AN3312

Arbitrary Waveform Generator Using DAC and DMA

Introduction

Author: Alec Miller, Microchip Technology Inc.

This application note describes how an Arbitrary Waveform Generator (AWG) can be implemented using Direct Memory Access (DMA) and an 8-bit buffered Digital-to-Analog Converter (DAC). The waveform that is generated in this application can be up to 255 samples long, and is created using a look-up table (LUT) in RAM with data from user-generated files loaded onto an SD card. Once the waveform has been read from the SD card, the AWG operates core independently without additional CPU intervention. The waveforms are generated by using a DMA to automatically load values from the LUT in RAM into the DAC output register at an interval determined by a timer.

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1. Theory of Operation

1.1 Waveform Generation

Arbitrary waveform generators are systems capable of generating an analog waveform and can take any form. They are often used as test equipment to test the response of a circuit to a particular input. The signal is generated by continuously adjusting the output of a Digital-to-Analog Converter (DAC) to create an analog signal made of a series of discrete steps. The values can either be generated programmatically in real time, or loaded from a look-up table.

The limitations of an Arbitrary Waveform Generator are the input voltage range, the characteristics of the DAC used to create the signal, and the performance characteristics of the device feeding data to the DAC. The quality of the generated waveform is directly related to the sample rate and resolution of the DAC module being used.

1.2 DAC

The Digital-to-Analog Converter (DAC) can be used to convert digital input values to an analog output. The DAC uses a reference voltage and outputs a corresponding fraction of that voltage, which is determined by the value loaded into the DACxDAT register.

The resolution of a DAC is determined by the number of bits in the input code and can be calculated using the following formula:

$$V_{STEP} = \frac{V_{REF}}{2^{No.ofbits} - 1}$$

This application uses the 8-bit DAC on the PIC18F47Q43, which at 5V, gives a resolution of 20 mV. The output of a DAC with a given input code is typically defined using the following formula:

$$V_{OUT} = \frac{V_{REF}}{2^{No.ofbits} - 1} \cdot Input\ Code$$

1.3 DMA

Direct Memory Access (DMA) is a subsystem that can transfer data between different memory regions, including register memory, without CPU intervention. This feature allows data to be transferred between peripherals with a much lower CPU overhead in comparison to transferring the data without DMA. DMA can be beneficial in applications that require data to be transferred at rates close to the clock frequency of the device, such as in this Arbitrary Waveform Generator application.

The DMA module is comprised of a DMA controller and multiple interface channels that allows data transfer between the device memory regions. The System Arbiter is used to allocate priority levels for different system events, and can be used to give a DMA higher priority than main code execution or even ISR execution. The DMA subsystem operates on an independent data and address bus which allows data to be transferred with no impact on CPU operation (assuming the DMA has been configured to have a lower priority than the CPU using the System Arbiter).

The transfer process can be configured to be triggered by various system events. For instance, a DMA can be configured to automatically transfer a message received by a UART to a user-defined storage buffer when the UART receive interrupt is triggered.

Each DMA channel has its own configurable priority level, which can be set using the System Arbiter. By default, DMA has lower priority than the CPU lowest priority and will only execute during holes in CPU execution due to two-cycle instructions, such as `GOTO`. The DMA can be configured to pause CPU execution when triggered, or to even pause interrupt execution, depending on the priority set using the System Arbiter.

2. Implementation

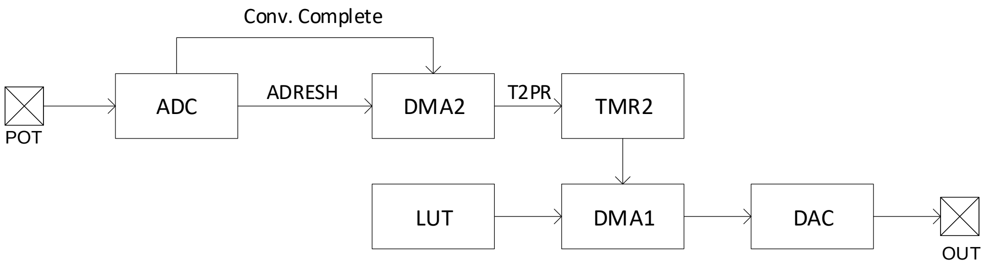
2.1 DAC

In this application, the DAC is configured to use V_{DD} as the positive reference and ground as the negative reference. To allow for smooth waveforms with desired amplitudes below V_{DD}, the Fixed Voltage Reference (FVR) can supply the positive reference, or a second DAC could supply V_{REF} to allow for greater flexibility, although this would require an external DAC in cases where the device has only a single DAC.

2.2 DMA

This application uses two DMA modules, as shown in Figure 2-1. One DMA module feeds data from the look-up table (LUT) into the DAC, and the other DMA feeds the Analog-to-Digital Converter (ADC) reading from a potentiometer to the period value of the Timer2 module, which determines the frequency of the waveform.

Figure 2-1. AWG Block Diagram



The DAC feeder (DMA1) is configured to be triggered by the Timer2 output. The source address and length are user selectable and the destination is DAC1DAT. The period selector (DMA2) is configured to be triggered by the conversion complete flag of the continuously converting ADC, which is continuously sampling a potentiometer. The source is the upper byte of the left-justified output, and the destination is the Timer2 period value.

Example 2-1. Set DMA Source

```
void dma_setSource(uint8_t dma, void * source, uint16_t length){
    DMASELECT = dma;
    DMAnCON0bits.EN = 0;
    DMAnSSA = source;
    DMAnSSZH = (length >> 8) & 0xFF;
    DMAnSSZL = length & 0xFF;
    DMAnCON0bits.EN = 1;
}
```

Example 2-2. DMA1 - Look-Up Table to Data Transfer

```
DMASELECT = 0;
DMAnCON1bits.DMODE = 0b00;    // Destination pointer unchanged
DMAnCON1bits.SMODE = 0b01;    // Increment source pointer
DMAnDSA = &DAC1DATL;
DMAnDSZL = 1;                 // Destination size 1
DMAnSIRQ = 0x1B;              // TMR2 trigger
DMAnCON0bits.SIRQEN = 1;      // Allow hardware to trigger start
```

Example 2-3. DMA1 - ADC to TMR2 Data Transfer

```
DMASELECT = 1;
DMAnDSA = &T2PR;            // Destination TMR0H
DMAnDSZL = 1;               // Destination size 1
DMAnSSZH = 0;
DMAnSSZL = 1;               // Source size 1
DMAnSSA = &ADRESH;          // Source ADC
DMAnSIRQ = 0xA;             // ADC Conversion
DMAnCON0bits.SIRQEN = 1;    // Allow hardware to trigger start
DMAnCON0bits.EN = 1;
```

2.3 Timer

In this application, the Timer2 module is configured with a prescaler of 1:8 and a source of F_{OSC}/4, meaning that when the period value is set to zero, a new value will be loaded every 32 clock cycles or eight instruction cycles. This action requires a hole in the form of a branch or `GOTO` at least once every eight words. Since the timer value will only be updated when a hole occurs, there is an increased risk that an update will be missed if no hole occurs before another transfer is triggered. Depending on the importance of uninterrupted execution of the main application versus the importance of waveform output quality, the System Arbiter can be used to adjust the priorities to give the DMA being used as the DAC feeder a higher priority than the main execution. Another option would be to cut the frequency in half and either limit the maximum frequency of the output or cut the number of sample points in half.

2.4 File System

The SD card file system used is based on a standard FAT file system, which can be loaded normally by a PC. Each waveform is comprised of its own file, with the file names consisting of sequential numbers starting at ‘0’. The contents of the file consist of a 16-character description (e.g., “Sawtooth”) that is buffered with spaces as needed, a one-byte length field indicating the length of the waveform and up to 255 single-byte samples of the waveform to be generated.

The waveforms on the SD card are generated using a Python script that converts standard single-channel signed 16-bit pulse code modulation (PCM) .WAV files to an 8-bit unsigned PCM with the meta data, as described above. The .WAV files that the Python script converts from can be created using standard audio editing software. The Python script also down-samples the audio waveform to the desired number of samples.

On start-up, the PIC® device reads the contents of the SD card to determine the number of waveforms saved on the SD card. The descriptions of each file are then stored in RAM to prevent the need to repeatedly read from the SD card while cycling through choices.

When a waveform is loaded, the contents of the data portion of the file are read into the look-up table addressed by the DMA, and the length field is used to control the length of data read by the DMA.

2.5 Hardware

This application was created using the Curiosity High Pin Count (HPC) Development Board with a PIC18F47Q43 microcontroller. The MikroElektronika microSD Click board™ and the LCD mini Click board™ were used for SD card reading and the display, respectively. The microSD Click board is a standard SD card connector that can be interfaced using the SPI protocol. The LCD Click board consists of a 2x16 HD44780-compatible LCD display in 4-data-pin mode, connected to a MCP23S17 port expander and MCP4161 digital potentiometer for contrast control (both controlled using SPI). The ADC continuously samples the potentiometer on pin RA0 to control the frequency of the waveform being generated. The buttons on pins RB4 and RC5 are used to select the waveform that will be generated, as described in the **User Interface** section, and the waveform is on pin RA2.

2.6 User Interface

This application implements a very simple user interface that is used to control the AWG. The button on pin RC5 cycles between the different waveforms saved to the SD card, displaying the 16-character descriptor on the bottom line of the LCD screen. If the selected file is already loaded, the top line displays the text “Current file,” otherwise it will display “Select file”. The button on pin RB4 loads the selected waveform into the DMA look-up table and sets the DMA scan length to the length of the sample.

3. Results

The waveform generator was able to create the triangular and sinusoidal waveforms shown in Figure 3-1 and Figure 3-2, respectively, with an adjustable frequency. With a clock speed of 64 MHz, an effective prescaler of 1:32 (1:8 prescaler and $F_{OSC}/4$ source) and that there were 100 samples in the look-up tables, the maximum frequency of the waveform is 20 kHz. Depending on the needs of the application, this frequency could be increased, either at the expense of the signal quality by reducing the number of samples, or at the expense of other program execution by prioritizing the DMA over CPU execution to allow for a faster sample rate.

Figure 3-1. Sinusoidal Output

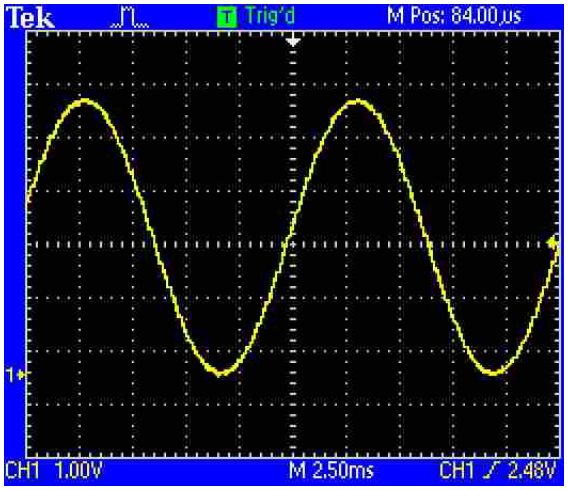
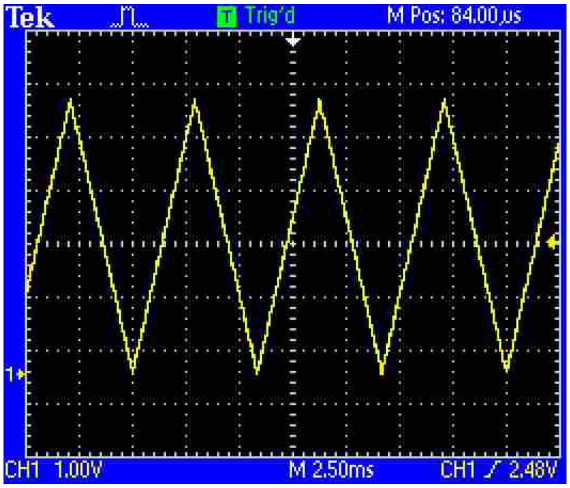


Figure 3-2. Triangular Output



4. Appendix

Figure 4-1. Main Schematic

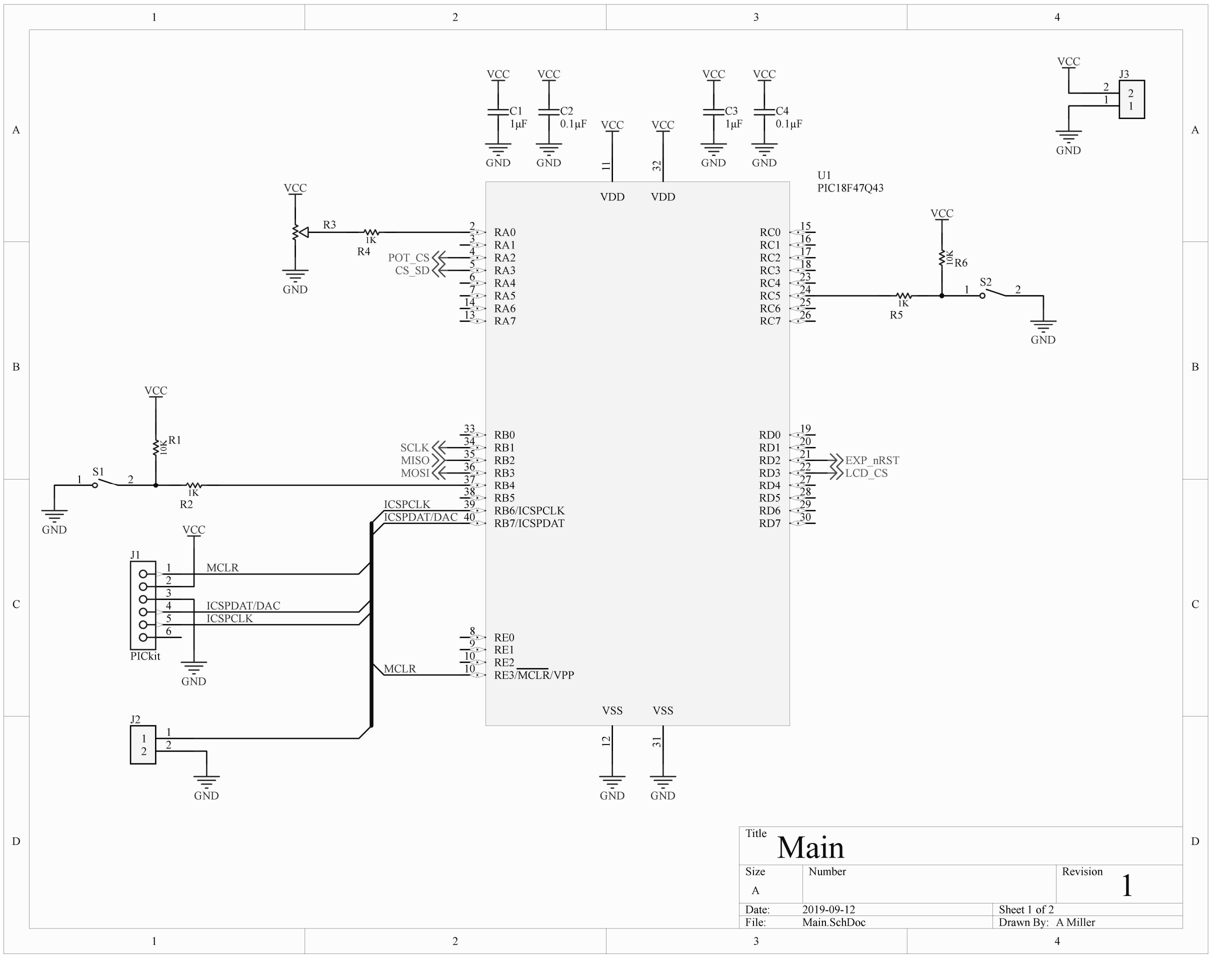
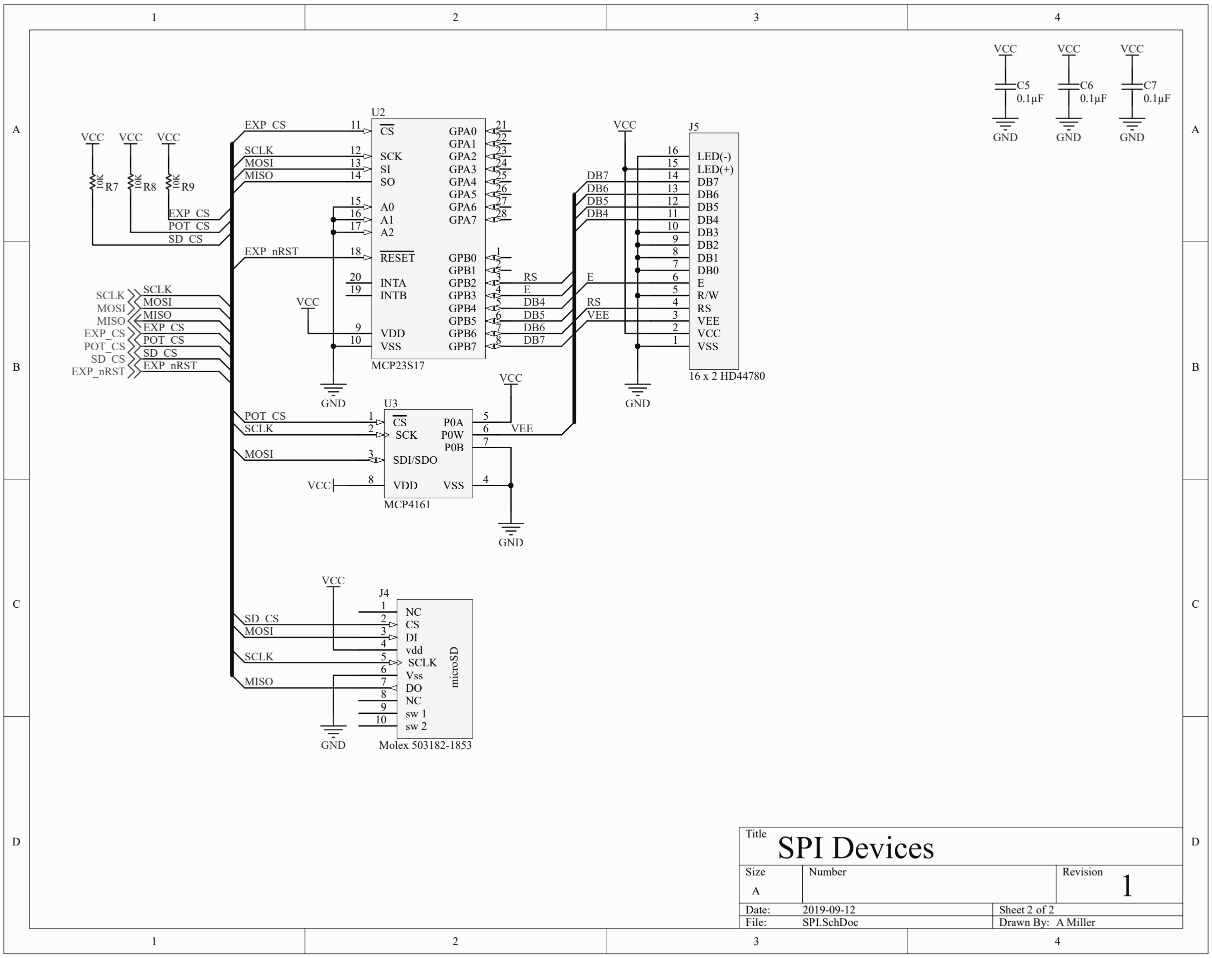


Figure 4-2. SPI Schematic



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ISBN: 978-1-5224-5423-6

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