digital-to-Analog Converter (DAC) converts a digital signal into an analog signal. The DAC module in the 8-bit PIC[®] microcontrollers offers flexible input source selection, provision of routing output to other peripherals, such as an Analog Comparator (AC) and Analog-to-Digital Converter (ADC), and configurable register sets.

This makes the DAC a flexible module suitable for numerous applications, such as:

- Signal Generation
- Reference Voltage Generation
- Converting Digital Output of Encoders to Analog Signals, etc.

This technical brief provides insight into the 5-bit DAC peripheral. Along with the working principle of the module, the technical brief describes the configurations of the DAC based on requirements and performance parameters of the module. This document also discusses the possible functional configurations of the DAC module, code examples, and code generation for DAC using the MPLAB[®] Code Configurator (MCC).

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1. Relevant Devices

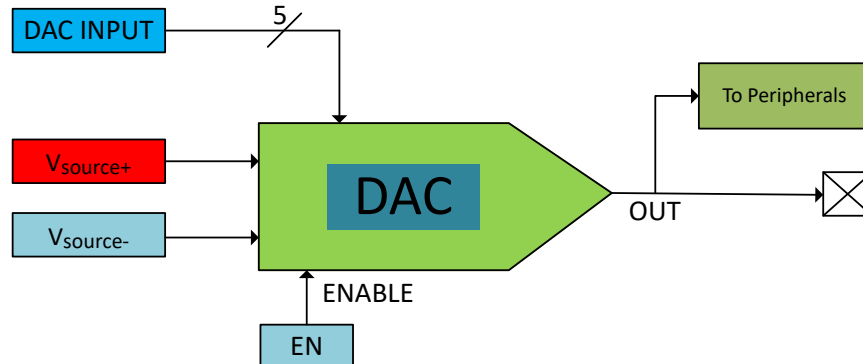
The following 8-bit PIC® microcontroller families offer feature-identical 5-bit DAC.

- PIC18-Q10
- PIC18-K83
- PIC18-K42
- PIC18-K40
- PIC16F18346
- PIC16F18446
- PIC16F15386
- PIC16F18877

2. Overview

The DAC supplies a variable voltage reference that is ratiometric with the input source and has 32 selectable output levels.

Figure 2-1. Block Diagram of DAC



The 5-bit DAC features include:

- Flexible input source (both positive and negative)
- Selection of the DAC output, as a reference to the following internal peripherals:
 - DACxOUT1 pin
 - DACxOUT2 pin
 - Comparator positive input
 - ADC input channel

The flexible input reference voltage (both positive input source (V_{source+}) and negative input source (V_{source-})) aids in configuring a range of reference voltages from negative (-) to positive (+).

The positive input source of the DAC can be connected to three sources:

- FVR Buffer
- External V_{REF+} Pin
- V_{DD} supply voltage

The Fixed Voltage Reference (FVR) is an internal module providing stable voltage references; [Table 4-5](#) showcases those levels of voltages, which are limited to less than the V_{DD} voltage. An external V_{REF+} pin is used when the user wishes to provide the input from an external source.

The V_{DD} supply voltage of the microcontroller can also be used as a voltage resource to the positive input source of the DAC. The negative input source (V_{source-}) of the DAC can be connected to the two sources:

- External V_{REF-} Pin
- V_{SS}

The external V_{REF-} pin is a negative reference voltage pin, which can be used when the user wishes to provide the input from an external voltage source. (Refer to Electric Characteristics in the device-specific data sheet).

The V_{SS} supply voltage pin is an operating supply ground (GND) pin, which can be used as a negative input source to the DAC. The output of DAC can be routed to other peripherals as a reference voltage. This includes:

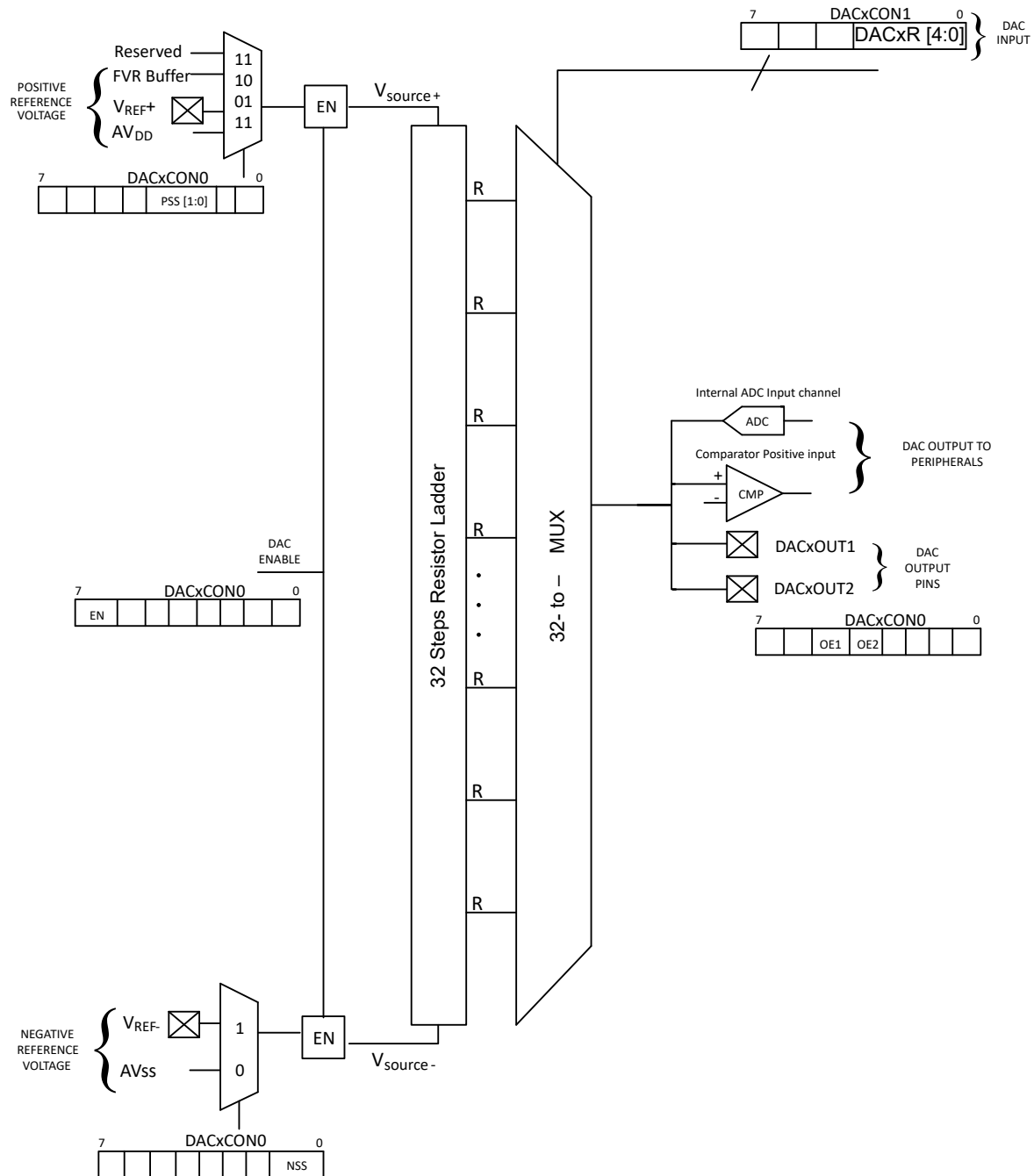
- Noninverting input of comparator
- ADC input channel
- Microcontroller pins: DACxOUT1 and DACxOUT2

This feature makes DAC a flexible module suitable for a wide range of applications.

3. DAC Operation

Illustrated below is the detailed architecture of the 5-bit DAC module. It can be enabled by setting the EN bit.

Figure 3-1. Detailed Architecture of 5-Bit DAC



The DAC has 32 voltage levels which are set with the DAC1R [4:0] bits of the DAC1CON1 register. The DAC output voltage is derived from the parameters V_{REF+} , V_{REF-} , 5-bit DAC input, and 32 voltage levels.

The internal structure of the DAC module is comprised of a 32-to-1 multiplexer and a 32-steps resistor ladder. The resistor ladder is a string of identical resistors connected to the multiplexer, as shown above. One end of the resistor ladder is connected to the positive input source ($V_{source+}$) and the other, to negative input source ($V_{source-}$). With this architecture, $V_{source+}$ to $V_{source-}$ is divided into 32 equal steps. The DAC output value is derived from the

resistor ladder and if the voltage of either input source fluctuates, this would result in fluctuations in the DAC output value. The DAC output voltage can be routed to the DACxOUTn pins and to other peripherals by setting the respective control register bits. Reading the DACxOUTn pin when it is configured for the DAC reference voltage output will always return a '0'.

The DAC output can be determined by using the following equation:

$$DACx_output = \left[\left(V_{REF+} - V_{REF-} \right) \times \frac{DACR[4:0]}{2^5} \right] + V_{REF-}$$

For example, the parameters configuration and DAC inputs:

- $V_{REF+} = 5V$
- $V_{REF-} = 0V$
- $DACR[4:0] = 31$ (Maximum)
- $2^5 = 32$
- $DACx_output = [(5 - 0) \times 31 / 32] + 0 = 4.843V$

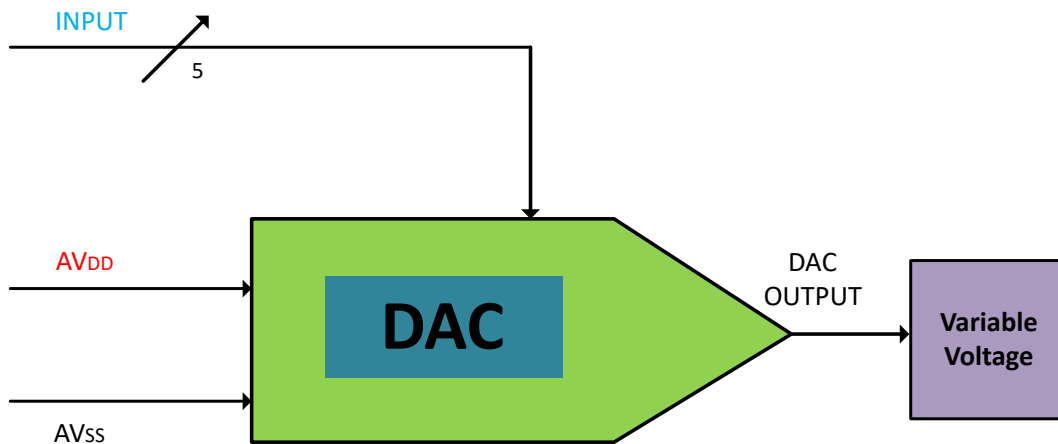
Thus, the 5-Bit DAC can provide a maximum output voltage of 4.843V

4. Possible Configurations

4.1 DAC Output as Reference Voltage

The following configuration can be used in an application where it is required to access the DAC output from an external pin.

Figure 4-1. DAC Output on DACxOUT1/2 Pin with Internal Reference Voltage Configuration



Here, the DAC positive and negative reference voltage is configured as microcontroller AV_{DD} and AV_{SS} , respectively. This configuration is required for the functionalities, where variable analog voltage is required as output from the DAC.

Table 4-1. DAC1CON0.PSS[1:0] DAC Positive Select Bit

Value	Description
11	Reserved
10	FVR buffer
01	FVR+ (External Positive Voltage Reference)
00	AV_{DD} (Microcontroller V_{CC})

Table 4-2. DAC1CON0.NSS DAC Negative Source Select Bit

Value	Description
1	V_{REF-} (External Negative Voltage Reference)
0	AV_{SS} (Microcontroller GND)

Table 4-3. DAC1CON0.OE1 DAC Voltage Output Enable Bit

Value	Description
1	DAC voltage level is output on the DAC1OUT1 pin
0	DAC voltage level is disconnected from the DAC1OUT1 pin

The DAC positive reference input source is configured as the microcontroller AV_{DD} , the negative input source is configured as AV_{SS} , and the output of the DAC is connected to the microcontroller Pin (GPIO Pin). The DAC1OUT1 pin must be configured as output and analog pin.

Table 4-4. Pin Allocation Table

	28-Pin SPDIP, SOIC, SSOP	28-Pin (V)QFN	A/D	Reference	Comparator
RA0	2	27	ANA0		C1IN0- C2IN0-
RA1	3	28	ANA1		C1IN1- C2IN1-
RA2	4	1	ANA2	DAC1OUT1 VREF-(DAC) VREF-(ADC)	C1IN0+ C2IN0+
RA3	5	2	ANA3	$V_{REF+}(DAC) V_{REF+}(ADC)$	C1IN1+
RA4	6	3	ANA4		

The MCC is a graphical programming environment that generates code seamlessly. Easy-to-use GUI helps to generate the desired code, which can be easily inserted into the project. [Figure 4-2](#) shows how to use the MCC for the DAC configuration.

Figure 4-2. MCC Configuration - DAC Output on DACxOUT1 Pin with Internal Reference Voltage

DAC1 (5 bit)

Easy Setup Registers

Hardware Settings

☒ Enable DAC

Positive Reference VDD

Negative Reference VSS

☒ Enable output on DACOUT1

☐ Enable output on DACOUT2

Enable Output on DACOUT

Software Settings

Vdd 5

Vref+ 4

Vref- 0

Required ref: 1

DAC out value: 4.844 calculated from DACR

Figure 4-3. Pin Manager in MCC Configuration

Pin Module

Easy Setup Registers

Selected Package: UQFN40

Pin Name ^	Module	Function	Custom Na...	Start High	Analog	Output	WPU	OD	IOC
RA2	DAC1	DAC1OUT1		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	none
RC2	Pin Module	GPIO	IO_RC2	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	pos...
RE0	Pin Module	GPIO	LED	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	none
RE2	Pin Module	GPIO	IO_RE2	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	none

The following code is generated by the MCC for DAC initialization:

```
void DAC1_Initialize(void)
{
    // DAC1EN enabled; NSS VSS; PSS VDD; OE1 enabled; OE2 disabled;
    DAC1CON0 = 0xA0;
    // DAC1R 31;
    DAC1CON1 = 0x1F; //Default input value
}
```

The DAC output value is set by using the DACxCON1 register. The following MCC-generated API/function can be used for the same purpose.

```
void DAC1_SetOutput (uint8_t inputData)
{
    DAC1CON1 = inputData;
}
```

After initializing this configuration, the DAC output can be connected to the DAC1CON1 (i.e., the RA2 pin). This DAC configuration can be used as a reference voltage generator and waveform/signal generator. Some of the examples are listed in the [MPLAB Xpress code Examples](#).

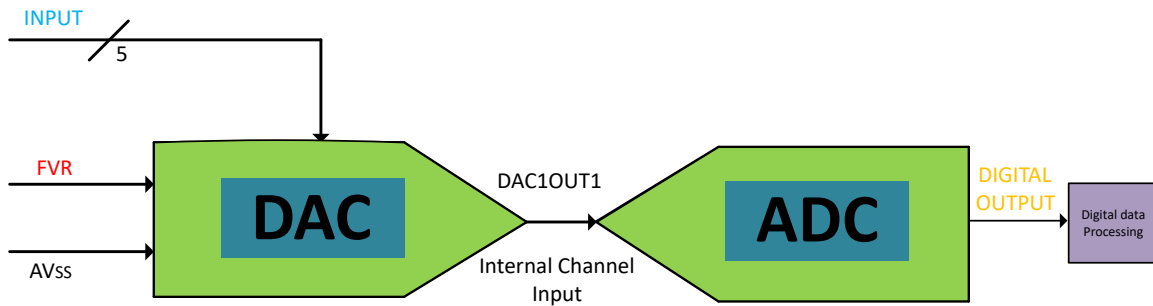
4.2 Reading DAC Output Using ADC

This particular configuration, useful for applications such as calibration, involves two peripherals:

- DAC for providing analog voltage to ADC channel
- ADC for application functionalities

The user can configure the DAC output as input to ADC, the DAC positive reference input as FVR buffer, the negative reference input source as microcontroller GND (i.e., AV_{SS}), and the DAC output routed to ADC as an input channel. The DAC output can be configured as an analog input channel to ADC by configuring the ADC input selection register.

Figure 4-4. DAC Output as ADC Input Configuration



The DAC1CON0 register must be configured as per requirements. [Figure 4-5](#) shows code generation using MCC for the DAC configuration.

Figure 4-5. DAC Configuration for Reading DAC Output Using ADC

DAC1 (5 bit)

Easy Setup Registers

Hardware Settings

☒ Enable DAC

Positive Reference FVR_buf2

Negative Reference VSS

☐ Enable output on DACOUT1

☐ Enable output on DACOUT2

Enable Output on DACOUT

Software Settings

Vdd 5

Vref+ 4

Vref- 0

Required ref: 1

DAC out value: 0

The following code is generated by the MCC for the DAC configuration:

```
//DAC0EN enabled; NSS VSS; PSS FVR_buf2; OE1 disabled; OE2 disabled;
void DAC1_Initialize(void)
{
    // DAC1EN enabled; NSS VSS; PSS FVR_buf2; OE1 disabled; OE2 disabled;
    DAC1CON0 = 0x88;
    // DAC1R 0;
    DAC1CON1 = 0x00;
}
```

Figure 4-6 showcases the block diagram of FVR, which can be used as a DAC positive reference input voltage. The FVRCON register is used to set the fixed reference voltage for DAC.

Figure 4-6. FVR Configuration for DAC Reference Voltage

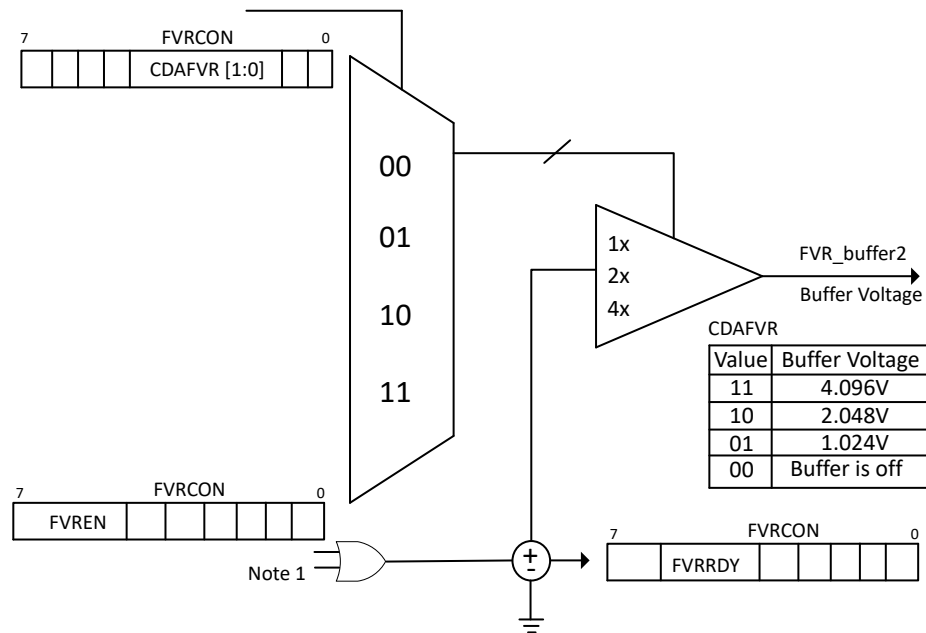


Figure 4-7 shows how the MCC can be used to generate the code for FVR initialization.

Figure 4-7. MCC Configuration to Set the FVR Voltage as DAC Reference Voltage

FVR

Easy Setup

Registers

Hardware Settings

☒ Enable FVR

FVR_buffer1 Gain (to ADC)

2x

2.048 V

FVR_buffer2 Gain (to other peripherals)

off

☐ Enable Temperature Sensor

Voltage Range Selection

Lo_range

The following code is generated by the MCC for the FVR configuration:

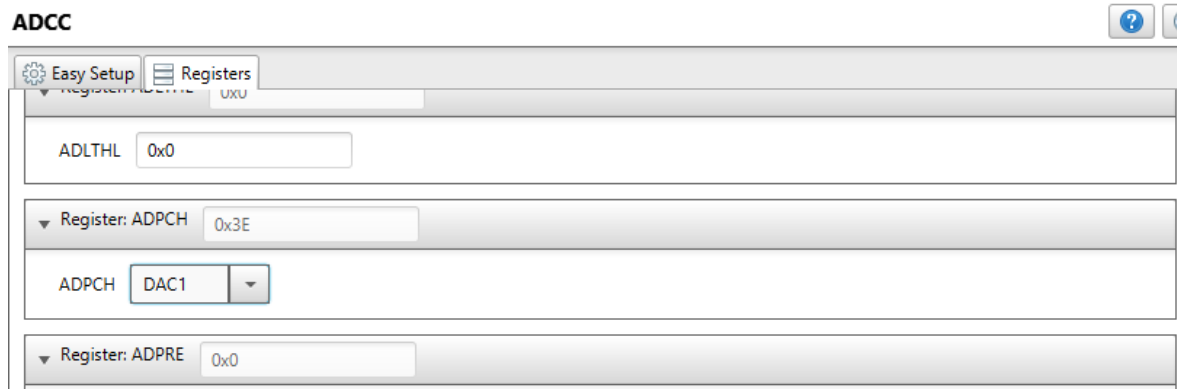
```
// FVRCON enabled; ADFVR [1:0] 2.048V;
void FVR_Initialize(void)
{
    // CDAFVR off; FVREN enabled; TSRNG Lo_range; ADFVR 2x; TSEN disabled;
    FVRCON = 0x82;
}
```

Table 4-5. Fixed Output Voltages from FVR

FVRCON.CDAFVR Value	Buffer Voltage
ob11	4.096V
ob10	2.048V
ob01	1.024V
ob00	Buffer is Off

The value of the ADPCH register for configuring the DAC output as an input channel to ADC is 0b111110. [Figure 4-8](#) shows the ADC module configuration to set the DAC output as input to the ADC channel.

Figure 4-8. MCC Configuration for Selecting DAC as an ADC Input



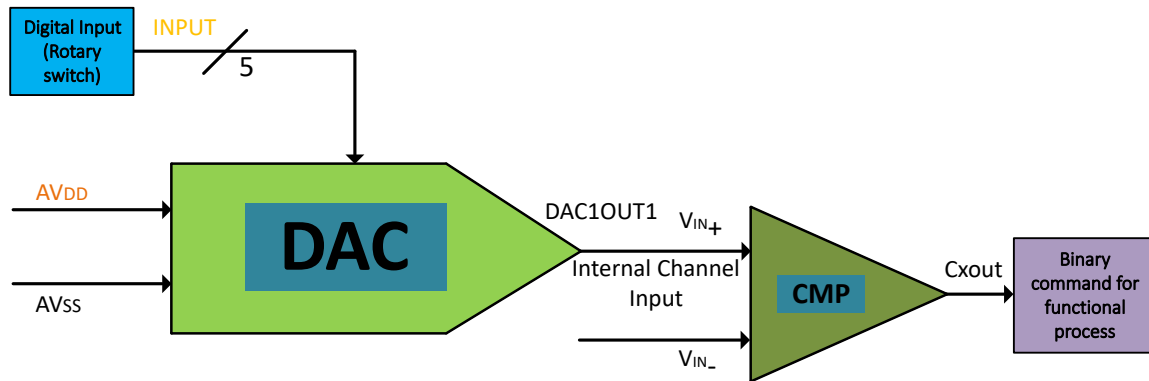
The following code is generated:

```
//code
ADPCH = 0x3E; // ADPCH DAC1;
```

4.3 DAC Output as an Analog Comparator Input

This configuration involves the AC and DAC peripherals, where the PIC 8-bit microcontroller has the flexibility to route the DAC output to the noninverting input of AC, internally.

Figure 4-9. DAC Output as an Analog Comparator Input Configuration



The comparator register CMXPCH must be used for selecting the DAC output as a noninverting channel. The polarity of the comparator output can be inverted by setting the CxPOL bit. Clearing the CxPOL bit results in a noninverted output. The CxPOL bit belongs to register CMxCON0 and the output of the comparator is listed in following table:

Table 4-6. Comparator Output

Input Condition	CxPOL	CxOUT
$V_{IN+} > V_{IN-}$	0	0
$V_{IN+} < V_{IN-}$	0	1
$V_{IN+} > V_{IN-}$	1	1
$V_{IN+} < V_{IN-}$	1	0

Figure 4-10 and Figure 4-11 show how the MCC can be used to generate code for this particular configuration.

Figure 4-10. DAC Output Configuration Using MCC

DAC1 (5 bit)

Easy Setup
Registers

Hardware Settings

☒ Enable DAC

Positive Reference FVR_buf2

Negative Reference VSS

☐ Enable output on DACOUT1

☐ Enable output on DACOUT2

Enable Output on DACOUT

Software Settings

Vdd 5

Vref+ 4

Vref- 0

Required ref: 1

DAC out value: 0

Figure 4-11. CMP1 Configuration for DAC Output as an Analog Comparator Input Using MCC

CMP1

Easy Setup
Registers

Hardware Settings

☒ Enable Comparator Positive Input DACOUT

☐ Enable Synchronous Mode Negative Input Vss

☐ Enable Comparator Hysteresis

Output Polarity ☐ inverted ☒ not inverted

☒ Enable Comparator Interrupt

Interrupt Flag Set On ☒ Rising Edge ☐ Falling Edge

The following code is generated by the MCC for the DAC configuration:

```
void DAC1_Initialize(void)
{
    // DAC1EN enabled; NSS VSS; PSS VREF+; OE1 disabled; OE2 disabled;
    DAC1CON0 = 0x84;
    // DAC1R 8;
    DAC1CON1 = 0x08;
}
```

The following code is generated by the MCC for the comparator configuration:

```
void CMP1_Initialize(void)
{
    PIE2bits.C1IE = 0; // C1HYS disabled; C1EN enabled; C1POL not inverted; C1SYNC
asynchronous;
    CM1CON0 = 0x80;
    CM1CON1 = 0x02; // C1INTN no_intFlag; C1INTP intFlag_pos
    CM1NCH = 0x07; // NCH Vss;
    CM1PCH = 0x05; // PCH DACOUT;
    PIR2bits.C1IF = 0; // Clearing IF flag before enabling the interrupt.
    PIE2bits.C1IE = 1; // Enabling CMP1 interrupt.
}
```

5. DAC in Power-Down Modes

In the Power-Saving Operation modes (Sleep, Idle, and Doze) of the PIC microcontroller, we may expect changes in current consumption when using the DAC.

When the device wakes up from Sleep mode by an interrupt or by a Windowed Watchdog Timer (WWDT) time-out, the contents of the DACxCON0 register are not affected.



Tip:

1. To minimize the current consumption in Sleep mode, the voltage reference must be disabled from the FVR before the controller enters Power-Down mode.
2. Refer to the device-specific data sheet for more details about Power-Saving Operation modes, DAC, FVR, and corresponding registers.

6. Conclusion

The DAC module of the 8-bit PIC microcontrollers offers flexible input source selection, provision of routing DAC output to other peripherals, such as analog comparator and ADC, and configurable register sets. This technical brief offers an overview of the DAC module and its various functional configurations. It also describes how MCC can be used to generate DAC peripheral configuration codes. For code examples visit [MPLAB Xpress code Examples](#).

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