Training Getting Started with AVR® DB OPAMP, XOSCHF and MVIO - MPLAB®

Prerequisites

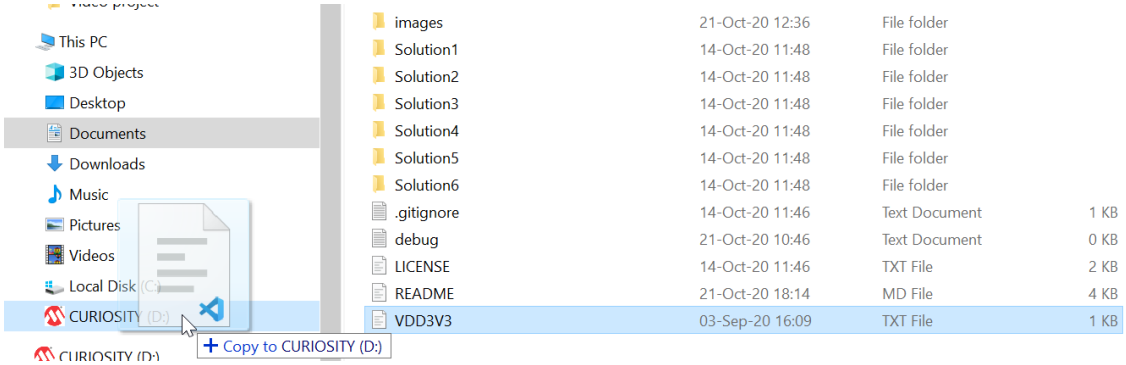
Authors: Martin Mostad, Martin Thomaz, Microchip Technology Inc.

- **Hardware Prerequisites**
  - The Microchip AVR128DB48 Curiosity Nano Curiosity Nano Evaluation Kit EV35L43A
  - Micro-USB cable (Type-A/Micro-B)
  - Logic Analyzer or oscilloscope with 100 MHz sampling speed (only needed for Assignment 2)
- **Software Prerequisites**
  - MPLAB® X 5.40 or later
  - MPLAB® X Dx_DFP version 1.4.75
  - MPLAB® Code Configurator version 4.0.2 (only needed for Assignment 4)
  - MPLAB® Data Visualizer Stand-alone version 1.1.793 or above
  - MPLAB® Mindi™ Analog Simulator
- **Other**
  - The MPLAB® X projects are available at:

    View Code Example on GitHub
    Click to browse repository

  - The AVR128DB48 Curiosity Nano needs to be running at 3.3V. This can be achieved by dragging the VDD3V3.txt file located in the GitHub repository over to the CURIOSITY memory device, as shown in Figure 1.

Figure 1. Setting AVR128DB48 Curiosity Nano to 3.3V



- **Estimated Completion Time: 210 minutes**

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1. Introduction

This training document contains assignments that give a general introduction to the new features of the AVR® DB Family. Each assignment starts with a basic introduction, then the functionality is verified through the MPLAB® *Data Visualizer*. Every assignment is provided with a preconfigured code, where most of the code is already in place, and only essential modules for the specific assignment need to be configured. Each assignment comes with a solution.

The new AVR® DB Family of microcontrollers comes with three features that will be highlighted in this training. The features are a new Clock Controller (CLKCTRL), Analog Signal Conditioning (OPAMP), and Multi-Voltage I/O (MVIO).

The new CLKCTRL has a new clock source called the High Frequency Crystal Oscillator (XOSCHF) and Clock Failure Detection (CFD). The XOSCHF enables the use of an external crystal or an external clock signal up to 32 MHz. This can be used as a clock source for the Main Clock (CLK_MAIN), the Real-Time Counter (RTC), and the 12-bit Timer/Counter Type D (TCDn). The CFD feature can be used to detect if the output from a clock source stops and can switch the Main Clock to a different clock source.

The OPAMP peripheral features up to three internal operational amplifiers (op amps) as well as a resistor ladder for each op amp. The resistor ladder can be used to create a variety of classical op amp configurations. The main purpose of op amps is to condition the analog signals before an acquisition or to provide the necessary output drive in control applications.

The MVIO allows a subset of the I/O pins to be powered by a different I/O voltage domain called V_{DDIO2}. The rest of the I/O pins runs on V_{DD}, which may remove the need for external level shifters when communicating with other devices running on a different target voltage.

This training covers the following topics:

- Assignment 1: CLKCTRL - External High-Frequency Oscillator (XOSCHF) and Clock Failure Detection (CFD)
- Assignment 2: CLKCTRL - High Frequency TCD using PLL
- Assignment 3: OPAMP - Voltage Follower
- Assignment 4: OPAMP - Instrumentation Amplifier
- Assignment 5: MVIO - OPAMP as a Regulated Power Supply for VDDIO2
- Assignment 6: MVIO - VDDIO2 Failure Detection

2. Icon Key Identifiers

The following icons are used in this document to identify different assignment sections and to reduce complexity.

Info: Delivers contextual information about a specific topic.

Tip: Highlights useful tips and techniques.

To do: Highlights objectives to be completed.

Result: Highlights the expected result of an assignment step.

Indicates important information.

Execute: Highlights actions to be executed out of the target when necessary.

3. Assignment 1: CLKCTRL - External High-Frequency Oscillator (XOSCHF) and Clock Failure Detection (CFD)

In this assignment, the AVR128DB48 Curiosity Nano will be configured to use the external high-frequency oscillator (XOSCHF) as the main clock source.

The clock failure detection will be configured to detect failures on the main clock. A failure on the main clock will result in a Non-Maskable Interrupt (NMI).

A failure will be triggered by the software when the switch (SW0) on the AVR128DB48 Curiosity Nano is pressed.

The AVR128DB48 Curiosity Nano will blink an LED with a frequency dependent on the main clock to show how the main clock source will be switched back to the default internal source when an error is detected.

The starting point for this assignment is the MPLAB® X project *Assignment1*.X.

- **Objectives**
  - Configure the main clock yo use XOSCHF as its clock source
  - Configure the CFD to generate an NMI on the failure of the main clock
  - Trigger a failure on the main clock using the built-in test functionality of the CFD

3.1 Configure the Main Clock to Use XOSCHF

To do:
- Edit the `CLOCK_XOSCHF_crystal_init()` function so that the main clock uses the XOSCHF as a clock source

Info:
Almost all the registers in the Clock Controller (CLKCTRL) peripheral are under Configuration Change Protection (CCP), which means that for write to this register, a certain key must first be written to the CPU.CCP register, followed by a write to the protected bits within four CPU instructions. To make sure this criterion is met when writing to the protected registers, the function `ccp_write_io()` is used, which can be found in the *avr/cpufunc.h* file. The function takes two arguments: A *uint8_t* pointer and the values to be written to the register. The register macros provided by the *io.h* file are not *uint8_t* pointers, so typecasting is therefore needed. A useful template showing how to use the function is:

```
ccp_write_io((uint8_t *) &<register>, new_value)
```

1. Configure the XOSCHF to use an external crystal, have a start-up time of four thousand cycles, a frequency range of 16 MHz, to always run, and enable XOSCHF. All this can be done by adding the following to `CLOCK_XOSCHF_crystal_init()`:

```
ccp_write_io((uint8_t *) &CLKCTRL.XOSCHFCTRLA, CLKCTRL_RUNSTDBY_bm
                  | CLKCTRL_CSUTHF_4K_gc
                  | CLKCTRL_FRQRANGE_16M_gc
                  | CLKCTRL_SELHF_CRYSTAL_gc
                  | CLKCTRL_ENABLE_bm);
```

Info: The frequency range setting determines the maximum frequency for the crystal that is supported. The larger the range, the higher the current consumption.

Info: The XOSCHF is set to always run so we can verify that the clock source is stable before being used. This setting will later be turned off to save power.

2. Wait until the external high-frequency crystal is stable by adding:

```
while(!(CLKCTRL.MCLKSTATUS & CLKCTRL_EXTS_bm))
    {
        ;
    }
```

3. Set the main clock source to be XOSCHF and enable the clock output pin by writing:

```
ccp_write_io((uint8_t *) &CLKCTRL.MCLKCTRLA, CLKCTRL_CLKSEL_EXTCLK_gc
                | CLKCTRL_CLKOUT_bm);
```

Info: By enabling the clock out pin, it is possible to observe the main clock frequency on the CLKCOUT (PA7) pin.

4. Wait for the main clock to switch successfully by polling the Main Clock Oscillator Change (SOSC) bit field in Main Clock Status (CLKCTRL.MCLKSTATUS) register:

```
while(CLKCTRL.MCLKSTATUS & CLKCTRL_SOSC_bm)
    {
        ;
    }
```

5. To save power, clear the Run Standby (RUNSTDBY) bit, so the oscillator is not running when it is not needed:

```
ccp_write_io((uint8_t *) &CLKCTRL.XOSCHFCTRLA, CLKCTRL.XOSCHFCTRLA &
~CLKCTRL_RUNSTDBY_bm);
```

Result: After adding all the code to configure XOSCHF, the `CLOCK_XOSCHF_crystal_init()` function will look like this:

```
void CLOCK_XOSCHF_crystal_init(void)
{
    /* Enable crystal oscillator
     * with frequency range 16MHz and 4K cycles start-up time
     */
    ccp_write_io((uint8_t *) &CLKCTRL.XOSCHFCTRLA, CLKCTRL_RUNSTDBY_bm
                | CLKCTRL_CSUTHF_4K_gc
                | CLKCTRL_FRQRANGE_16M_gc
                | CLKCTRL_SELHF_CRYSTAL_gc
                | CLKCTRL_ENABLE_bm);

    /* Confirm crystal oscillator start-up */
    while(!(CLKCTRL.MCLKSTATUS & CLKCTRL_EXTS_bm))
    {
        ;
    }

    //PORTA.DIRSET = PIN7_bm;
    /* Set the main clock to use XOSCHF as source, and enable the CLKOUT pin */
    ccp_write_io((uint8_t *) &CLKCTRL.MCLKCTRLA, CLKCTRL_CLKSEL_EXTCLK_gc
                | CLKCTRL_CLKOUT_bm);

    /* Wait for system oscillator changing to complete */
    while(CLKCTRL.MCLKSTATUS & CLKCTRL_SOSC_bm)
    {
        ;
    }

    /* Clear RUNSTDBY for power save when not in use */
    ccp_write_io((uint8_t *) &CLKCTRL.XOSCHFCTRLA, CLKCTRL.XOSCHFCTRLA &
~CLKCTRL_RUNSTDBY_bm);

    /* Change complete and the main clock is 16 MHz */
}
```

Info: The main function will be as follows, containing a call to the CLOCK_XOSCHF_crystal_init() function.

```
int main(void)
{
        CLOCK_XOSCHF_crystal_init();
        CLOCK_CFD_CLKMAIN_init();
        LED0_init();
        SW0_init();

        /* Enable global interrupts */
        sei();

        /* Replace with your application code */
        while(1)
        {
            LED0_toggle();
            _delay_ms(200);
    }
}
```

3.2 Configure the CFD to Detect Failures on the Main Clock

To do:

- Edit the `CLOCK_CFD_CLKMAIN_init()` function so that the CFD is set up to monitor the main clock and generates an NMI upon clock failure
- Set up the NMI handler
- Create a main clock failure using the software test

1. Enable the CFD and set the main clock as the source by adding:

```
ccp_write_io((uint8_t *) &CLKCTRL.MCLKCTRLC, CLKCTRL_CFDSRC_CLKMAIN_gc
                | CLKCTRL_CFDEN_bm);
```

   to `CLOCK_CFD_CLKMAIN_init()`.

2. Enable the CFD interrupt and set the interrupt type to NMI by writing:

```
ccp_write_io((uint8_t *) &CLKCTRL.MCLKINTCTRL, CLKCTRL_INTTYPE_bm
                | CLKCTRL_CFD_bm);
```

Info: The CFD can create a normal interrupt or non-maskable interrupt depending on the setting in the Interrupt Type (INTTYPE) bit in the Main Clock Interrupt Control (CLKCTRL.MCLKINTCTRL) register. The advantage with an NMI is that the interrupt will trigger even if the microcontroller is in an interrupt or the global interrupt is disabled. This ensures that the interrupt will be executed straight away, and the error can be handled straight away. The only way to exit an NMI is by a device reset.

3. In the `ISR(NMI_vect)`, add the code to check if a CFD triggered the NMI and to blink the LED:

```
if(CLKCTRL.MCLKINTFLAGS & CLKCTRL_CFD_bm)
    {
    /* This interrupt will trigger if the source for the main clock fails
     * and the CFD is able to switch to a different working clock.
     * In this case that means XOSCHF has failed and is replaced by OSCHF.
     * The main clock is therefore reduced to 4 MHz.
     */

    /* Toggle the LED forever */
    while(1)
    {
        LED0_toggle();
        _delay_ms(200); // 200 ms calculated from 16 MHz == 800 ms
    }

    }
    else
    {
        /* A different NMI has been triggered */
    }
```

Info: There is only one interrupt vector for all the NMIs, so to be sure which NMI caused the interrupt, check the respective interrupt flags.

4. In the `ISR(PORTB_PORT_vect)`, add the code to trigger a clock failure when SW0 is pressed:

```
ccp_write_io((uint8_t *) &CLKCTRL.MCLKCTRLC, CLKCTRL.MCLKCTRLC | CLKCTRL_CFDTST_bm);
```

Info: When setting the Clock Failure Detection Test (CFDTST) bit in the Main Clock Control C (MCLKCTRL) register, hardware simulates a clock failure to test the CFD feature.

5. Verify that the solution/project builds by selecting the *Build Main Project* from the top menu bare in MPLAB® X or by pressing the *F11* key.
6. Flash the device by selecting the *Make and Program Device Main Project* from the top menu bar in MPLAB® X.

Result: After pressing SW0, the LED0 will start blinking with a lower frequency. This because the main clock source is switched to the start-up clock source, and the Main Clock Control B (CLKCTRL.MCLKCTRLB) register will be written to the reset value when a clock failure is detected. The number of clock ticks needed to create the `delay_ms(200)` is calculated using the XOSCHF clock frequency of 16 MHz, resulting in the `delay_ms` being four times as slow when the clock source is switched to the 4 MHz internal clock.

Info: The start-up clock source is decided by the Clock Select (CLKSEL) bit field in the Oscillator Configuration (OSCCFG) fuse.

WARNING As the MCLKCTRLB register is written to its default values by the CFD, the clock will not be available on the CLKOUT pin until it is set by the user again.

4. Assignment 2: CLKCTRL - High Frequency TCD using PLL

In this assignment, the AVR128DB48 Curiosity Nano will be configured to create a high-resolution PWM signal using TCD with the PLL as a clock source.

The PLL will increase the clock frequency of OSCHF.

The output from the PLL will be used as a clock source for TCD, which will create a high-resolution PWM signal.

The starting point for this assignment is the MPLAB® X project *Assignment2*.X.

- **Objectives**
  - Configure the PLL to use OSCHF as a clock source
  - Configure the TCD to use the PLL as a clock source and output a PWM signal
  - Visualize the PWM signal using a logic analyzer or an oscilloscope

4.1 Configure TCD to Use the PLL as a Clock Source

To do:

- Edit the `CLOCK_OSCHF_crystal_PLL_init()` to configure the PLL to use OSCHF as a source and multiply it by 3x
- Edit the `TIMER_TCD0_init()` so the TCD uses the PLL as a clock source and creates a PWM signal
- Plot the PWM signal using a logic analyzer

1. Edit `CLOCK_OSCHF_crystal_PLL_init()` so it sets the OSCHF frequency to 16 MHz by adding:

```
ccp_write_io((uint8_t *)&CLKCTRL.OSCHFCTRLA, CLKCTRL_FREQSEL_16M_gc);
```

Info: The minimum input frequency to the PLL is 16 MHz, and it has a maximum output of 48 MHz.

2. Set the PLL multiplication factor to 3x by adding the following to `CLOCK_OSCHF_crystal_PLL_init()`:

```
ccp_write_io((uint8_t *) &CLKCTRL.PLLCTRLA, CLKCTRL_MULFAC_3x_gc);
```

Info: The PLL has two input sources: The OSCHF and XOSCHF. The default source is OSCHF, but the XOSCHF can be configured by setting the Select Source for PLL (SOURCE) bit in the PLL Control A (PLLCTRLA) register.

3. Edit `TIMER_TCD0_init()` to include the following to set the PLL as the clock source with no prescaler:

```
TCD0.CTRLA = TCD_CLKSEL_PLL_gc | TCD_CNTPRES_DIV1_gc | TCD_SYNCPRES_DIV1_gc;
```

4. Set the TCD to one ramp PWM mode by writing:

```
TCD0.CTRLB = TCD_WGMODE_ONERAMP_gc;
```

5. Make the PWM signal available on the pins by adding:

```
/*Set TCD pins as output*/
PORTA.DIRSET = PIN4_bm | PIN5_bm;
ccp_write_io((uint8_t *) &TCD0.FAULTCTRL, TCD_CMPAEN_bm | TCD_CMPBEN_bm);
```

6. Enable the TCD by first ensuring that the Enable Ready (ENRDY) bit in the Status (TCDn.STATUS) register is set to '1' and then setting the ENABLE bit in Control A (TCDn.CTRLA) register:

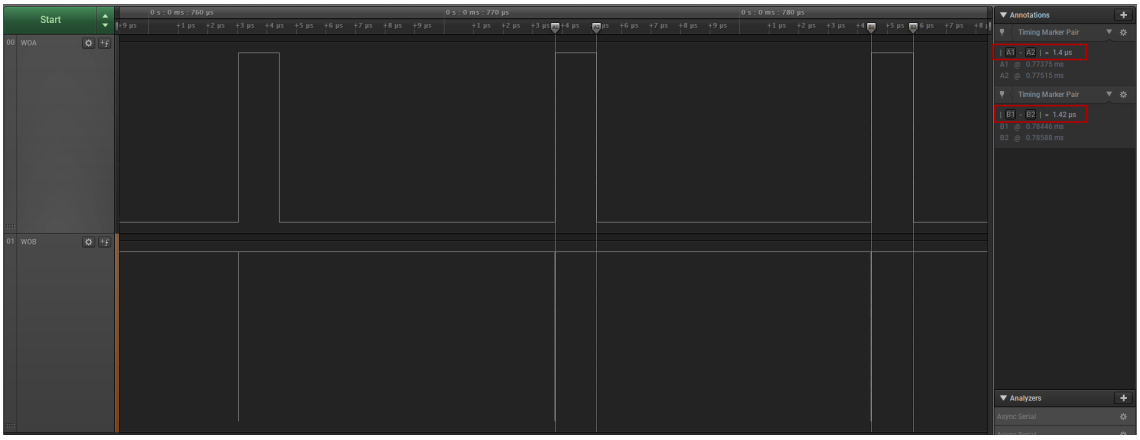
```
/* Wait for synchronization */
while(!(TCD0.STATUS & TCD_ENRDY_bm))
{
    ;
}
/* Enable TCD0 */
TCD0.CTRLA |= TCD_ENABLE_bm;
```

Info: In addition to the configurations that have been set, the TCD is set to increment the duty cycle of WOA by one bit after every period. See `ISR(TCD0_OVF_vect)` how this is implemented.

7. Verify that the solution/project builds by selecting the *Build Main Project* from the top menu bare in MPLAB® X or by pressing the *F11* key.
8. Flash the device by selecting the *Make and Program Device Main Project* from the top menu bar in MPLAB® X.
9. Plot the PWM signal using a Logic Analyzer the output for WOA is available on PA4, while the output for WOB is available on PA5.

Result: The PLL and TCD are combined to create a very high-resolution PWM signal. In Figure 4-1, you can seen that the duty cycle is increased by about 20 ns from 1.4 µs to 1.42 µs after each period showing the high-resolution of the PWM signal.

Figure 4-1. Assignment 2: Result



5. Assignment 3: OPAMP - Voltage Follower

In this assignment, the AVR128DB48 Curiosity Nano will be configured to use the op amp OP0 in the Analog Signal Conditioning (OPAMP) peripheral as a voltage follower.

The Digital-to-Analog Converter (DAC) is configured to create a sinusoidal signal, which will be used as an input to the op amp.

The Analog-to-Digital Converter (ADC) is configured to sample the output of the op amp.

Both the input and output of the op amp are streamed over to the MPLAB® Data Visualizer using the data streamer protocol.

The starting point for this assignment is the MPLAB® X project *Assignment3*.X.

- **Objectives**
  - Understand the necessary steps to configure an op amp instance in the OPAMP peripheral
  - Configure OP0 as a voltage follower
  - Plot the input and output from OP0 using the MPLAB® Data Visualizer

5.1 Configure OP0 as a Voltage Follower

To do:

- Edit the `OPAMP0_init()` so it configures OP0 to be a voltage follower
- Plot the input and output of OP0 in the MPLAB® Data Visualizer

1. Edit `OPAMP0_init()` to set the time base for the OPAMP peripheral by writing:

```
OPAMP.TIMEBASE = OPAMP_TIMEBASE_US;
```

Info: For internal timing purposes, the Timebase (OPAMP.TIMBASE) register needs the maximum number of CLK_PER cycles to achieve a timing interval equal to or larger than 1 µs. The rule to determine what number to write into the TIMBASE is: Determine the number of CLK_PER cycles equal to 1 µs. If this is an integer, subtract one. If not, round it down. The following macro can be used to calculate the value for the TIMEBASE register:

```
#define OPAMP_TIMEBASE_US      (ceil(F_CPU /1e6)-1)
```

2. Set the output mode to normal and the Always On (ALWAYSON) bit for OP0 by writing:

```
OPAMP.OP0CTRLA = OPAMP_OP0CTRLA_OUTMODE_NORMAL_gc | OPAMP_ALWAYSON_bm;
```

Info: Each op amp instance in the OPAMP peripheral has an independent output mode. The two modes are off and normal. In the off mode, the output driver for the op amp is off but can be overwritten by the DRIVE event. In the normal mode, the driver is always on.

Info: Each op amp instance in the OPAMP peripheral can be individually turned on or off. This can be achieved either by setting/clearing the ALWAYSON bit or by the ENABLEn/DISABLEn events. If events are used to control the op amp, the ALWAYSON bit has to be cleared.

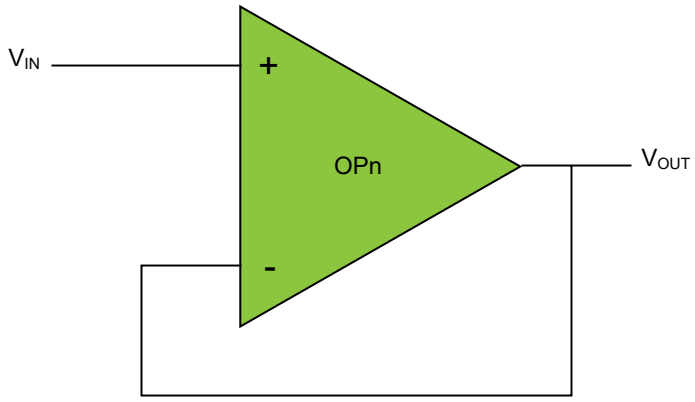
WARNING The Event Enable (EVENTEN) bit must be set in the OPnCTRA register to control the op amp using events

3. Configure OP0 to be a voltage follower with the DAC as an input by writing:

```
OPAMP.OP0INMUX = OPAMP_OP0INMUX_MUXNEG_OUT_gc | OPAMP_OP0INMUX_MUXPOS_DAC_gc;

/* Configure the Op Amp n Resistor Wiper Multiplexer */
OPAMP.OP0RESMUX =  OPAMP_OP0RESMUX_MUXBOT_OFF_gc | OPAMP_OP0RESMUX_MUXWIP_WIP0_gc |
                   OPAMP_OP0RESMUX_MUXTOP_OFF_gc;
```

Info:

Figure 5-1. Op Amp in Voltage Follower Configuration



To achieve a voltage follower configuration, the output of the op amp needs to be connected directly to the negative input. This is done by setting the Multiplexer for Negative Input (MUXNEG) bit field in the Op Amp n Input Multiplexer (OPnMUX) register to OUT. The output of the DAC and the positive input to OP0 are connected through an internal channel by setting the Multiplexer for Positive Input (MUXPOS) bit field in the OPnMUX register to DAC. There is no need to use the resistor ladder in the voltage follower, so all the bit fields in the Op Amp n Resistor Ladder Multiplexer (OPnRESMUX) register can be set to their default values.

4. Set the settling time by writing:

```
OPAMP.OP0SETTLE = OPAMP_MAX_SETTLE;
```

Info: The value in the Op Amp n Settle Timer (OPnSETTLE) register is the number of microseconds needed for the output of the op amp to settle. This time is highly application dependent. If it is not known, it is recommended to set it to the max value `0x7F`. This value, together with the value in the TIMEBASE register, is used by an internal timer to determine when to generate the READYn event and set the SETTLED flag in the OPnSTATUS register.

5. Enable the OPAMP peripheral by writing:

```
OPAMP.CTRLA = OPAMP_ENABLE_bm;
```

6. Wait for the op amp to settle before leaving the initialization by checking the Op Amp has Settled (SETTLED) bit field in the Op Amp n Status (OPnSTATUS) register:

```
while (!(OPAMP.OP0STATUS & OPAMP_SETTLED_bm))
    {
        ;
    }
```

7. Verify that the solution/project builds by selecting the *Build Main Project* from the top menu bare in MPLAB® X or by pressing the *F11* key.
8. Flash the device by selecting the *Make and Program Device Main Project* from the top menu bar in MPLAB® X.

Result: The device is now flashed and ready to start streaming data to the MPLAB® *Data Visualizer*.

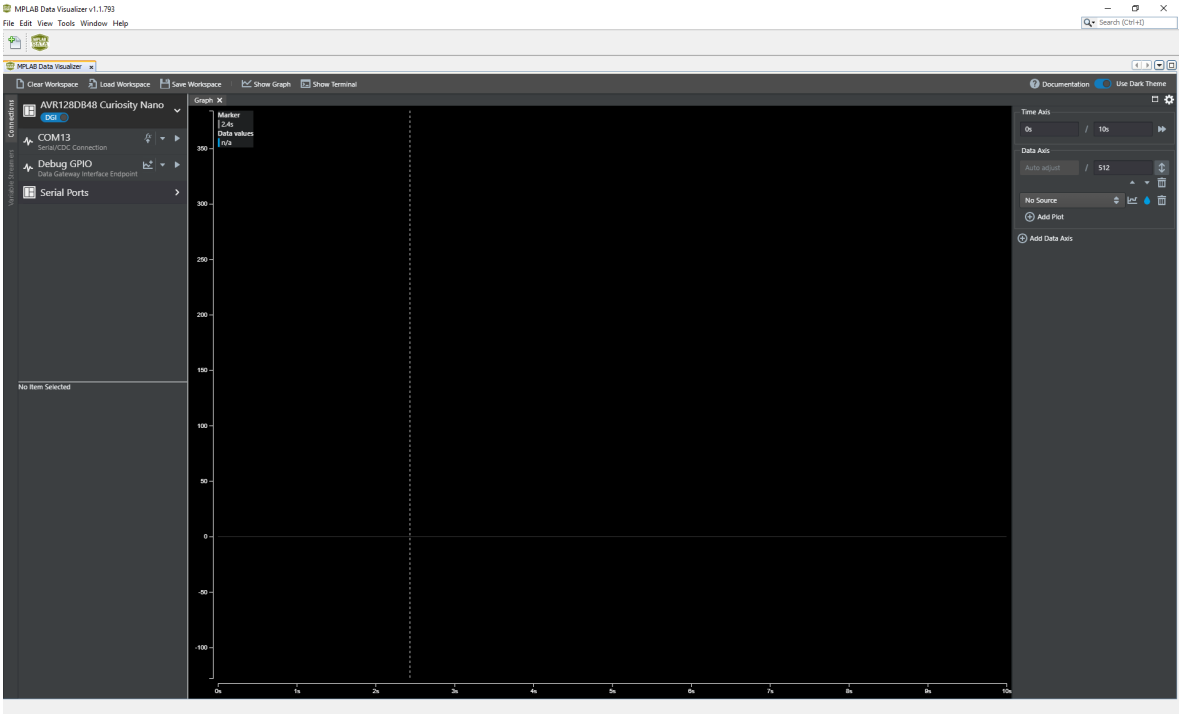
5.2 Plot Graph In MPLAB® Data Visualizer

The MPLAB® *Data Visualizer* is a program used to process and visualize data from a running embedded target. The program may be accessed as an MPLAB X IDE plugin or a stand-alone program. In this assignment, the *Data Visualizer* will be configured to graph the input and output of OP0 received over USART. The configuration is done through a saved workspace, and the basics of how to display the data are explained. To find out how to set up your own workspace, a detailed guide can be found by clicking on the *Documentation* button in MPLAB *Data Visualizer*.

To do: Configure MPLAB *Data Visualizer* to graph received OP0 input and output samples.

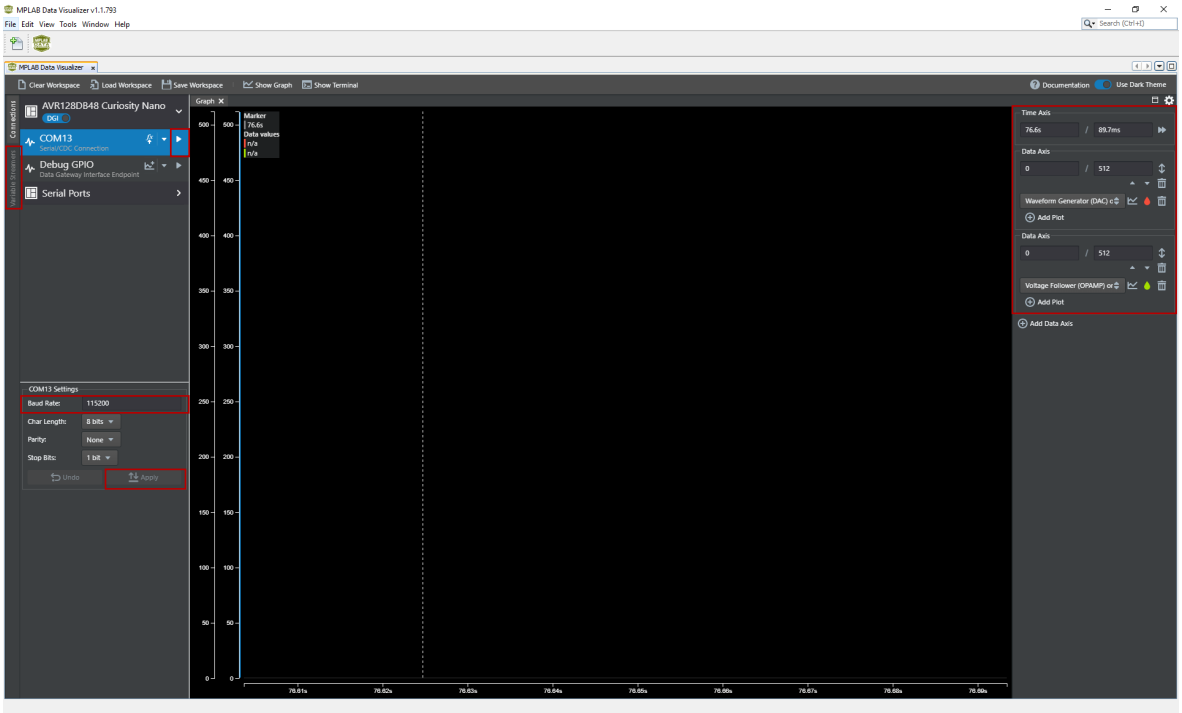
1. Open the program and plug in an already flashed device. Make sure the COM-port used for USART communication is not already in use. The start screen will be similar to Figure 5-2.

Figure 5-2. Assignment 3: MPLAB® Data Visualizer Starting Page



2. Load the workspace. Press the *Load Workspace* button and add the workspace-file called *Assignment3.json*. All the workspaces for this training can be found in `DataVisualizer`. Two axes appear in the graph. These can be configured on the panel on the right-hand side, as illustrated in Figure 5-3.

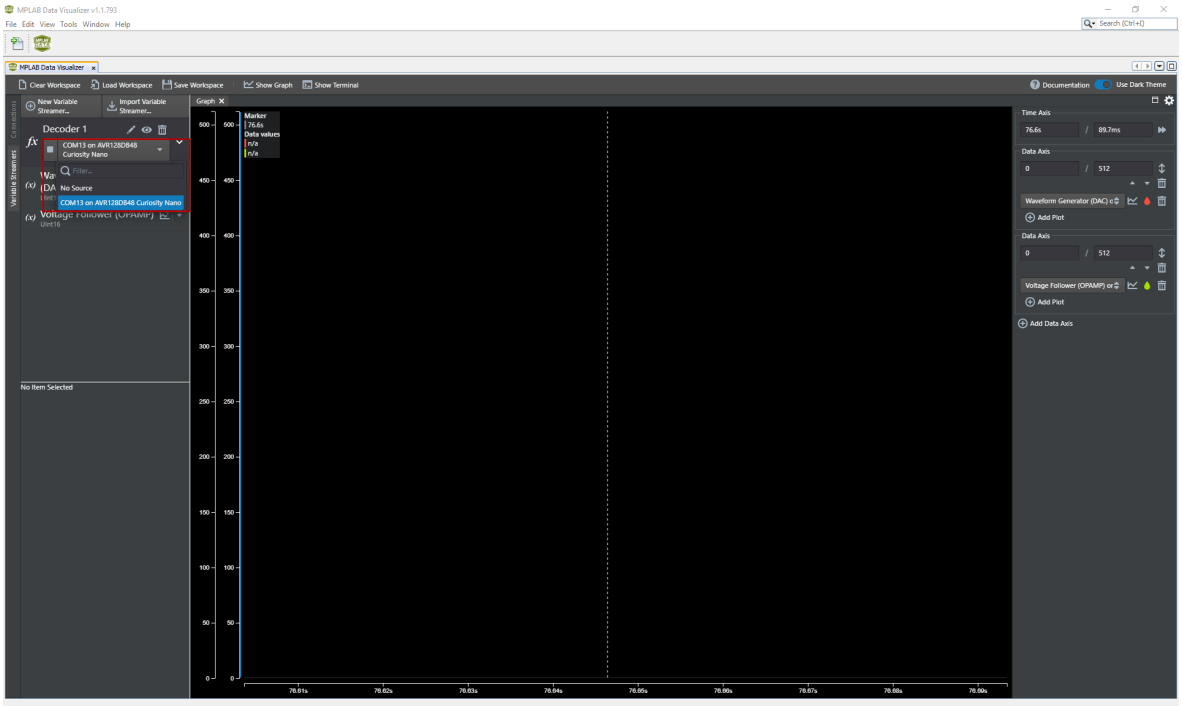
Figure 5-3. Assignment 3: Data Visualizer Loaded Work Space



3. Choose the COM-port on the left-hand side panel seen in Figure 5-3 to plot the data. Make sure the *Baud Rate* is *115200* and press the *Apply* button to set the baud rate. Press the *Play* button next to the COM field

shown in Figure 5-3. Press the *Variable Streamers* button to connect the decoder to the USART data stream. Set the COM port as input to Decoder 1, as shown in Figure 5-4.

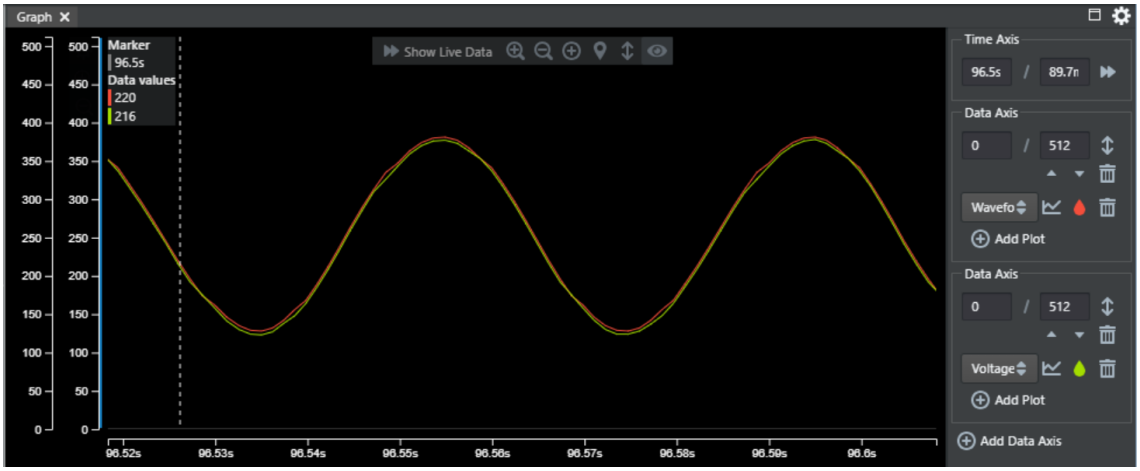
Figure 5-4. Assignment 3: Variable Streamers



4. Press *Show Live Data* to start plotting live data from the device.

Result: The data streamed to the PC over USART are plotted in the MPLAB® *Data Visualizer*, as shown in Figure 5-5. The red waveform is the output from the DAC, while the green is the output from the op amp. As expected, we can see that the output of the op amp closely follows the input to the op amp.

Figure 5-5. Assignment 3: Result



Info: The DAC outputs a 50 Hz sinusoidal wave with 256 mV_{pp} and 256 mV DC offset. The sinusoidal wave is pre-calculated at startup in the sine_wave_table_init() function, and DAC updated with values upon TCB0 ISR (SINE_WAVE_TIMER_vect).

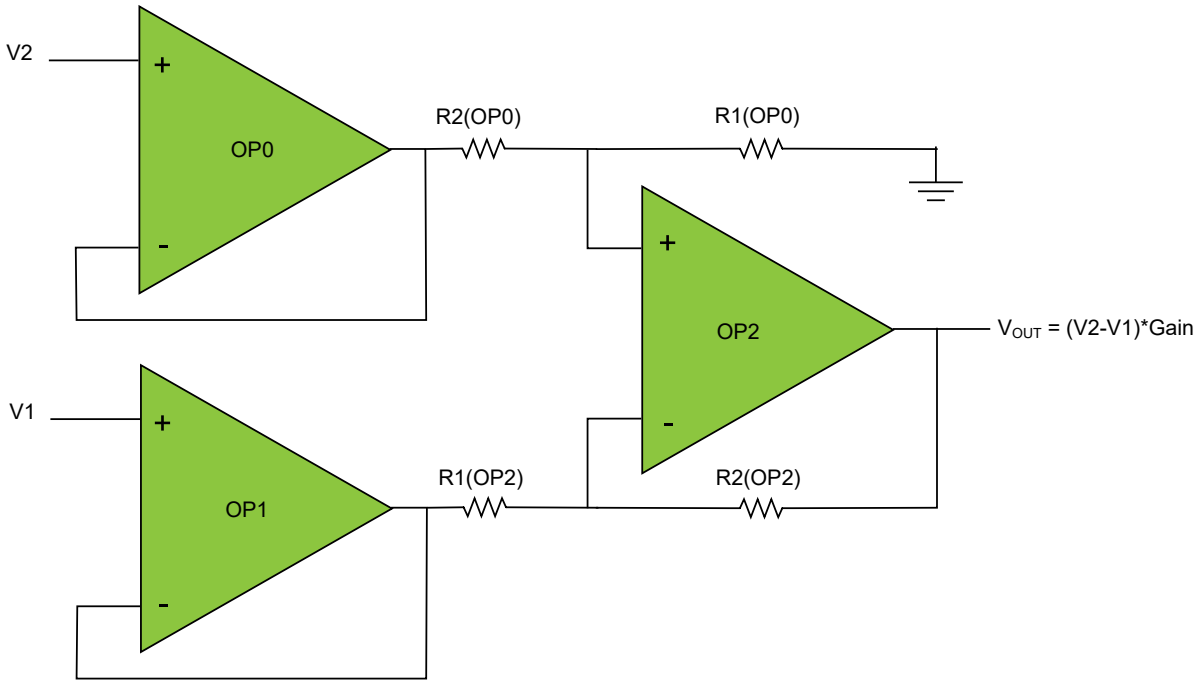
```
void sine_wave_table_init(void)
{
    for(uint16_t i = 0; i < SINE_WAVE_STEPS; i++)
    {
        sine_wave[i] = SINE_DC_OFFSET + SINE_AMPLITUDE * sin(i * M_2PI /
SINE_WAVE_STEPS);
    }
}
```

```
ISR(SINE_WAVE_TIMER_vect) {
    volatile static uint16_t sine_wave_index = 0

    data_stream.dacVal = sine_wave[sine_wave_index];
    DAC0_setVal(data_stream.dacVal);
    sine_wave_index++;
    sine_wave_index = sine_wave_index % SINE_WAVE_STEPS;

    /* Clear interrupt flag */
    SINE_WAVE_TIMER.INTFLAGS = TCB_CAPT_bm;
}
```

6. Assignment 4: OPAMP - Instrumentation Amplifier

In this assignment, the AVR128DB48 Curiosity Nano will be configured to combine all the op amps in the Analog Signal Conditioning (OPAMP) peripheral to create an instrumentation amplifier, as shown below in Figure 6-1.

Figure 6-1. Assignment 4: Instrumentation Amplifier



The configuration is done through MCC.

The Digital-to-Analog Converter (DAC) is configured to create a sinusoidal signal, which will be used as one of the inputs to the instrumentation amplifier. The second input will be V_{DD} divided by two.

The Analog-to-Digital Converter (ADC) is configured to sample the output of the instrumentation amplifier. Both the input and output of the op amp is streamed over to the MPLAB® *Data Visualizer* using the data streamer protocol.

The circuit will also be simulated using the pre-made schematic containing a model of the AVR DB op amp. The schematic will be found in MCC.

The starting point for this assignment is the MPLAB® X project *Assignment4*.X.

- **Objectives**
  - Understand how to configure an op amp in MCC
  - Configure OPAMP peripheral as an instrumentation amplifier using MCC
  - Plot the input and output from the instrumentation amplifier using the MPLAB® Data Visualizer
  - Simulate the instrumentation amplifier in Mindi™ using the pre-made schematic containing a model of the AVR DB op amp

6.1 Configure the OPAMP Peripheral as an Instrumentation Amplifier

To do:

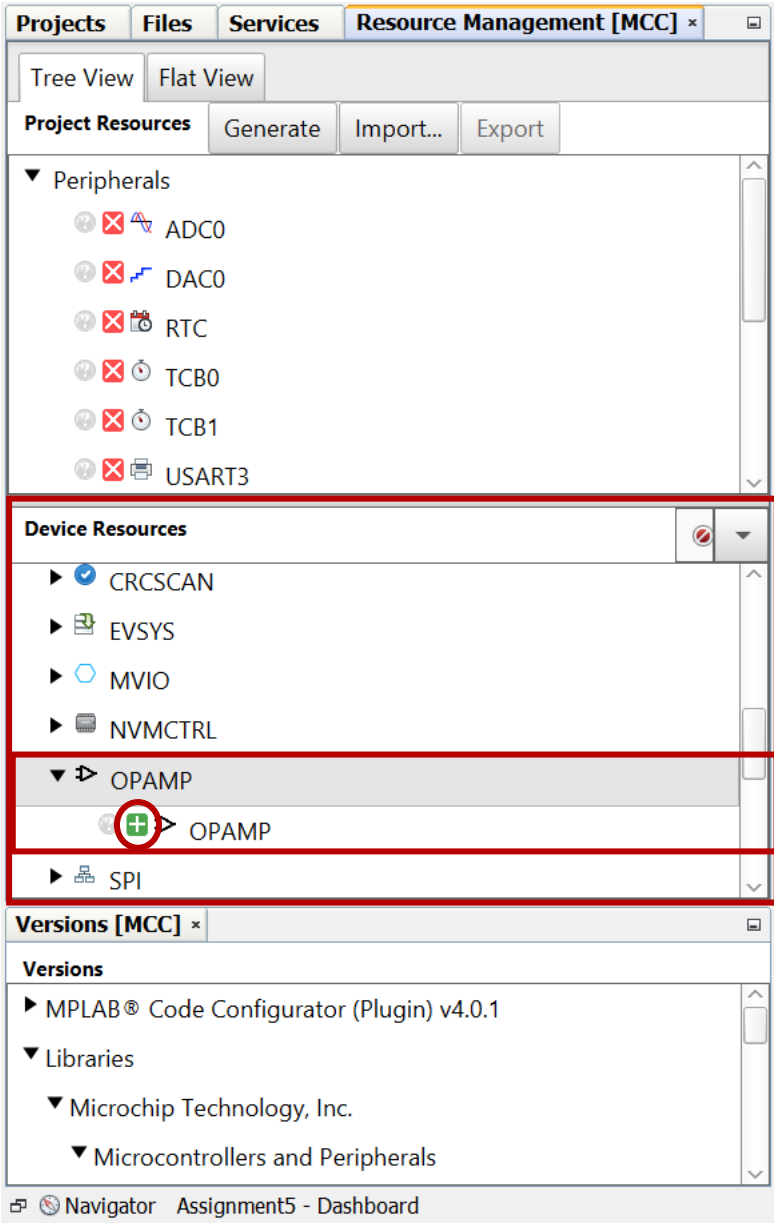
- Edit the MCC project, so the OPAMP peripheral is configured as an instrumentation amplifier
- Plot the input and output of the instrumentation amplifier in the MPLAB® Data Visualizer

1. Press the *MPLAB® Code Configurator v4: open/close* button in the toolbar to be able to edit the MCC project. Figure 6-2 shows the position of the button.

Figure 6-2. Assignment 4: MCC Button

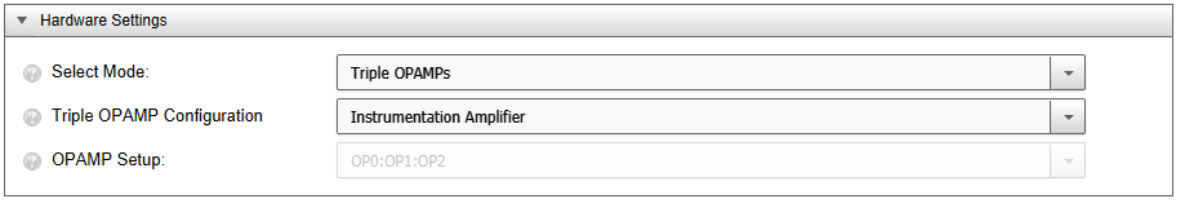
2. In the Device Resources window, scroll down to the OPAMP peripheral, press the arrow to expand it, and press the green plus button the add the OPAMP peripheral to the project, as shown in Figure 6-3.

Figure 6-3. Assignment 4: Add OPAMP



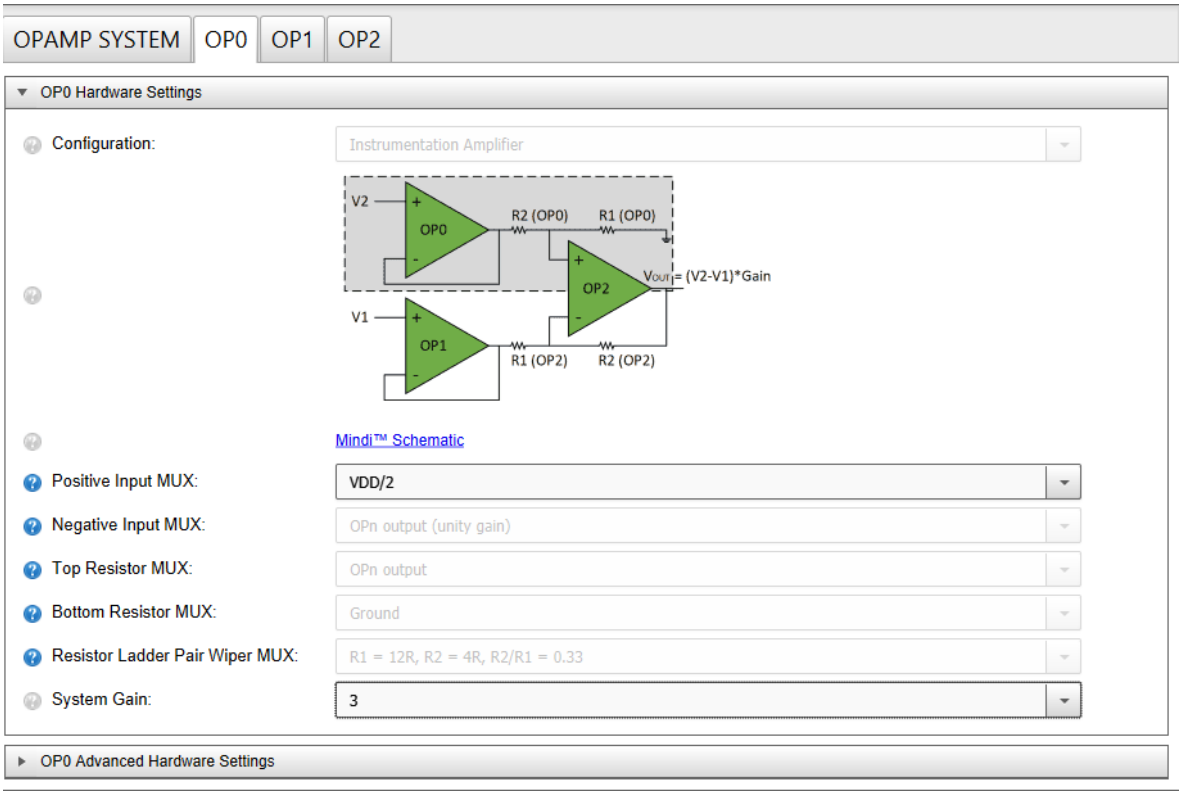
3. In the OPAMP Hardware Settings window, set Select Mode to Triple OPAMP's and Triple OPAMP Configuration to Instrumentation Amplifier, as shown in Figure 6-4.

Figure 6-4. Assignment 4: Hardware Settings



4. Go to the OP0 tab and sett the Positive Input MUX to VDD/2 and the System Gain to 3, as shown in Figure 6-5.

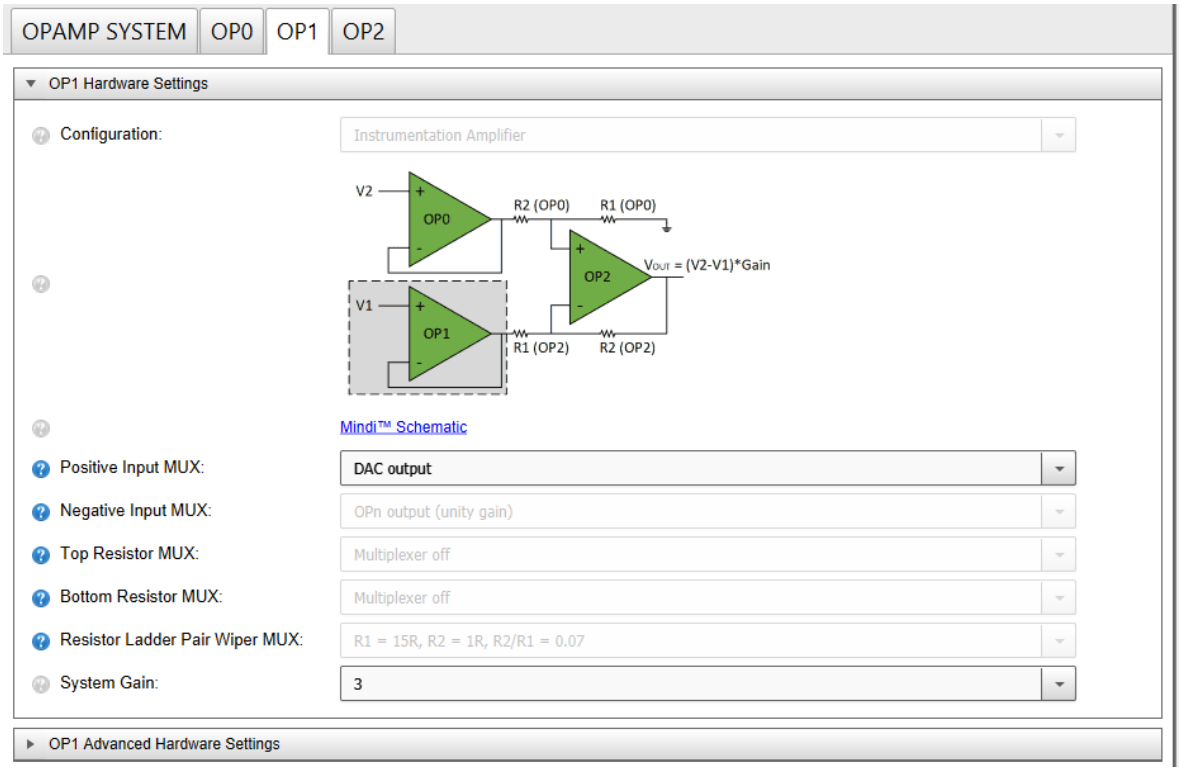
Figure 6-5. Assignment 4: OP0



Info: The settings combination for the resistor ladder for OP0 and OP2 controls the instrumentation amplifier gain. To make this easier to use the resistor ladder settings for OP0 and OP2 are, therefore, controlled by the system gain setting. The system gain setting is shared between all three op amp tabs.

5. Go to the OP1 tab and set the Positive Input MUX to DAC output, as shown in Figure 6-6.

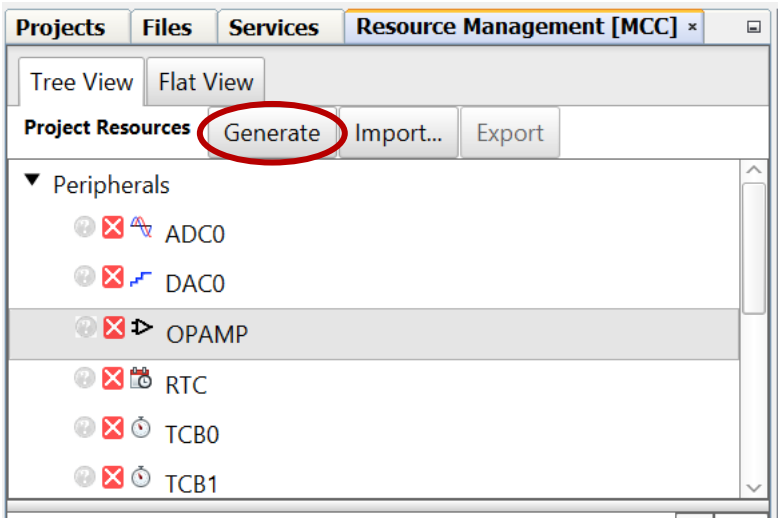
Figure 6-6. Assignment 4: OP1



Info: There is no customizable option for OP2 as it is connected directly to the other op amps, and the system gain controls it's resistor ladder settings.

6. Press the *Generate* button to regenerate the project code with the OPAMP peripheral added. The *Generate* button can be found next to Project Resources, as shown in Figure 6-7.

Figure 6-7. Assignment 4: Generate



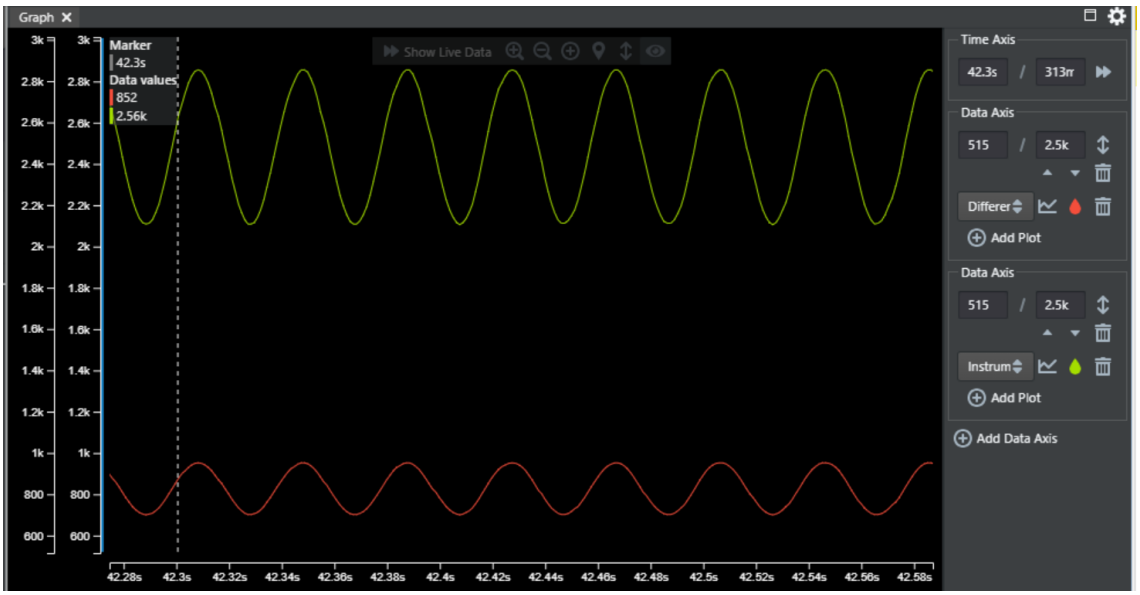
7. Verify that the project builds by pressing *Production→Build Project* or by pressing *F11*.
8. Flash the device by pressing the *Make and Program Device Main Project*.

9. Plot the DAC output vs. the op amp output using the MPLAB® *Data Visualizer* by load the workspace *Assignment4.json*.

Info: The DAC outputs a 25 Hz sinusoidal wave with 256 V_{pp} and a DC offset of 856 mV.

Result: The input and output to the instrumentation amplifier are plotted in the MPLAB® *Data Visualizer*, as shown in Figure 6-8. The red waveform is the differential input to the instrumentation amplifier, while the green is the output from the instrumentation amplifier. As expected, the output is about three times as large as the input.

Figure 6-8. Assignment 4: MPLAB® *Data Visualizer*



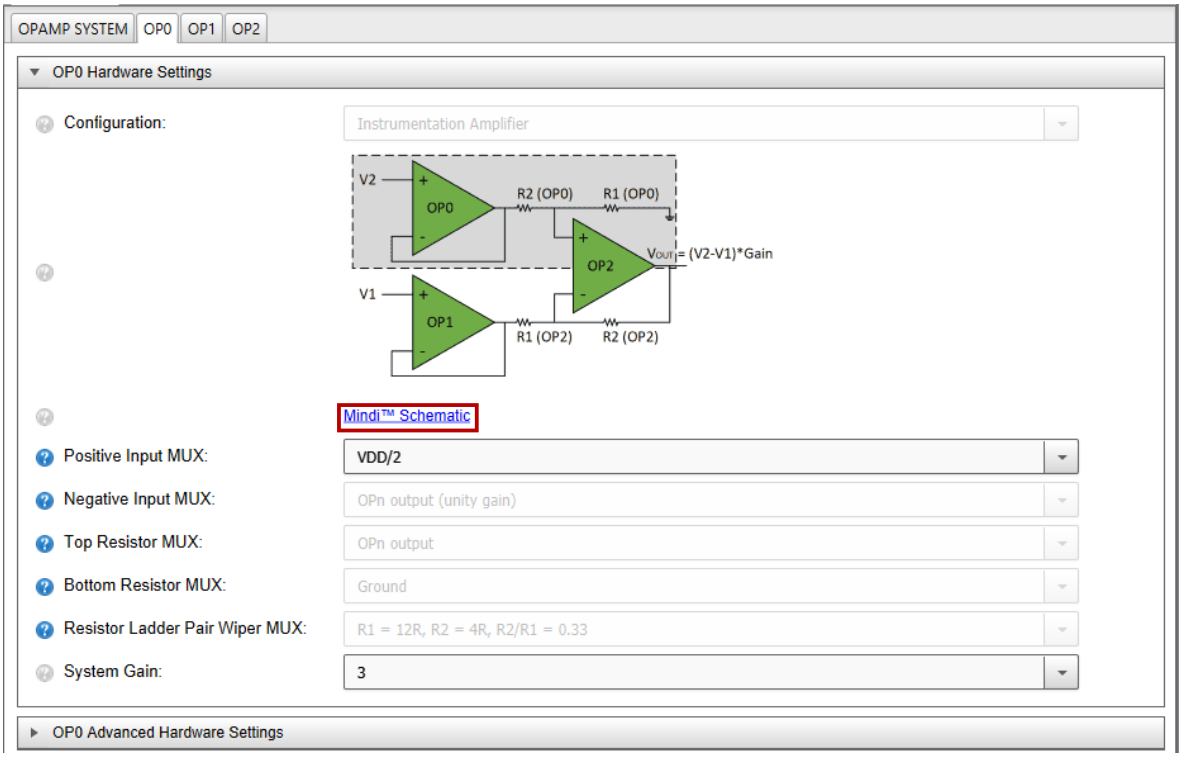
6.2 Simulate the Instrumentation Amplifier in Mindi™

To do:

- Download the pre-made instrumentation amplifier simulation file containing the AVR DB op amp model
- Run the simulation

1. Go to any of the OPn banners and press the Mindi™ Schematic link to get to the GitHub repository for the instrumentation amplifier. The position of the link is shown in Figure 6-9.

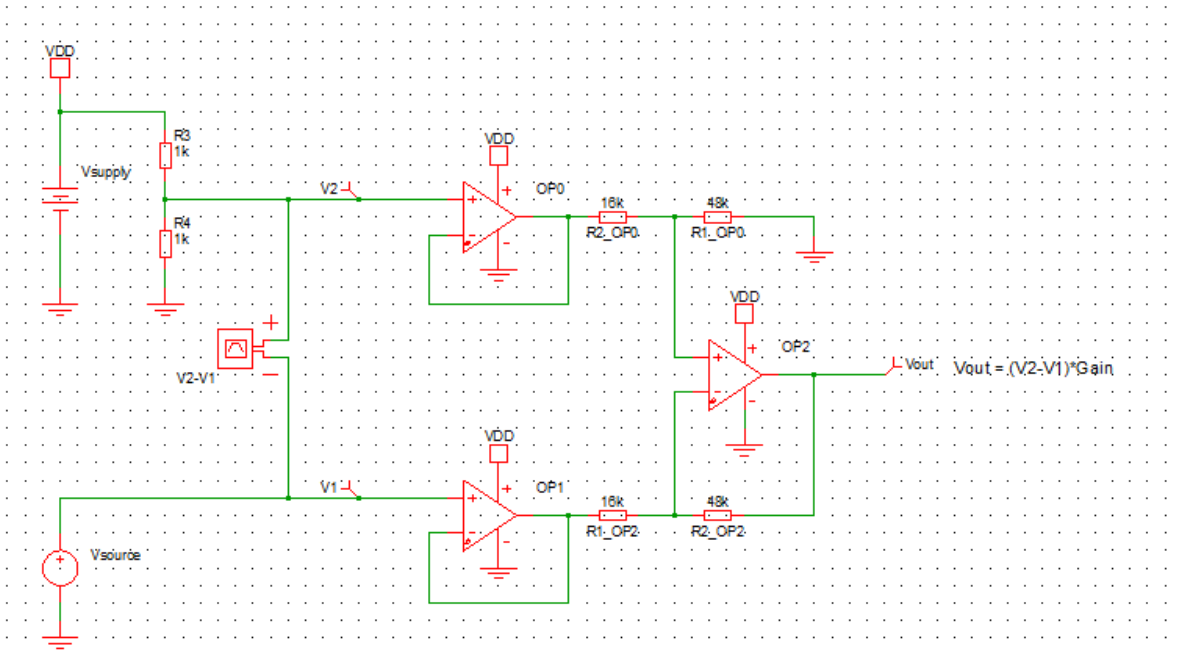
Figure 6-9. Assignment 4: Mindi™ Link



Info: A similar link to the one presented in MCC is also available in Atmel START.

2. On the GitHub page, press the *Releases* button and then press the *Source Code (zip)* for the latest release to download the schematic.
3. Unzip the folder to your location of choice.
4. Open MPLAB® Mindi, press *File→Open* or *Ctrl+o*, and locate the file *Instrumentation_Amplifier* in the location where the zip file was extracted.
5. Make sure the resistor values for OP0 and OP2 are correct for a 3x gain by looking at the Instrumentation Amplifier Gain Settings table under the schematic shown in Figure 6-10.

Figure 6-10. Assignment 4: Instrumentation Amplifier Gain



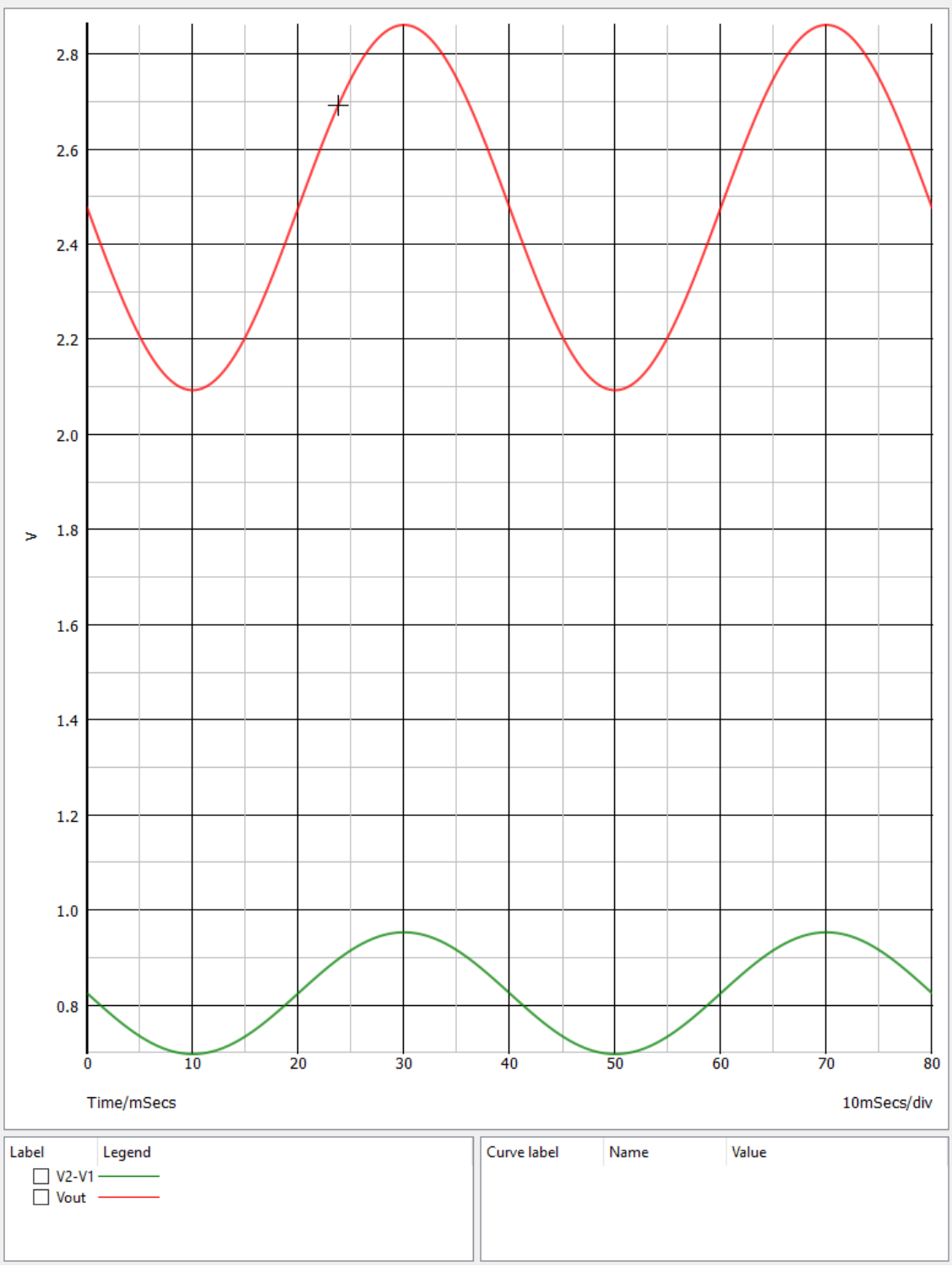
Instrumentation Amplifier Gain Settings

Gain	MUXWIP				Wiper Resistor Values			
	OP0		OP2		OP0		OP2	
	Value	Name	Value	Name	R1	R2	R1	R2
0.06	0x7	WIP7	0x0	WIP0	4k	60k	60k	4k
0.14	0x6	WIP6	0x1	WIP1	8k	56k	56k	8k
0.33	0x5	WIP5	0x2	WIP2	16k	48k	48k	16k
1	0x3	WIP3	0x3	WIP3	32k	32k	32k	32k
3	0x2	WIP2	0x5	WIP5	48k	16k	16k	48k
7	0x1	WIP1	0x6	WIP6	56k	8k	8k	58k
15	0x0	WIP0	0x7	WIP7	60k	4k	4k	60k

6. Simulate by pressing the *Run Schematic* button.

Result: The input and output of the instrumentation amplifier are plotted in MPLAB® Mindi™, as shown in Figure 6-11. The red waveform is the output from the instrumentation amplifier, and the green is the differential input. As expected, the output is three times as large as the input, and the plot is very similar to the one in the MPLAB® *Data Visualizer*.

Figure 6-11. Assignment 5: Mindi™ Result



7. Assignment 5: MVIO - OPAMP as a Regulated Power Supply for VDDIO2

In this assignment, the AVR128DB48 Curiosity Nano will be configured to use two voltage domains V_{DD} and V_{DDIO2}. V_{DD} is supplied by the CNANO voltage regulator, while V_{DDIO2} is supplied by OP0, which is configured as a voltage follower with the DAC as an input. The reason the DAC is not used directly to supplying V_{DDIO2} is that the DAC can source very little current compared to the op amp.

The Digital-to-Analog Converter (DAC) is configured to create the input voltage to OP0. Therefore, the output from the DAC will be the voltage level for V_{DDIO2}.

The Analog-to-Digital Converter (ADC) is configured to sample V_{DDIO2} divided by 10. The measured V_{DDIO2} is streamed over to the MPLAB® Data Visualizer using the data streamer protocol.

The starting point for this assignment is the MPLAB® X project *Assignment4.X*.

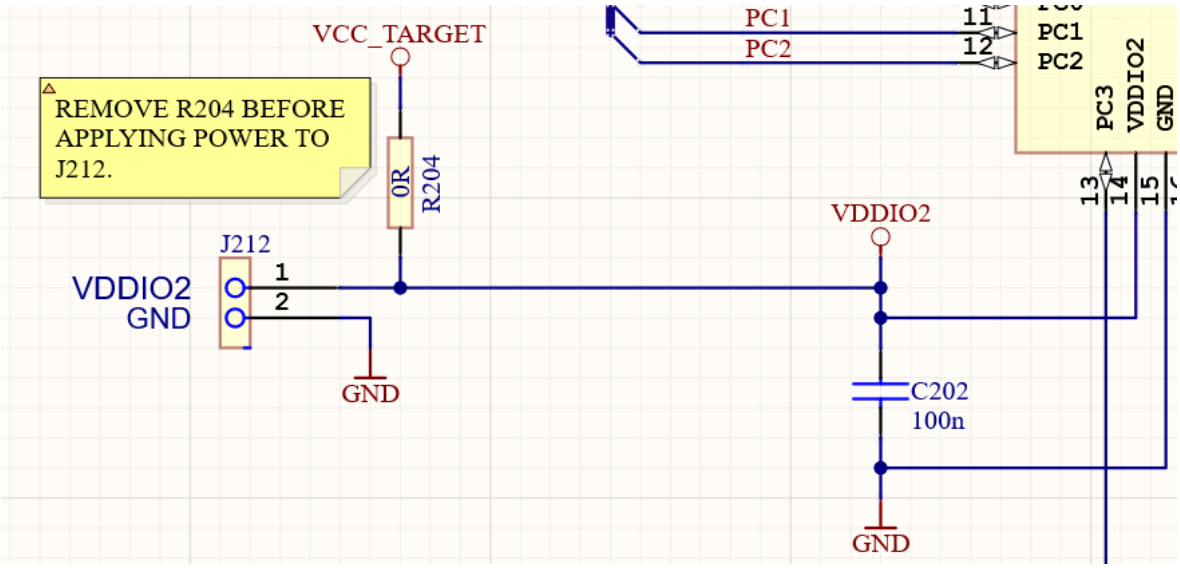
- **Objectives**
  - Understand how the AVR DB can work with two different voltage domains
  - Use the ADC to measure V_{DDIO2} using the internal connection
  - Plot the measured V_{DDIO2} using the MPLAB® Data Visualizer

7.1 MVIO Hardware Setup

To do:
- Modify the AVR128DB48 Curiosity Nano to work with two voltage domains
- Set the AVR128DB48 Curiosity Nano fuses so it operates with two voltage domains

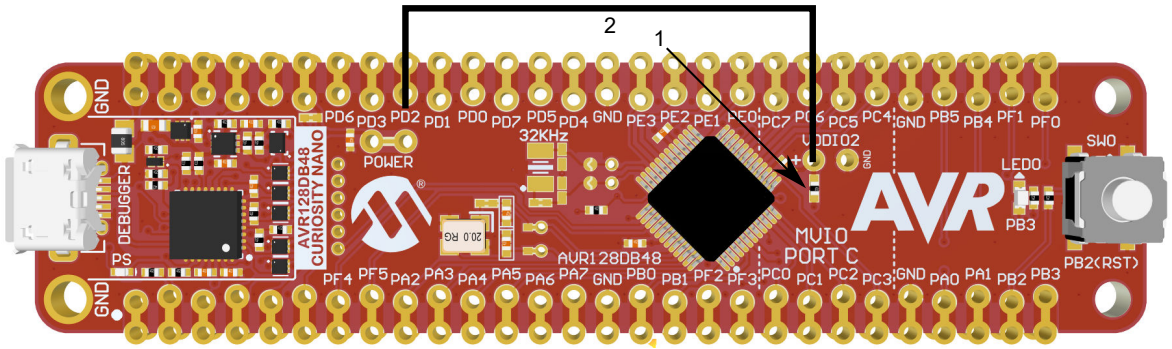
1. Remove the resistor right below the VDDIO2 label to disconnect VDDIO2 from VDD. This is the resistor R204 in Figure 7-1, pointed to by the arrow in Figure 7-2.

Figure 7-1. Assignment 6: VDDIO2 Schematic



2. Connect a wire between PD2 and VDDIO2+, as shown in Figure 7-2.

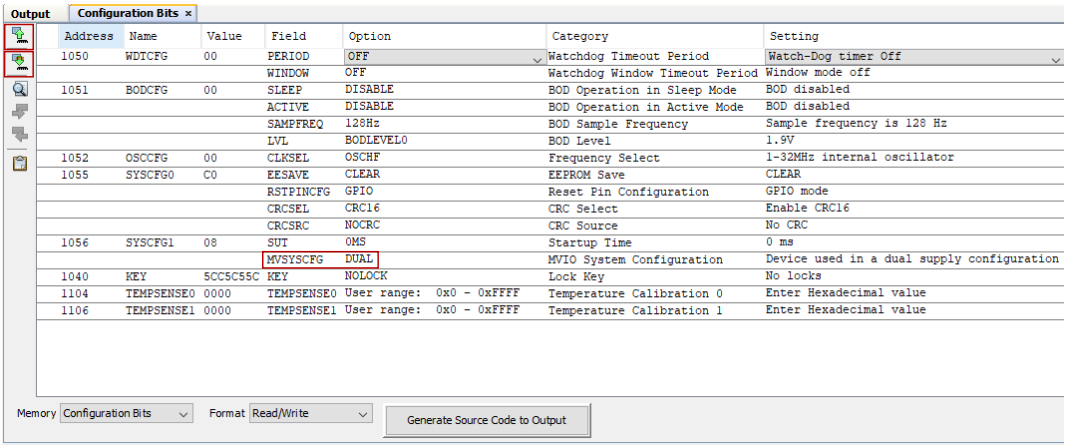
Figure 7-2. Assignment 5: Curiosity Nano AVR128DB48



3. Set the MVSYSCFG bit field in the System Configuration 1 (SYSCFG) fuse to DUAL.

Info: To program fuses in MPLAB® X, go to *Production→Set Configuration Bits* to open up the Configuration Bits window shown in Figure 7-3. Press the *Read Configuration Bits* button to read back the current fuse settings on the device. Set MVSYSCFG to DUAL and press *Program Configuration Bits* to program the current fuse settings onto the device.

Figure 7-3. Assignment 5: MPLAB® X Fuse Programing



Result: The AVR128DB48 Curiosity Nano CNANO is ready to run with two power domains.

7.2 Measuring VDDIO2 Using the ADC

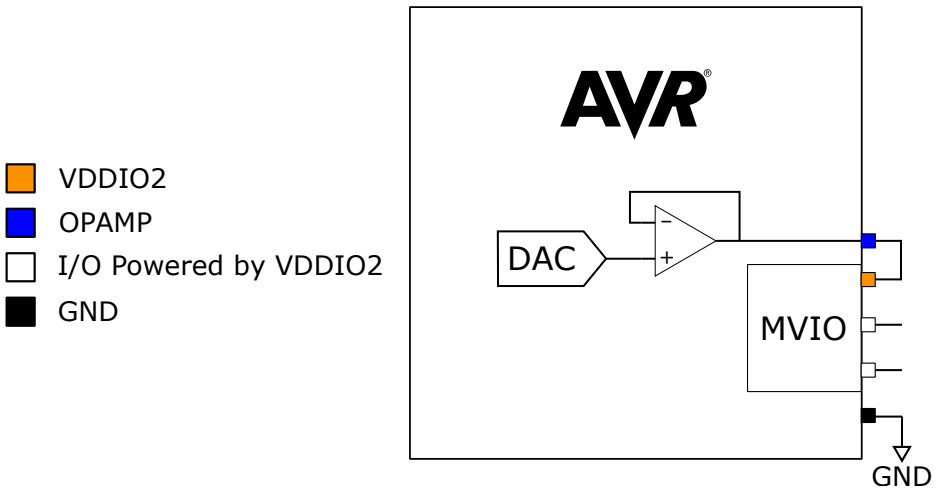
To do:

- Understand how the op amp and DAC combine to create a power supply for V_{DDIO2}
- Edit `adc0_init()` so it configures the ADC to measure V_{DDIO2}
- Plot the measured V_{DDIO2} values in MPLAB® *Data Visualizer*

1. Study the `op_amp_ini()` function to see how OP0 is configured as a voltage follower with the DAC as an input.
2. Study the `dac_init()` function to see how it outputs a constant voltage called `VDDIO2`, which is defined in `dac.h`.

Info: Combining the DAC and op amp with the hardware modifications used earlier in this assignment, the op amp will be a power supply for V_{DDIO2}. This is illustrated in Figure 7-4.

Figure 7-4. Assignment 5: Op Amp as a Power Supply



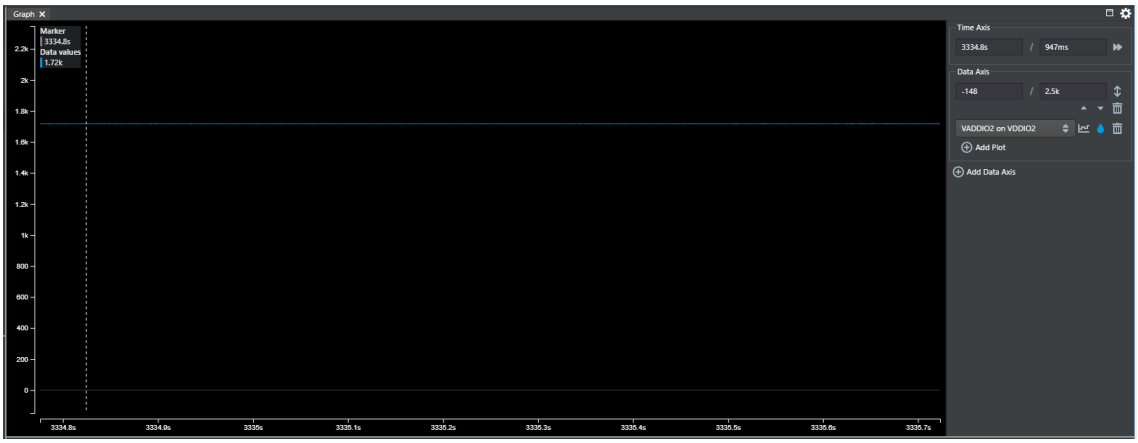
3. In the `adc0_init()` function, set VDDIO2DIV10 as an input to the ADC by writing:

```
ADC0.MUXPOS = ADC_MUXPOS_VDDIO2DIV10_gc;
```

4. Verify that the solution/project builds by selecting the *Build Main Project* from the top menu bare in MPLAB® X or by pressing the *F11* key.
5. Flash the device by selecting the *Make and Program Device Main Project* from the top menu bar in MPLAB® X.
6. Plot the measured ADC reading in the MPLAB® *Data Visualizer* by loading the workspace *Assignment6.json*.

Result: The ADC measurements are plotted in MPLAB® *Data Visualizer*, as shown in Figure 7-5. Note that the unit is millivolts.

Figure 7-5. Assignment 5: Result



8. Assignment 6: MVIO - VDDIO2 Failure Detection

In this assignment, the AVR128DB48 Curiosity Nano will be configured to use two voltage domains V_{DD} and V_{DDIO2}. V_{DD} is supplied by the CNANO voltage regulator, while V_{DDIO2} is supplied by OP0, which is configured as a voltage follower with the DAC as an input.

The Digital-to-Analog Converter (DAC) is configured to create the input voltage to OP0. The output from the DAC will therefore be the voltage level for V_{DDIO2}.

The Analog-to-Digital Converter (ADC) is configured to sample V_{DDIO2} divided by 10. The measured V_{DDIO2} is streamed over to the MPLAB® Data Visualizer using the data streamer protocol.

When SW0 is pressed, the output from the DAC will be reduced, resulting in a VDDIO2 interrupt detecting the failure on the VDDIO2 line.

The starting point for this assignment is the MPLAB® X project *Assignment6*.X.

- **Objectives**
  - Introduce an error to V_{DDIO2} by lowering the supply voltage bellow it's specifications
  - Understand how the AVR DB can detect that V_{DDIO2} falls bellow its minimum requirement
  - Use the ADC to measure V_{DDIO2} using the internal connection
  - Plot the measured V_{DDIO2} using the MPLAB® Data Visualizer

8.1 Set Up VDDIO2 Failure Detection

To do:

- Edit `mvio_init()` so it enables the VDDIO2 status change interrupt
- Edit `ISR(MVIO_MVIO_vect)` to handle the VDDIO2 status change interrupt
- Plot the measured V_{DDIO2} values in MPLAB® *Data Visualizer*

This assignment assumes the hardware setup steps described in Assignment 6 have been completed. If they have not been completed, the step-by-step instructions can be found in 7.1 MVIO Hardware Setup.

Info: The DAC, ADC and OPAMP peripheral are all configured in the same way as it was done for assignment 6. The description of the setup can be found in 7.2 Measuring VDDIO2 Using the ADC.

1. Enable the VDDIO2 status change interrupt by editing `mvio_init()` to include:

```
MVIO.INTCTRL = MVIO_VDDIO2IE_bm;
```

2. Handle the interrupt by clearing the interrupt flag and toggling LED0 by adding the following to `ISR(MVIO_MVIO_vect)`:

```
MVIO.INTFLAGS = MVIO_VDDIO2IF_bm;
LED0_toggle();
```

3. Understand how the V_{DDIO2} fault is injected when SW0 is pressed by lowering the op amp output by looking at the `ISR(PORTB_PORT_vect)` found in `gpio.c`.

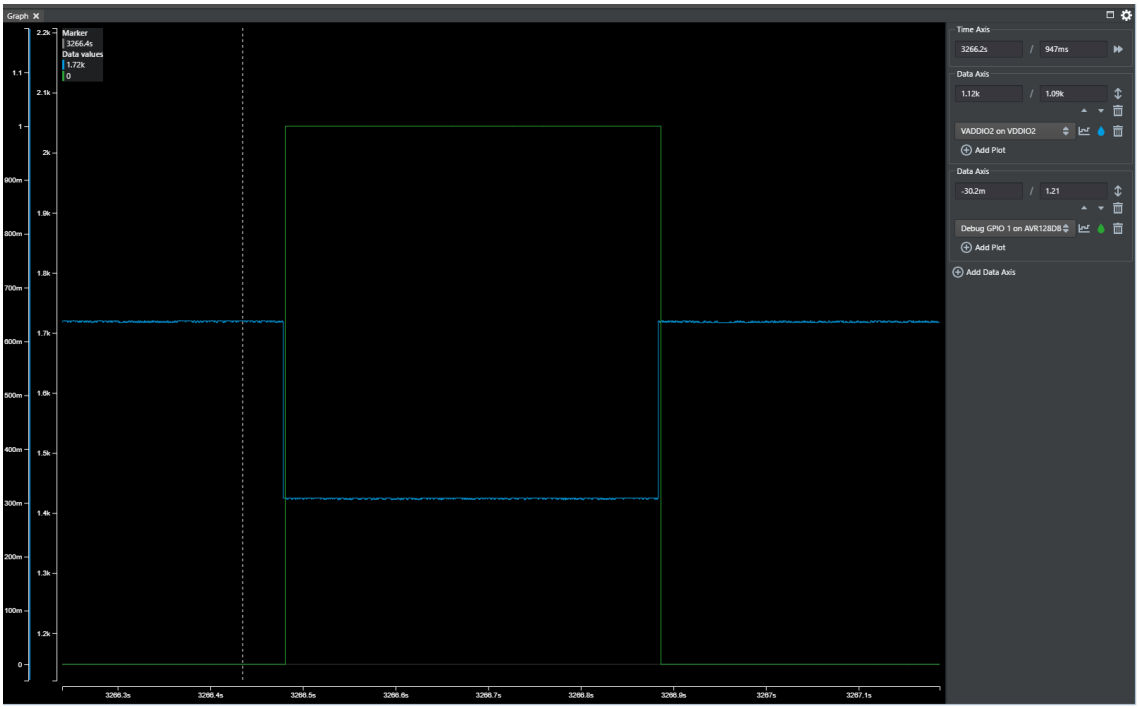
Info: When V_{DDIO2} goes below the acceptable range, the VDDIO2 Status bit goes low, triggering the VDDIO2 status change interrupt. When V_{DDIO2} is below the acceptable range, all the pins on PORTC are tri-stated. When V_{DDIO2} goes back up again, the values from the PORTC registers are loaded again.

4. Verify that the solution/project builds by selecting the *Build Main Project* from the top menu bare in MPLAB® X or by pressing the *F11* key.
5. Flash the device by selecting the *Make and Program Device Main Project* from the top menu bar in MPLAB® X.
6. Plot the measured ADC reading and the status of LED0 in MPLAB® *Data Visualizer* by loading the workspace Assignment7.json.

Info: LED0 is active low, so the plot in MPLAB® *Data Visualizer* will show '0' when the led is lighting and '1' when it is off.

Result: The ADC measurements and SW0 states are plotted in MPLAB® *Data Visualizer*, as shown in Figure 8-1. It can be seen that as soon as SW0 is pressed and V_{DDIO2} goes below the acceptable value, the VDDIO2 status change interrupt triggers, and the LED0 line goes high. When SW0 is pressed again and V_{DDIO2} goes back into the acceptable range, the LED0 goes back low. The blue line is the V_{DDIO2} reading, while the green line is LED0.

Figure 8-1. Assignment 6: Result



9. Revision History

Doc. Rev.	Date	Comments
A	11/2020	Initial document release

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