This version (20 Apr 2021 15:17) was ***approved*** by Shine Cabatan.
The Previously approved version (16 Apr 2021 15:13) is available.

Evaluating the AD9106/AD9102 Waveform Generator Digital-to-Analog Converter

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Preface

Analog Devices is an Mbed Partner and develops code on the platform for multiple products. The AD9106 and AD9102 Mbed-enabled evaluation boards and example Mbed codes can be used as starting point for characterizing the high-speed waveform generator digital-to-analog converters before integrating them into specific applications.

This guide will focus on how AD9106-ARDZ-EBZ/AD9102-ARDZ-EBZ works with SDP-K1 controller board developed by Analog Devices. Users are not limited to using SDP-K1 for evaluation or prototyping. The evaluation boards and the example source codes with minor changes can work with other ARM-based Mbed-enabled boards. The user interface is text based.

The evaluation setup can be powered by USB only and does not require a high-frequency waveform generator for clock input. The evaluation board has an on-board 156.25 MHz crystal oscillator. To fit the evaluation system in a small form factor and manage power consumption within USB specifications, AD9106 and AD9102 supply voltages AVDD, DVDD and CLKVDD are limited to 3.3V only.

Typical Setup

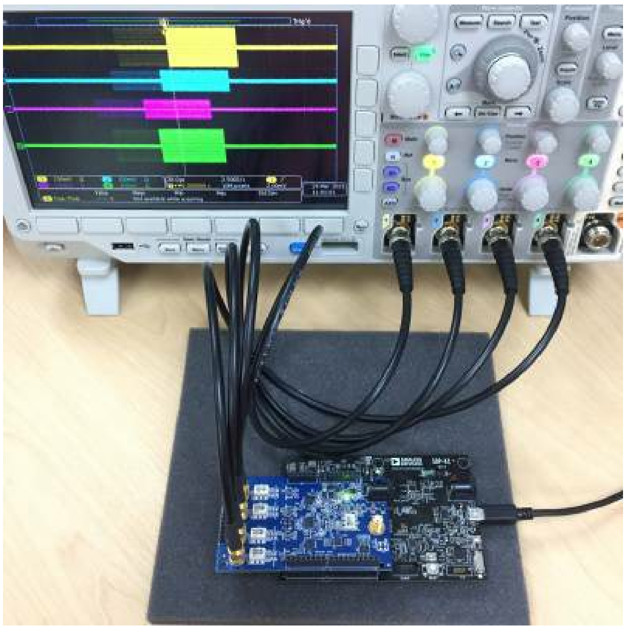


Figure 1a. EVAL-AD9106 Typical Evaluation Setup

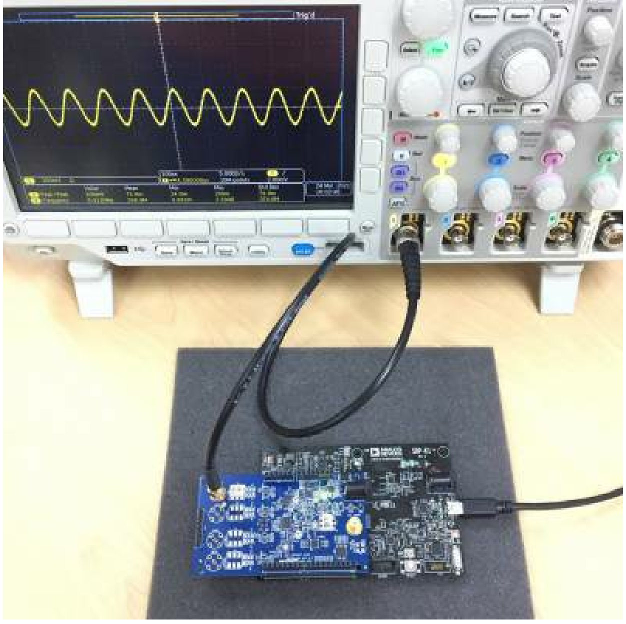


Figure 1b. EVAL-AD9102 Typical Evaluation Setup

Tip: Click on any picture in this guide to open an enlarged version.

Helpful Files

- AD9106 Data Sheet
- AD9102 Data Sheet
- AD9106 IBIS Model
- AD9102 IBIS Model
- AD9106-ARDZ-EBZ Schematic AD9102-ARDZ-EBZ Schematic
- AD9106-ARDZ-EBZ BOM AD9102-ARDZ-EBZ BOM
- AD910x-ARDZ-EBZ Gerber Files
- AD910x-ARDZ-EBZ Board File

AD910x-EBZ (Obsolete) Documentation

- AD9106-EBZ RevC Schematic AD9102-EBZ RevA Schematic
- AD9106-EBZ RevC BOM AD9102-EBZ RevA BOM
- AD9106-EBZ RevC Gerber Files AD9102-EBZ RevC Gerber Files
- AD9106-EBZ RevC Board File AD9102-EBZ RevA Board File
- AD9106-EBZ Quick Start Guide AD9102-EBZ Quick Start Guide

Tip: Open this page in Internet Explorer to avoid problems when downloading files.

Software Needed

- Mbed Compiler
- EVAL-AD910x Example Mbed Code
- CoolTerm (Recommended) or Tera Term or PuTTy Serial Port Terminal Application

Useful Links

- Mbed Documentation
- Mbed User Guide for SDP-K1
- SDP-K1 Wiki Page
- Mbed OS 6 SPI Documentation
- AD910x Engineer Zone FAQs

Hardware Needed

Minimum:

- AD9106-ARDZ-EBZ / AD9102-ARDZ-EBZ Evaluation Board
- SDP-K1 (EVAL-SDP-CK1Z) Board
- PC with Internet Connection (while using the compiler) and Terminal Application
- USB Cable for SDP-K1
- Oscilloscope
- SMA to BNC Cables

Additional:

- 7V to 12V 30W Wall Wart (if on-board amplifiers will be used)
- High-frequency Continuous Wave Generator (for clock input frequency other than 156.25 MHz)

Quick Start Guide

1. Attach AD9106-ARDZ-EBZ / AD9102-ARDZ-EBZ evaluation board to SDP-K1. Make sure SDP-K1 VIO is set to 3.3V through the P14 jumper by placing the shunt on the center and 3.3V pins.
2. Connect SDP-K1 to PC over USB. DS1 and DS2 on SDP-K1 and DS1 on the evaluation board should light up. Refer to Figure 1. If DAC outputs are connected to the on-board amplifiers, connect a 7V to 12V 30W wall wart to SDP-K1 DC Jack or to P15 on the evaluation board.
3. Connect the outputs of the evaluation board to an oscilloscope using SMA to BNC cables. Apply the oscilloscope settings shown in the waveform captures of the example patterns in Figures 11a to 12c and 17a to 18c.

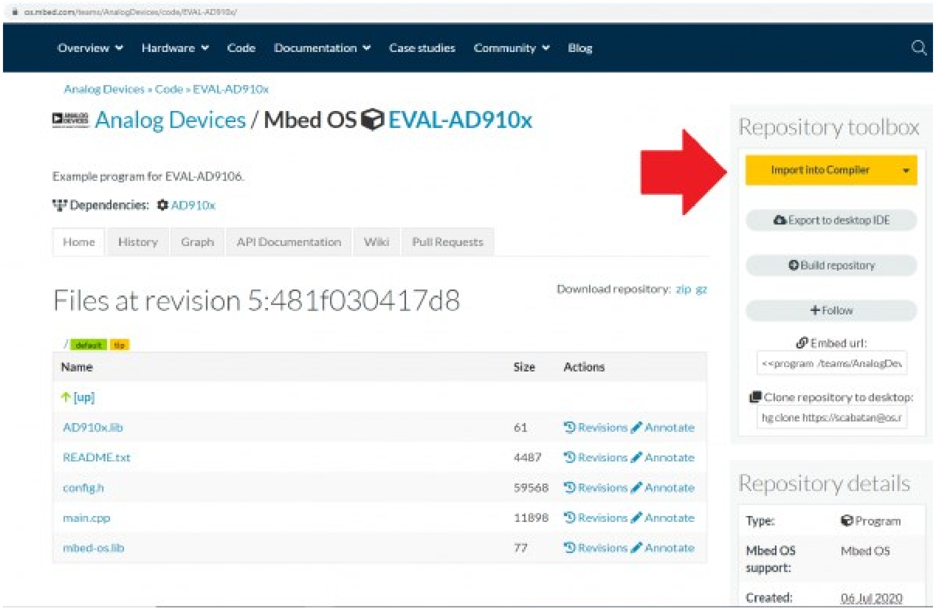


Figure 3. EVAL-AD910x Mbed code in Analog Devices repository

4. Log on to https://os.mbed.com/ then go to the EVAL-AD910x example code repository. Click the “Import into Compiler” button as shown in Figure 3. The browser should automatically redirect to the Mbed compiler. Select SDP-K1 as development platform then import codes as program. See Figure 4.

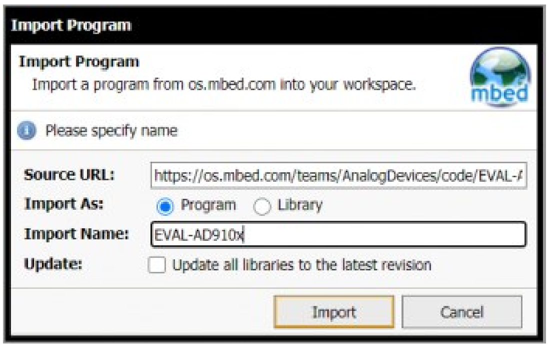


Figure 4. Importing code as program

5. Open config.h in the Mbed compiler and define the active device. If evaluation board is AD9102-ARDZ-EBZ, uncomment line 24 by deleting the two forward slashes. Refer to Figure 5. Otherwise, proceed to compiling the code by clicking the “Compile” button.

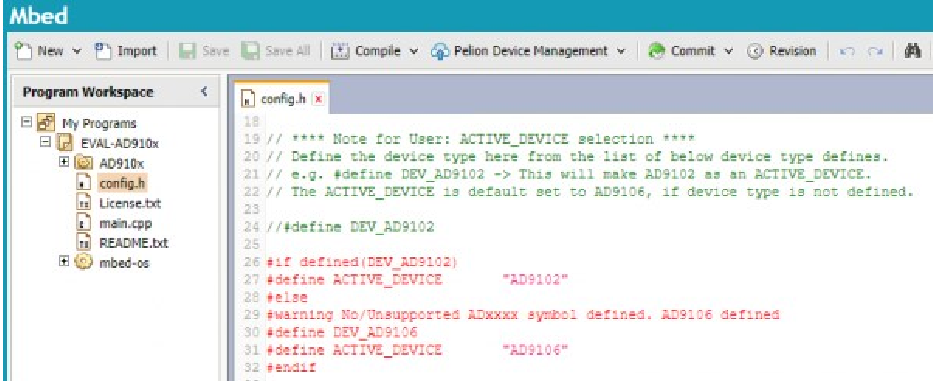


Figure 5. Active device selection in config.h

6. As shown in Figure 6, binary code will be downloaded to the computer after successful compilation. Drag and drop this code to the SDP-K1 drive or right click the binary file then send it to SDP-K1. See Figure 7. DS1 on SDP-K1 will be blinking while the file is being sent.

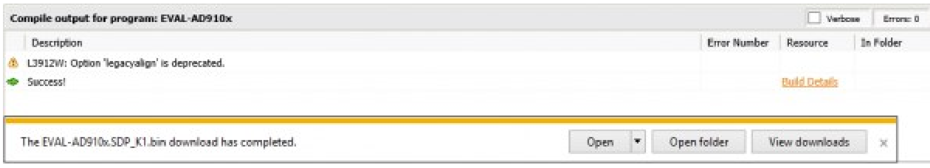


Figure 6. Successful program compilation

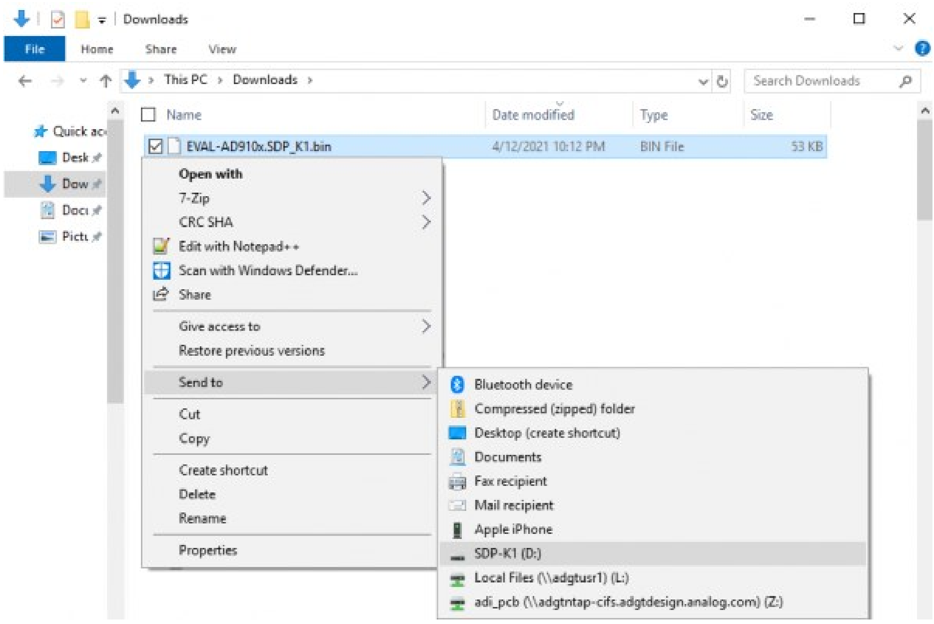


Figure 7. Sending binary file to SDP-K1 drive

7. After sending the code and DS1 stopped blinking, start up CoolTerm or any similar serial port terminal application. Select the com-port the SDP-K1 board is connected to. Set baudrate to 115200.

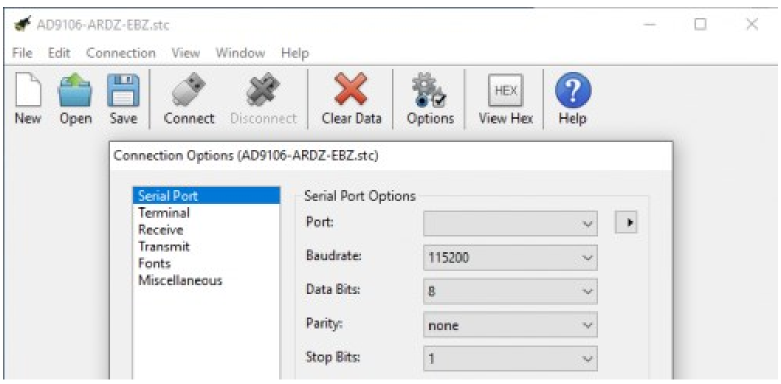
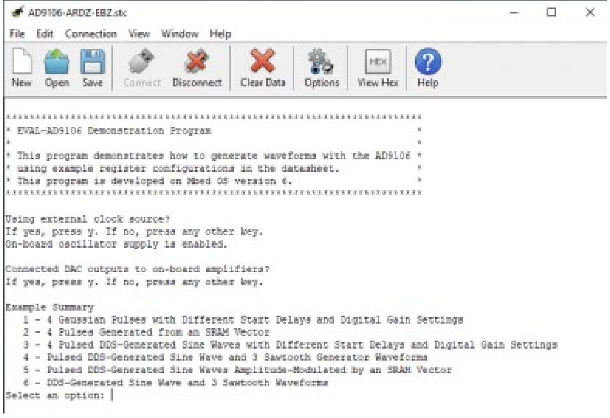


Figure 8. CoolTerm connection settings

8. Press SDP-K1 reset button. Wait for DS1 in SDP-K1 to stop blinking. Then click "Connect" on the terminal.



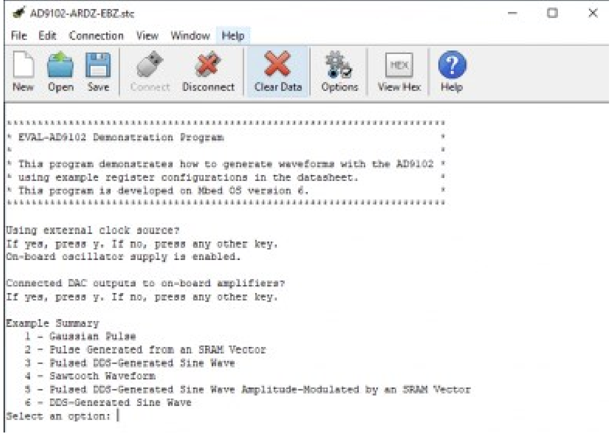


Figure 9a. EVAL-AD9106 Demo Program Menu | Figure 9b. EVAL-AD9102 Demo Program Menu

9. Follow the application menu that will appear on the terminal window. Since the device's clock inputs are connected to the on-board crystal oscillator and the DAC outputs to the RF transformers by default, press any key other than 'y' after the first two questions. Refer to Figures 9a and 9b.
10. Select an option from the example summary by typing the number to left of the example description. Recommended examples for the default hardware configuration are 3 and 5 for AD9106 and 3, 5, and 6 for AD9102. To observe waveforms with frequency components outside the RF transformer's bandwidth of 0.5-600 MHz, connect the DAC outputs to the on-board amplifiers. Refer to Table 1.

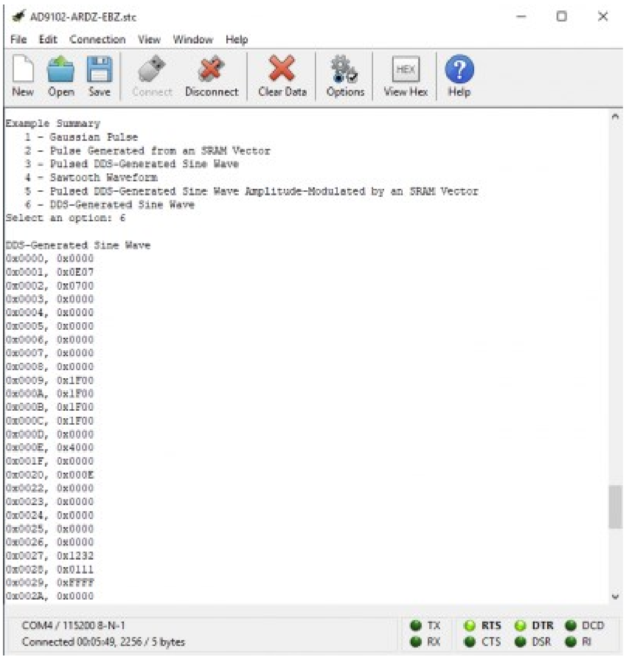
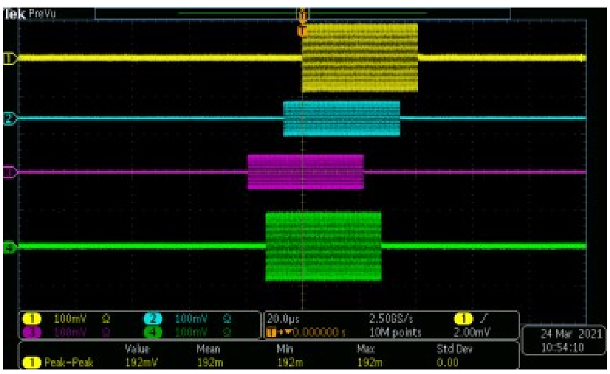


Figure 10. Printing of SPI register addresses and data on CoolTerm

11. After selecting an example, the device's register addresses and corresponding data words will be displayed on the console and patterns will be generated at the DAC outputs as demonstrated in Figure 10. Resulting waveforms are shown in Figures 11a to 12c.



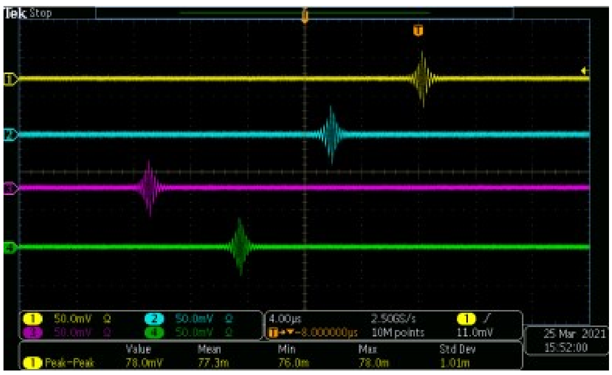
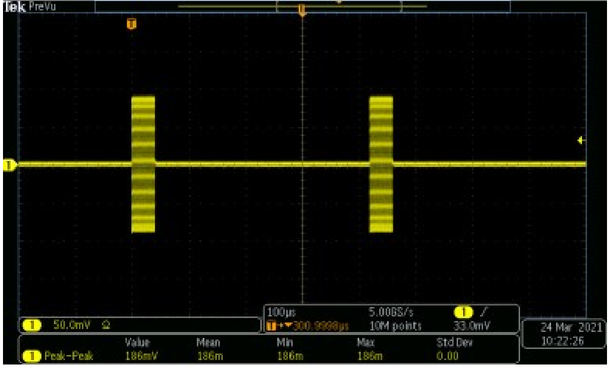


Figure 11a. AD9106 example 3 waveforms out of RF transformers | Figure 11b. AD9106 example 5 waveforms out of RF transformers



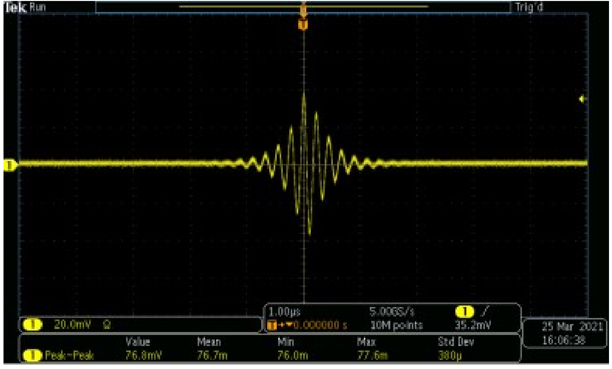


Figure 12a. AD9102 example 3 waveform out of RF transformer | Figure 12b. AD9102 example 5 waveform out of RF transformer

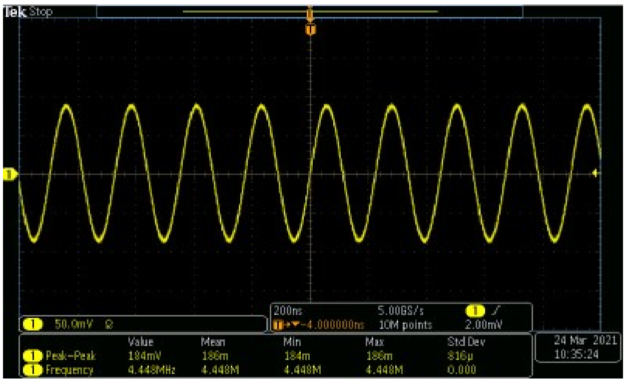
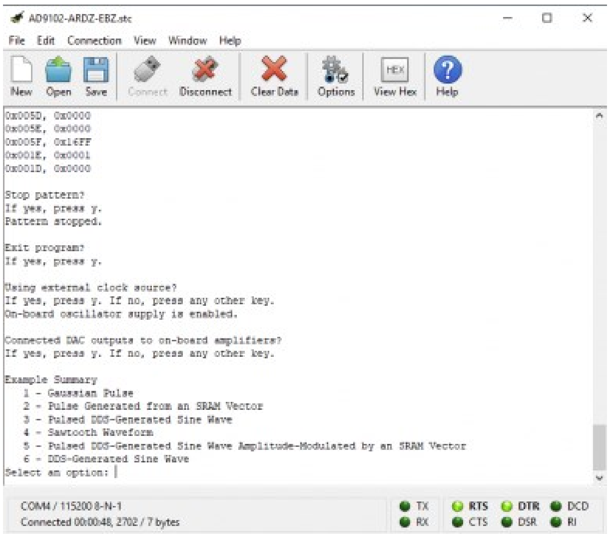


Figure 12c. AD9102 example 6 waveform out of an RF transformer

12. After playing one set of patterns, play another pattern or exit the program. If program is not exited after stopping pattern generation, the program will restart like in Figure 13a. Otherwise, after exiting the program like in Figure 13b, disconnecting then re-connecting to the console is needed to restart the program.



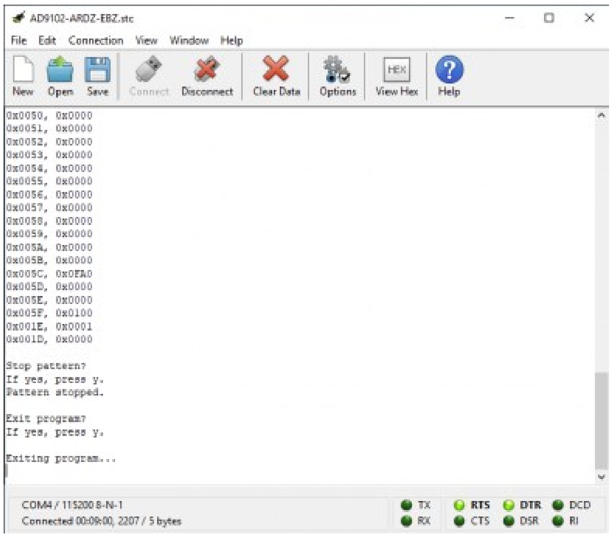


Figure 13a. Restarting the program | Figure 13b. Exiting the program

Reconfiguring the Evaluation Board

On-board jumpers and other hardware provisions are listed, and their functions described in Table 1. Meanwhile, the test points are enumerated and described in Table 2.

Table 1. List of Jumpers and Hardware Provisions

Reference Designator	Function
JP1, JP2	COM-A: Connects DAC CLKP and CLKN to 156.25 MHz on-board oscillator Y2. (default) COM-B: Connects DAC CLKP and CLKN to T9 secondary side. Clock input can be connected to J10 at T9 primary side.
JP3	COM-A / 2-1: Connects board OUT1 to T1 RF transformer (default) COM-B / 2-3: Connects board OUT1 to U1 amplifier Out1
JP4	COM-A / 2-1: Connects board OUT2 to T2 RF transformer (default) COM-B / 2-3: Connects board OUT2 to U1 amplifier Out2
JP5	COM-A / 2-1: Connects board OUT3 to T3 RF transformer (default) COM-B / 2-3: Connects board OUT3 to U2 amplifier Out1
JP6	COM-A / 2-1: Connects board OUT4 to T4 RF transformer (default) COM-B / 2-3: Connects board OUT4 to U2 amplifier Out2
JP7, JP8	COM-A / 2-1: Connects DAC1 OUTP and OUTN to T1 RF Transformer (default) COM-B / 2-3: Connects DAC1 OUTP and OUTN to U1 +IN1 and -IN1
JP9, JP10	COM-A / 2-1: Connects DAC2 OUTP and OUTN to T2 RF Transformer (default) COM-B / 2-3: Connects DAC2 OUTP and OUTN to U1 +IN2 and -IN2
JP11, JP12	COM-A / 2-1: Connects DAC3 OUTP and OUTN to T3 RF Transformer (default) COM-B / 2-3: Connects DAC3 OUTP and OUTN to U2 +IN1 and -IN1
JP13, JP14	COM-A / 2-1: Connects DAC4 OUTP and OUTN to T4 RF Transformer (default) COM-B / 2-3: Connects DAC4 OUTP and OUTN to U2 +IN2 and -IN2
P14	Headers as alternative board output connectors
P15	V_{IN} DC jack provision for ARM-based Mbed-enabled hardware other than SDP-K1
R85	Uninstalled (default) Installed: Allows automatic full-scale output current calibration when on-chip R_{SET} is used
R87, R89, R96, R97	Uninstalled: Connects board OUTx only to the SMA jack (default) Installed: Connects board OUTx to both the SMA jack and the male header P14
R61 & R63, R62 & R64, R48 & R70, R47 & R60	Uninstalled (default) Installed: Changes DC offset of AMP_Nx inputs to on-board amplifier
R59, R25, R44, R66	Uninstalled (default) Installed: Changes DC offset of AMP_Px inputs to on-board amplifier

Using an Off-board Clock Source

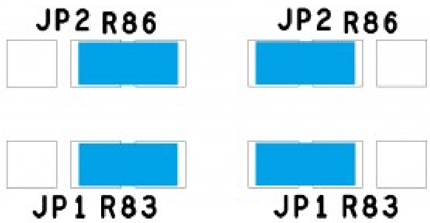


Figure 14a. DAC clock is connected to on-board oscillator (default) | Figure 14b. DAC clock is connected to J10

By default, DAC CLKP and CLKN are connected to the differential outputs of the on-board crystal oscillator as shown in Figure 14a. If clock frequency other than 156.25 MHz is desired, an off-board clock source can be used and connected to J10. Change JP1 and JP2 connections first as shown in Figure 14b.

Using the On-board ADA4817-2 Amplifiers

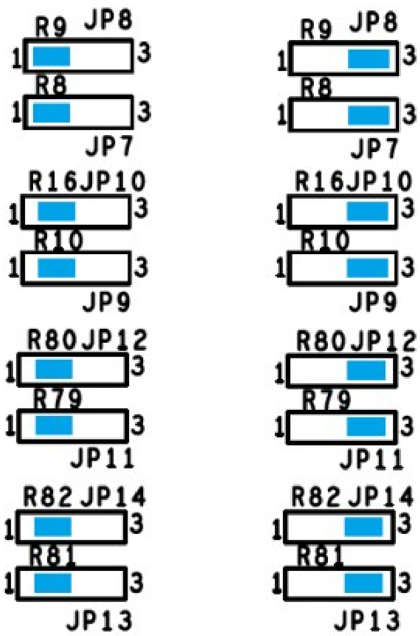
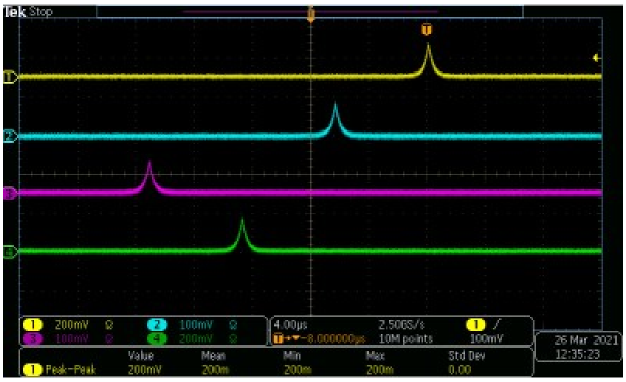


Figure 15a. DAC ouputs are connected to RF transformers (default) | Figure 15b. DAC ouputs are connected to ADA4817-2 amplifiers

Figure 16a. SMA output connectors are connected to RF transformers (default)

Figure 16b. SMA output connectors are connected to ADA4817-2 amplifier outputs

The waveforms in Figures 11a to 12c can also be observed out of the on-board amplifiers. To do this, disconnect the DAC outputs from the RF transformers and connect them to the corresponding amplifiers as shown in Figure 15b, then disconnect the SMA connectors from the RF transformers and connect them to the amplifier outputs as shown in Figure 16b. It is expected that the amplifier output amplitudes will be higher. Lower signal amplitudes out of the RF transformers are due to insertion loss and output voltage division resulting from impedance matching between the secondary and primary sides.



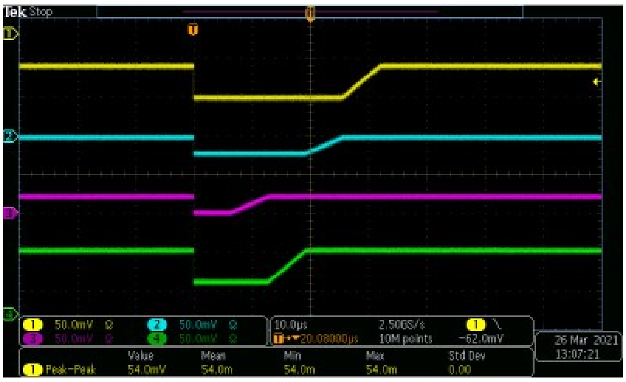
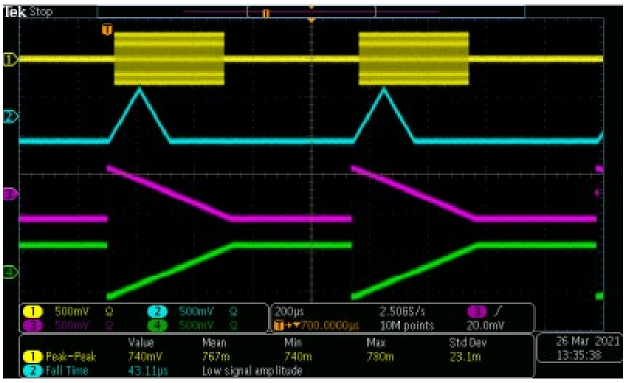


Figure 17a. AD9106 example 1 waveforms out of ADA4817-2 | Figure 17b. AD9106 example 2 waveforms out of ADA4817-2



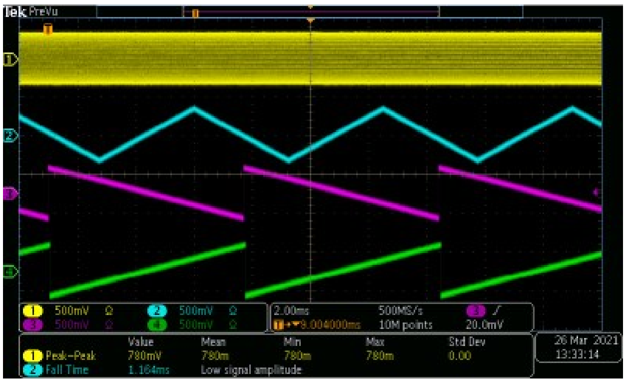
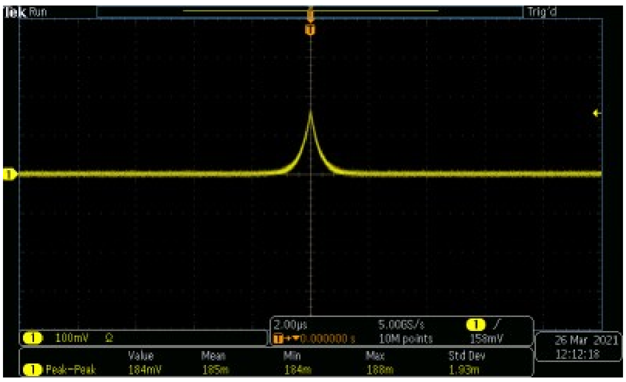


Figure 17c. AD9106 example 4 waveforms out of ADA4817-2 | Figure 17d. AD9106 example 6 waveforms out of ADA4817-2



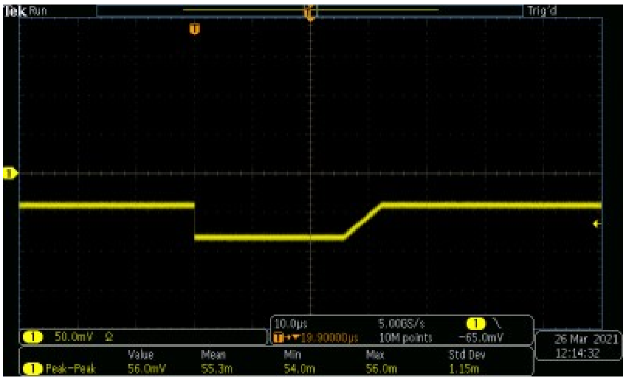


Figure 18a. AD9102 example 1 waveform out of ADA4817 | Figure 18b. AD9102 example 2 waveform out of ADA4817

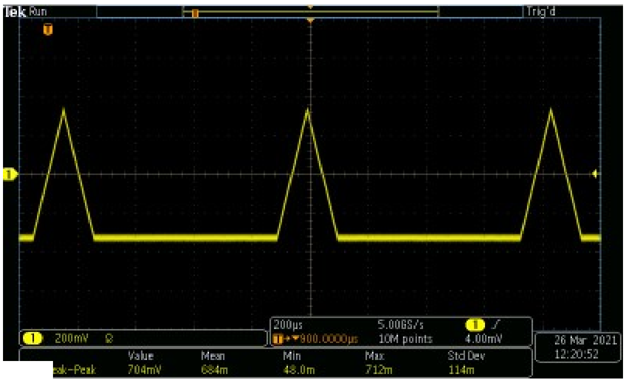


Figure 18c. AD9102 example 4 waveform out of ADA4817

To properly observe the other patterns out of the amplifiers, replace C25, C26, C54, and C55 with 0Ω resistors or remove the capacitors then solder each pair of pads together. Waveforms are shown in Figures 17a to 18c.

The common-mode voltage of the amplifier outputs can also be changed by installing resistors for DC offset correction of amplifier inputs. Refer to Table 1. Keep C25, C26, C54, and C55 pads shorted.

Table 2. List of Test Points

TP No.	Rating (V)	Remarks
1	1.0	AD9106 / AD9102 Reference Voltage Output
2		V_{IN} Power Supply Input (Provided for power supply other than a wall wart.)
3		Circuit Ground
4	-5.2	Negative Amplifier Supply (If enabled in program, V_{IN} supply is required.)
5	5.2	Positive Amplifier Supply (If enabled in program, V_{IN} supply is required.)
6	5.0	Supply from SDP-K1 / U4 Input
7	3.6	U4 Output
8		Circuit Ground
9	3.3	U7 Output / DVDD and CLKVDD
10	3.3	U8 Output / AVDD1 and AVDD2
11	3.3	U9 Output / On-board Crystal Oscillator Supply (Enabled in program.)

The on-board amplifiers can be characterized using off-board power supplies by removing E1 and E2 then connecting 5.2V 0.2A across TP5 and ground and -5.2V 0.2A across TP4 and ground.

Evaluation Board Output Interface Options

When tapping to the evaluation board outputs, users are not limited to the SMA jacks. P14 headers are provided as alternative connectors but performance is not as good as when using SMA connectors.

Using the Example Mbed Codes

The EVAL-AD910x Example Mbed Codes can be used as starting point for developing firmware for targeted applications. The codes in the repositories below demonstrates how to setup SPI communication between the ARM-based Mbed-enabled hardware, SDP-K1, and the waveform generator DACs, AD9106 or AD9102.

- Link to Program Files: https://os.mbed.com/teams/AnalogDevices/code/EVAL-AD910x/
- Link to Library Files: https://os.mbed.com/teams/AnalogDevices/code/AD910x/

To import the program files to the Mbed compiler as discussed in the Quick Start Guide, the user should have a free Mbed account and is logged on to https://os.mbed.com/. After successful program import, the user is free to use and modify the codes without violating the Analog Devices Inc. Software License Agreement in the License.txt file.

Each file and each of the functions in the files have short descriptions or briefs. This section will focus on how several files and functions can be modified using the Mbed online compiler.

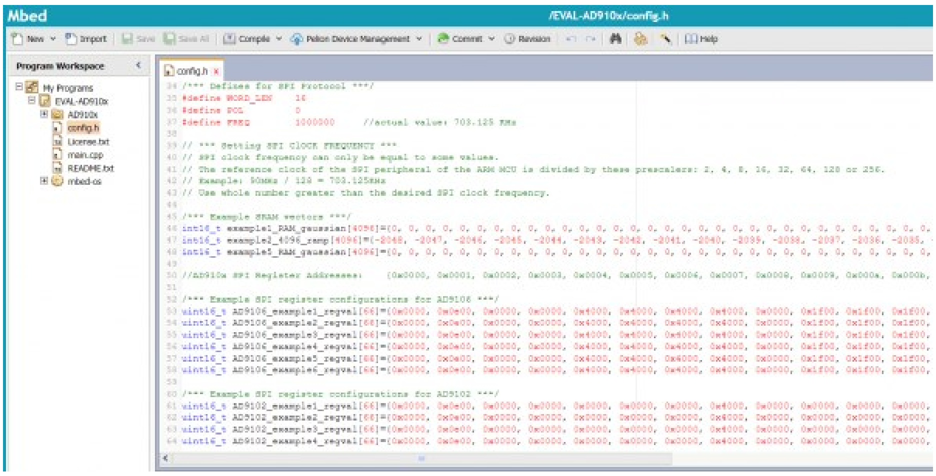


Figure 19. SPI protocol definitions, example SRAM vectors, and example SPI register configurations in config.h

Setting up the SPI Interface

Aside from choosing the active device as shown in the Quick Start Guide, SPI protocol parameters particularly the clock frequency can be set at the application-level codes. Word length WORD_LEN and polarity POL need not be changed and are already set specifically for AD9106 and AD9102. Refer to Mbed OS 6 SPI Documentation for more information on these parameters.

Instructions on setting the SPI clock (SCLK) frequency are already provided in **config.h** as shown in Figure 19. The reason why SCLK can only be set to a number of fixed frequencies is discussed in this Mbed wiki page on SPI output clock frequency. SPI lines out of the Arduino headers or SPI1 module of the SDP-K1 ARM processor, uses 90MHz peripheral clock. Refer to these relevant source codes:

- SDP-K1 system_clock.c
- Spi_api.c

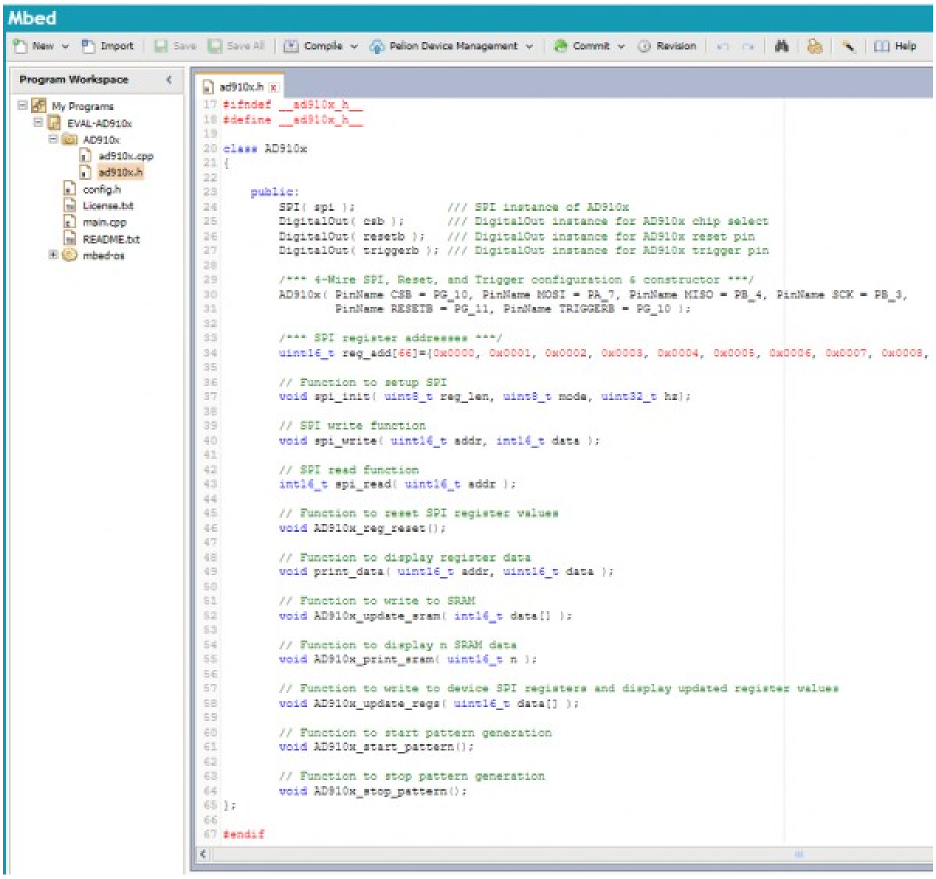


Figure 20. Device-specific I/O pins and functions declarations in ad910x.h

Initialization of digital I/O pins connected to the DAC being evaluated, and declaration of SPI register addresses and device-specific functions are in **ad910x.h**. See Figure 20. The functions are implemented in **ad910x.cpp**. The Mbed platform drivers allow setup of 4-wire SPI interface. Refer to Mbed documentation for other configurations.

Modifying SRAM Vectors

SRAM Vectors in **config.h** can be easily modified for a specific application. For both AD9106 and AD9102, there are 4096 addresses in the on-chip SRAM. Word length is 14 bits for AD9102, 12 bits for AD9106, and is left justified. For AD9102, data should be written in bits [15:2] and for AD9106 in bits [15:4] of each SRAM address.

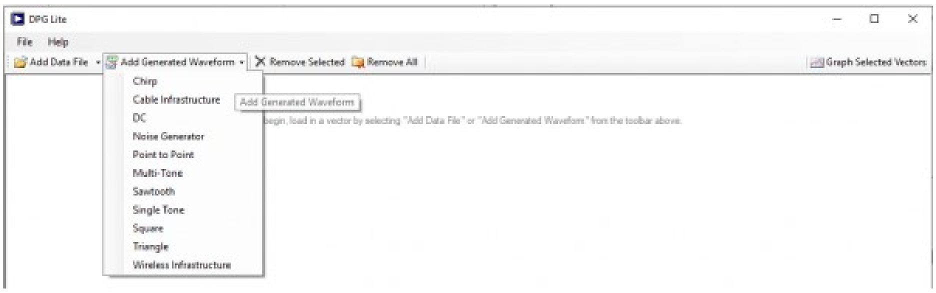


Figure 21a. Waveforms that can be generated using DPG Lite

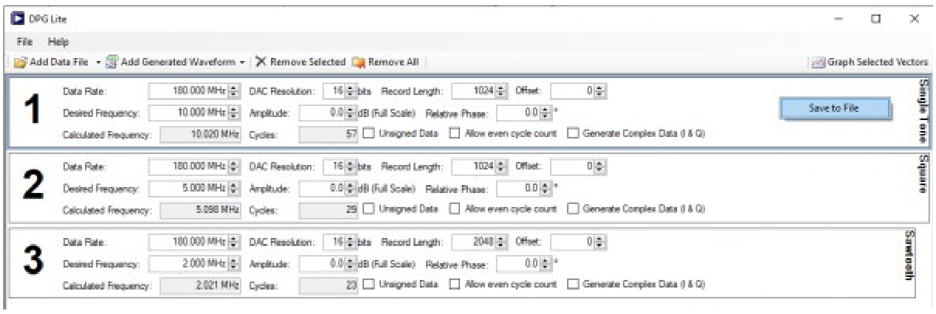


Figure 21b. Waveform vector generation using DPG Lite

Although the SRAM vectors can be modified manually, it will be more convenient to create new vectors using DPG Lite. Shown in Figure 21a are types of waveforms that can be generated using the software.

When creating data vectors for AD9106 and AD9102, make sure to choose the proper DAC resolution and leave the Unsigned Data box unchecked. A continuous wave vector with record length of 4096 can be created but the SRAM can also be composed of different types of waveforms like in the example in Figure 21b where there are 3 vectors with combined record length of 4096. These can be saved as text files and integrated into the source code.

It is not required to write to all 4096 addresses. Each DAC channel in a device can fetch data from a fixed SRAM address to another. The start and stop addresses can be set using the following registers:

- 0x5E and 0x5F for AD9102,
- 0x5E and 0x5F, 0x59 and 0x5A, 0x55 and 0x56, and 0x51 and 0x52 for AD9106 Channels 1 to 4, respectively.

Table 3. Range of SRAM Data Values

14-bit DAC Input Code (Base 10)	AD9102 SRAM Data (Base 16)	12-bit DAC Input Code (Base 10)	AD9106 SRAM Data (Base 16)	I_{OUTxP}	I_{OUTxN}
8191	0x7FFC	2047	0x7FF0	I_{OUTFS}	0
0	0x0000	0	0x0000	$I_{OUTFS}/2$	$I_{OUTFS}/2$
-8192	0x8000	-2048	0x8000	0	I_{OUTFS}

SRAM data format or code follows two's complement notation. Refer to Table 3 for the equivalent current output for an input code. 14-bit code should be shifted left by 2 bits before writing it to AD9102 SRAM while 12-bit code should be shifted left by 4 bits before writing it to AD9106 SRAM. Alternatively, 14-bit data shifted left by 2 bits can be written to AD9106 SRAM but the last two bits with be truncated. This is why in **AD910x_update_sram()** function in **ad910x.cpp**, SRAM data is by default shifted 2 bits to the left. Refer to Figure 22.

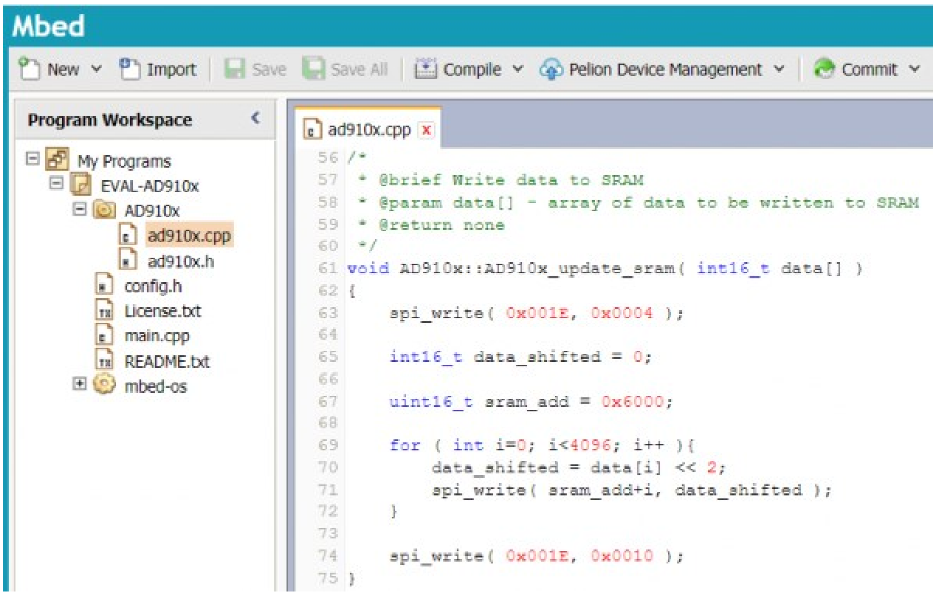


Figure 22. Function that writes to on-chip SRAM in ad910x.cpp

AD910x_print_sram() function is declared in **ad910x.h** and implemented in **ad910x.cpp** but is by default not called in the main program **main.cpp**. The function can be used to print in the console n number of data words from SRAM. This can be done by calling the function in **main.cpp** after an **AD910x_update_sram()**.

Changing SPI Register Values

AD9106 and AD9102 have similar register maps. The latter only has less number of registers that affect device functionality because writing to registers for the 3 other DAC channels will only have an effect to AD9106. Nonetheless, the defined SPI registers address in **ad910x.h** will work for both devices.

The SPI register addresses were written as comment in **config.h** and aligned with example SPI register values for user's convenience. Same as the SRAM vectors, these SPI register values can also be easily modified for specific applications. Refer to the device datasheets for the SPI register descriptions.

Power Supply Enable/Shutdown Pins

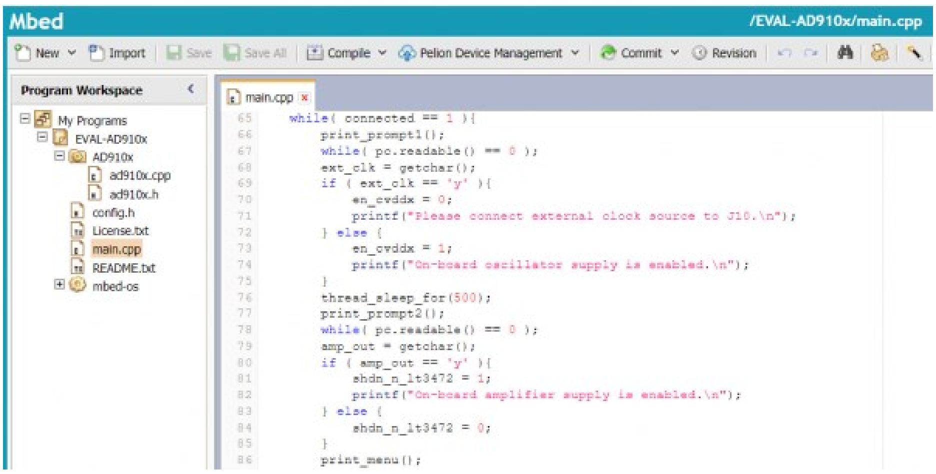


Figure 23. Power supply enable/shutdown pins in main.cpp

Other I/Os like the ones connected to the EN pin of the on-board oscillator supply, CVDDX, and to the SHDN_N pin of the on-board amplifier supply, LT3472, are defined in **main.cpp**.

As shown in Figure 23, if external or off-board clock source is chosen, *en_cvddx = 0* and no power is supplied to CVDDX. If the on-board oscillator is chosen, *en_cvddx = 1* and 3.3V is supplied to CVDDX.

If the user confirms that the DAC outputs are connected to the on-board amplifiers, *shdn_n_lt3472 = 1* and 5.2V and -5.2V are supplied to the amplifiers provided a wall wart is connected to SDP-K1 or the evaluation board. Otherwise, *shdn_n_lt3472 = 0* and the amplifiers are not powered up.

Troubleshooting

This section lists items to check and practices to use when debugging any unexpected performance of a board. If unexpected results occur

- Restart the program by stopping pattern generation and pressing “Disconnect” from the terminal window. Press “Connect” again then follow the application menu.
- Power down the whole system by disconnecting the wall wart, if using, and the USB cable from SDP-K1, then power up the system again following the steps in the Quick Start Guide.
- Measure voltages on the evaluation board. Refer to Table 2. If the voltages are off by 10% or more from the rated values, check if there are problems on component assembly or look for damaged ICs. Re-solder or replace components if necessary.
- If signal amplitude is lower than expected, compare oscilloscope settings to the recommended setup in the Quick Start Guide. Check for loose cable connections or try changing SMA-to-BNC cables. Loose connections and cable damage cause impedance mismatch.
- If there is no output at all, check if clock input to AD9106 / AD9102 is stable by measuring clock leakage. Connect one of the evaluation board outputs to a spectrum analyzer. Boards and the clock source should be powered up but the DAC should not be generating a pattern. A low-power tone should be detected at the clock frequency. Otherwise, the clock source is not properly driving the clock input pins. Try using an off-board continuous waveform generator as clock source or if already using, try increasing waveform generator output signal level to 3 dBm.