Renesas Synergy™ Platform

DK-S124 Simple Tone Generator

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Introduction

This simple tone generator example dynamically generates the data necessary to represent one full cycle of a sine wave. It uses that data to generate an audio tone by repetitively driving the on-board Digital-to-Analog converter (DAC) of the DK-S124 Synergy™ MCU, that in turn drives the amplifier connected to the earphone jack. The frequency of the sine wave is varied by changing the sample rate used to output the data.

While the DK-S124 Synergy MCU comes with the PMOD LCD display shown in Figure 1. This program uses a simple two-button interface for control and the on-board LEDs for operator feedback. The PMOD LCD is not used in this example application.

Required Resources

The example application targets the DK-S124 Synergy MCU Group. To build and run the application, you will need:

- DK-S124 kit v3.0 or later
- PC running Microsoft® Windows® 7 or later with the following Renesas software installed:
  - e^2 studio ISDE v6.2.0 or newer
  - Synergy Software Package (SSP) v1.3.0 or later
  - IAR Embedded Workbench® for Renesas Synergy™ v8.21.1
  - Synergy Standalone Configurator (SSC) v6.2.0.

You can download the required Renesas software from the Renesas Synergy™ Gallery: https://synergygallery.renesas.com

Prerequisites

You should have some experience with either the Renesas Synergy e^2 studio ISDE or the IAR Embedded Workbench® for Renesas Synergy™ ISDE. This program may be compiled and run using either tool chain.

You should also be familiar with the Synergy Software Package (SSP). Before you perform the procedures in this application note, you may want to follow the procedure referenced in your board's *Quick Start Guide* to build and run the **Blinky** project. By doing so, you will become familiar with building and running the SSP applications while ensuring that the debug connection to your board is functioning properly.

Time Required

You should be able to install, build, and run the example application in under 30 minutes. The high-level steps involved are:

1. Configure the DK-S124 Synergy MCU to run the tone generator example application.
2. Import, build, and debug the project.
3. Play audio tones through the earphone jack or an external speaker.
4. Cycle through a predefined list of audio tones using the momentary push button S1.
5. Enable/disable the audio output using the momentary push button S2.
6. Vary the volume using POT1.

Contents

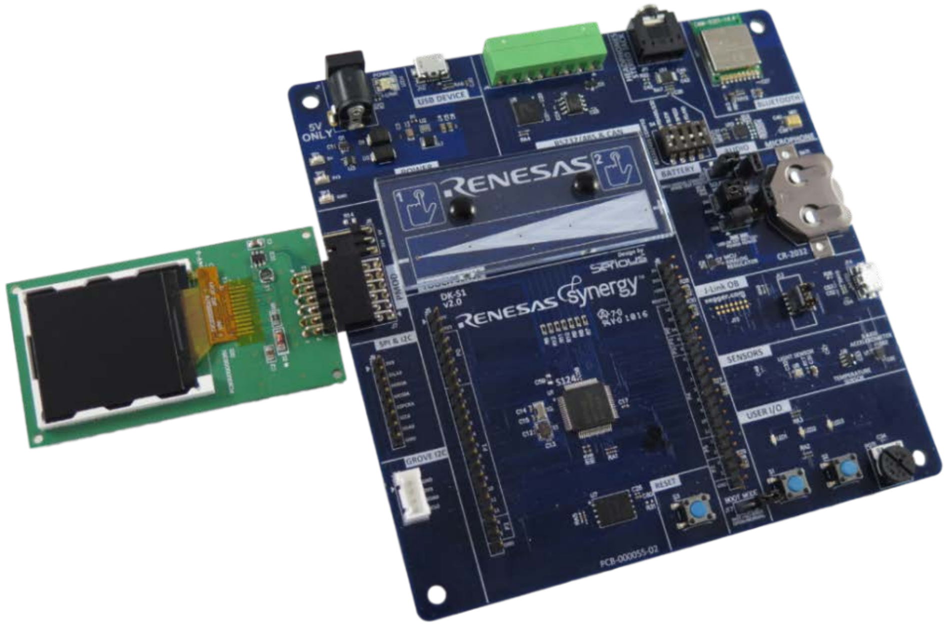


Figure 1 DK-S124 with included PMOD LCD attached

1. Overview and Design Considerations

The main goal of this application is to generate a pure audio tone, which could be used to examine the fidelity of the amplifier circuit connected to the earphone jack. The application builds the data points that are necessary to represent one cycle of a sine wave, and stores the data in a buffer. That data is then used to repeatedly drive the 12 bit Digital-to-Analog Converter connected to the amplifier that drives the earphone jack.

One of the design challenges in this application is to playback this sine wave data at varying frequencies. This is accomplished by one of the timer API calls that changes the period of the timer each time the momentary button **S1** is pressed.

Another design challenge is to use the on-board potentiometer (POT1) to vary the volume of the tone being output by the application. The application must periodically read the analog voltage present at POT1 and adjust the output volume accordingly. Some ways to achieve this are:

1. Manually perform a single scan of data each time the main thread loop executes.
2. Use the periodic ADC framework and a callback function to scan the analog channel at a rate determined by a timer module dedicated to the ADC scan.

This application uses the second approach. Other example applications like the Thermostat application use the first method.

2. Synergy Platform Capabilities

This application primarily deals with writing data to the on-board Digital-to-Analog Converter, that drives the earphone amplifier (U9). The playback is performed at a controlled rate, using the General Purpose Timer module. This controlled rate determines the frequency of the tone being generated. The SSP provides both higher level framework modules as well as the lower level driver modules to interface with these types of hardware peripherals without the need to write any low level driver code.

The following figure, highlights the S1 hardware peripherals used by the tone generator example application.

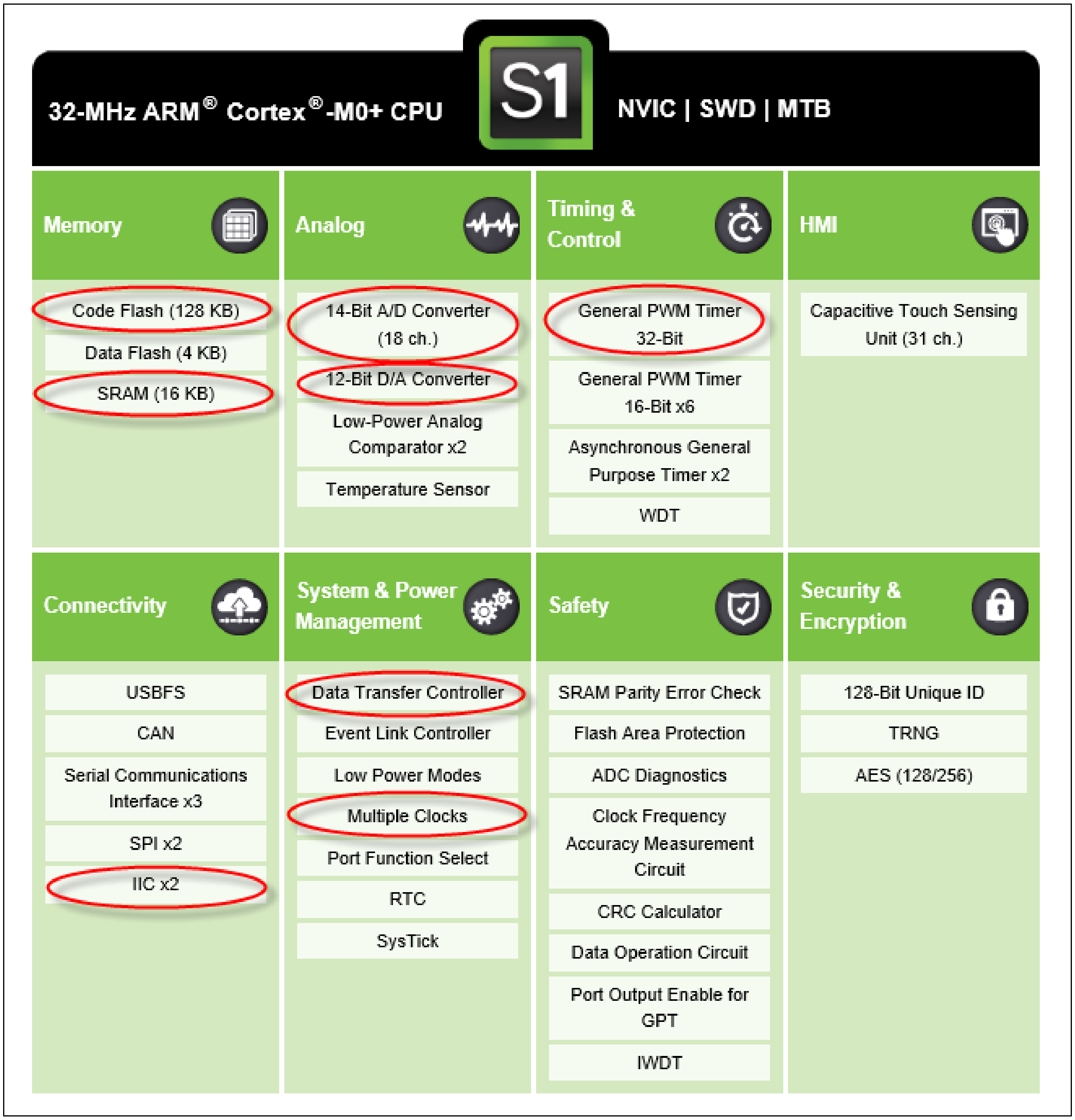


Figure 2 S1 peripherals used by the tone generator example

The following table, defines the processor pin connections used to connect the peripherals used in this example to the various external components on the DK-S124 Synergy MCU board. For additional information, you may also refer to the DK-S124 Synergy MCU Group schematics.

Table 1 Port summary of peripheral connections used by the Tone Generator

Schematic part	Description	S1 port connection	Pin function
S1	Momentary switch	Port 2 pin 6	I/O port pin
S2	Momentary switch	Port 0 pin 4	I/O port pin
POT1	10K potentiometer	Port 0 pin 12	Analog channel 7
U13	BMA250 3-axis Accelerometer	Port 2 pin 6	IRQ
U13	BMA250 3-axis Accelerometer	Port 4 pin 1	SDA0 (I2C clock)
U13	BMA250 3-axis Accelerometer	Port 0 pin 0	SCL0 (I2C data)
U11	Audio power amplifier	Port 0 pin 14	DAC output

3. Design Overview

The DK-S124 Synergy MCU Group board contains two momentary switches **S1** and **S2**, and a potentiometer (**POT1**) that can be used for operator input. While the PMOD LCD display is not used, the DK-S124 Synergy MCU has three LEDs that can be used for operator feedback. The board also contains an earphone jack, that accepts the standard 3.5 mm connector found on typical earbuds. The following figure shows a simple block diagram of how inputs and outputs are connected to the S124 MCU.

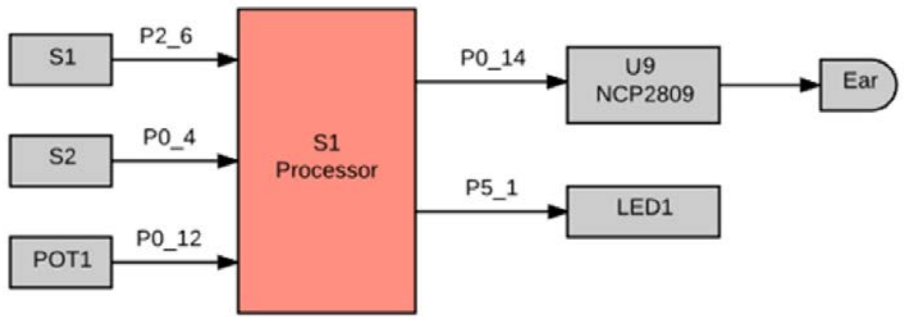


Figure 3 Simple block diagram showing hardware connections

The Tone Generator example application has a single operation mode. The two push buttons on the DK-S124, **S1** and **S2**, control the application. Only one of the three on-board LEDs are used for operator feedback. For more details on the operator interface, see section 4, Design Demonstration.

3.1 Debouncing switch input

One of the challenges always present when dealing with the switch input is the switch bounce. Most mechanical switches have what is known as contact bounce. This is a period of time when the state of the switch bounces from one state to the next, after being pressed. To avoid false triggers, these false transitions must be ignored by either the hardware or the firmware. A typical firmware technique is to sample the switch state at regular intervals, waiting for the switch state to remain constant for a pre-determined number of samples, before considering it a valid state.

Both the pushbuttons on the DK-S124 Synergy MCU Group are connected to hardware pins with interrupt capability. Some applications such as the Simple Record application poll these pins using the `g_ioport` driver. This driver is typically added to your application automatically in the **HAL/Common** area before any user defined threads. This application highlights the use of the Synergy External IRQ driver (`r_icu`) to simultaneously detect button presses and filter out the switch bounce.

In the following figure, shows the delayed sweep of an oscilloscope trace being used to examine the contact bounce on **S2**. The oscilloscope is set to a single capture mode, triggering on a falling edge. The top trace is 200 ms per division, and multiple button presses are captured. The bottom trace uses the delayed sweep (zoom) mode to expand one of the edges where contact bounce exists. As seen in the following figure, switch only bounced once and the bounce is of short duration. The board mounted momentary switches used on the DK-S124 have minimal bounce, and this necessitated many samples to be taken before capturing the bounce shown in the below figure. Many mechanical switches have a bounce that is much worse, and no longer a debounce period is needed.

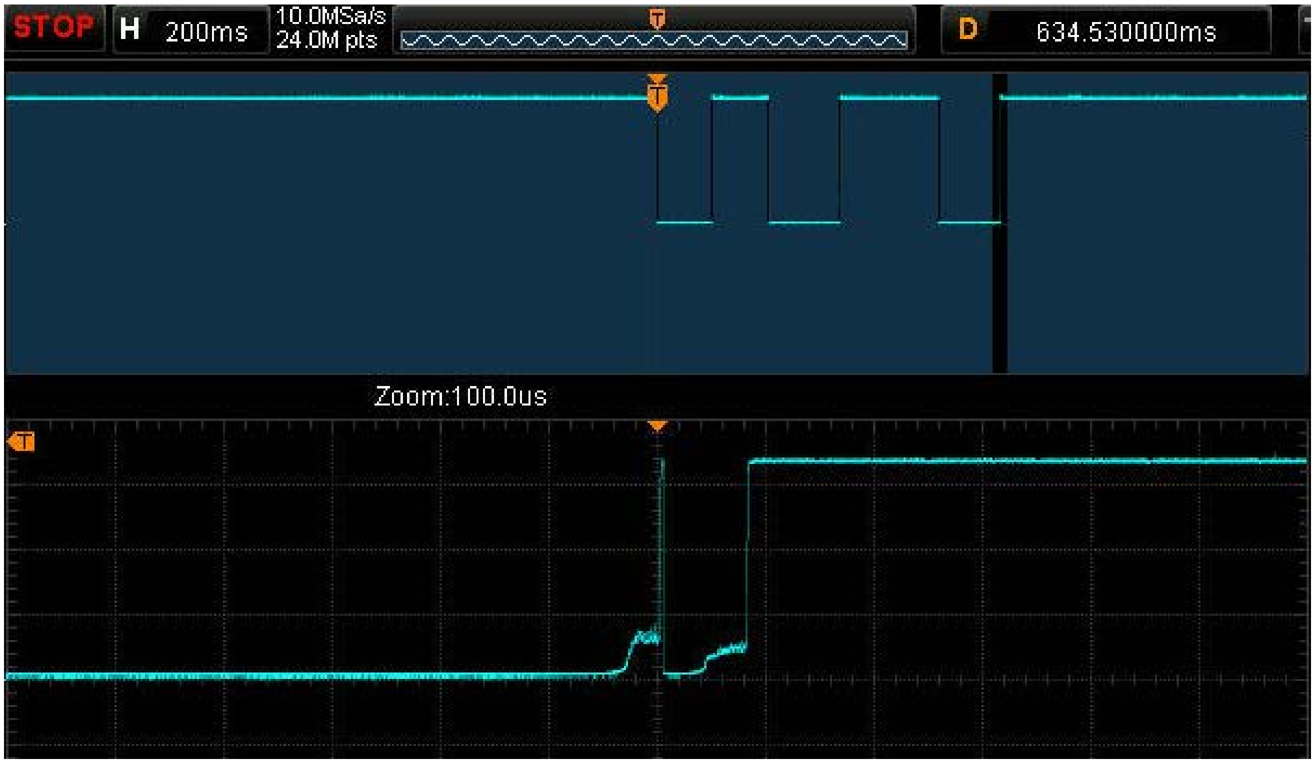
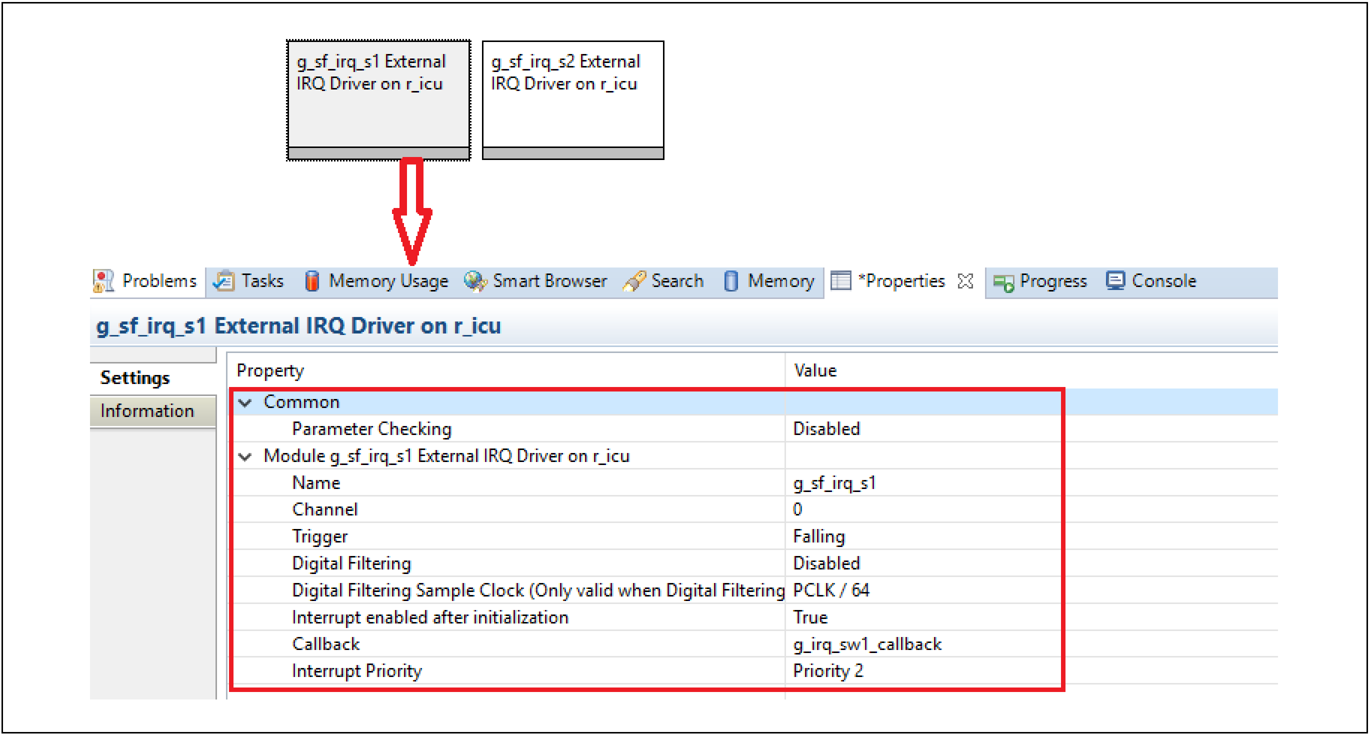


Figure 4 Contact bounce on S2

The external interrupt pins on the S124 MCU provides digital filtering that eliminates the need to debounce inputs in firmware. You can configure this filtering using two properties in `r_icu` stack as highlighted in the following figure. The digital filter samples the input signal and ignores any signal with a pulse width less than three sample cycles. The sample cycle is based on the current setting of PCLKB divided by the value set in the **Properties** tab, which in this case is 64.


g_sf_irq_s1 External IRQ Driver on r_icu
g_sf_irq_s2 External IRQ Driver on r_icu
Problems
Tasks
Memory Usage
Smart Browser
Search
Memory
*Properties
Progress
Console
g_sf_irq_s1 External IRQ Driver on r_icu
Settings
Information

Property	Value
Common	
Parameter Checking	Disabled
Module g_sf_irq_s1 External IRQ Driver on r_icu	
Name	g_sf_irq_s1
Channel	0
Trigger	Falling
Digital Filtering	Disabled
Digital Filtering Sample Clock (Only valid when Digital Filtering	PCLK / 64
Interrupt enabled after initialization	True
Callback	g_irq_sw1_callback
Interrupt Priority	Priority 2

Figure 5 Digital filtering properties for r_icu driver

The value of PCLKB may be set using the **Clocks** tab in the Synergy configurator. As seen in the following figure, PCLKB for the Tone Generator Application is set to the high-speed oscillator (HOCO) divided by 2, for a frequency of 24 MHz. Dividing this 24 MHz frequency by 64 yields a digital filter frequency of 375 kHz, which means that the sampling period is 1/375,000 or 2.66 µs. Three of these sampling periods are just under 8 µs. This means that any pulse width less than 8 µs is ignored by the digital filter.

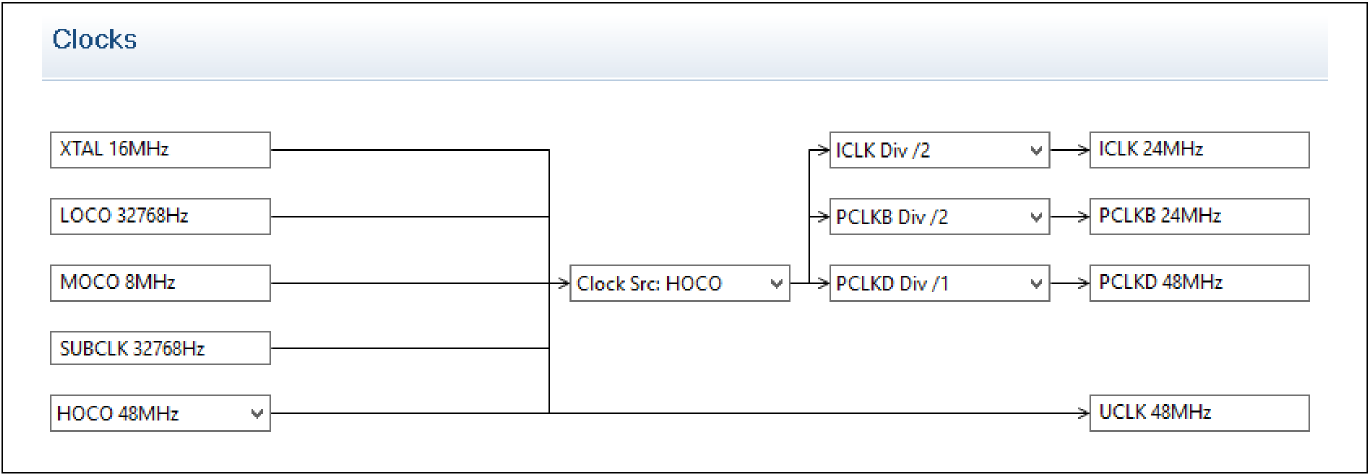


Figure 6 Clock tree as displayed in the Clocks tab for the Tone Generator example

As mentioned previously, the switches used on the DK-S124 board have minimal bounce and so this value of 10 µs for the digital filtering works well for the tone generator application. However, it is quite possible that you will encounter switches with longer bounce times. In this case, you would need to increase the digital filter time to avoid false triggers.

Since the maximum divide ratio you can set in the digital filter properties (Figure 5) is 64, you would need to increase the divide ratio of PCLKB in the **Clocks** tab, thereby lowering the frequency of PCKLB. For example, you could increase the divide ratio to PCLKB Div/4 to double the effective debounce time provided by the digital filtering, or quadruple it by increasing the divide ratio to PCLKB Div/8 for a total of ~32µs of debounce time.

Note: When increasing the digital filtering time by reducing the PCLKB frequency, keep in mind that PCLKB is also used for other peripherals on the S124 MCU (such as the SCI, IIC, SPI). Section 8 of the *SSP User's Manual* describes the S124 MCU clocks, and lists all the peripherals that are driven by PCLKB. You may find that a throughput reduction in other peripherals, resulting from a slower PCLKB frequency, may adversely affect your application. In such a case, you would need to leave PCLKB set to a higher frequency and either replace or augment the digital filtering with a firmware debounce scheme.

3.2 Accelerator Initialization

On the DK-S124 Synergy MCU v2.0, the accelerometer IRQ line is shared with S1, seen in the following figure.

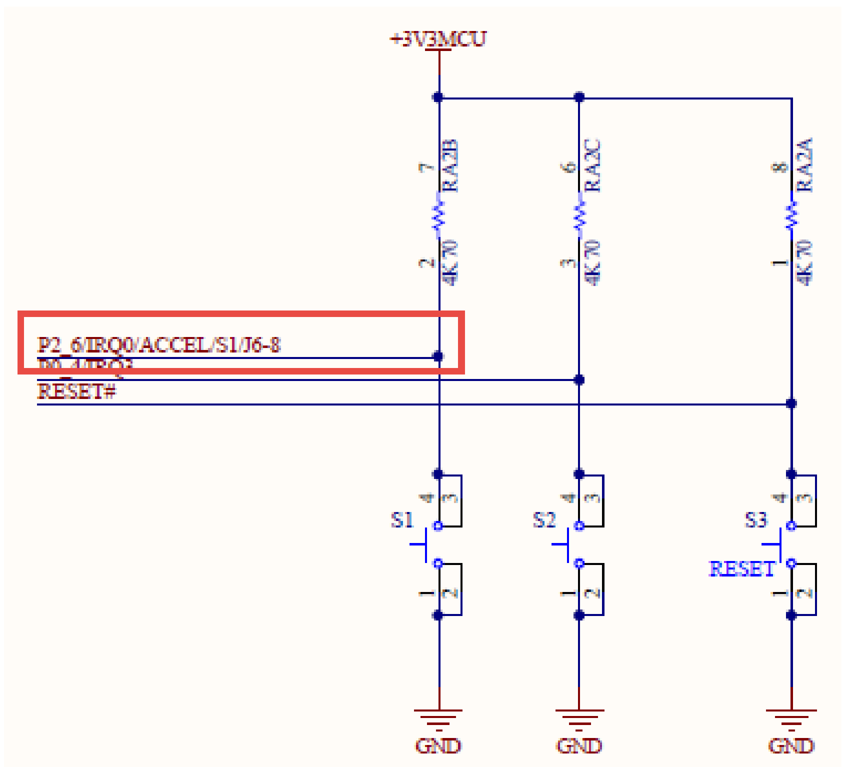


Figure 7 S1 input shared with accelerometer IRQ line

The accelerometer IRQ pin defaults to a push/pull configuration and active high IRQ state. This means that it is always pulling down on the line connected to **S1**, which prevents the use of this line for reading the state of **S1**. To use **S1**, you must change the interrupt configuration of the accelerometer. To do this, the I^2C framework is added to the audio thread, and several I^2C commands are issued to the accelerometer during the audio thread initialization sequence.

3.3 Threads

For simplicity, this application is designed with a single thread, as summarized in the table below.

Table 2 Application thread names and functions

Thread name	Thread function
Audio thread	Handles all logic associated with the tone generator

In the following figure is a conceptual diagram of the Tone Generator example application. Peripherals internal to the S124 MCU are highlighted in blue, and external peripherals (such as the accelerometer) are highlighted in gray. The component used to access each peripheral is shown in text on the connecting line.

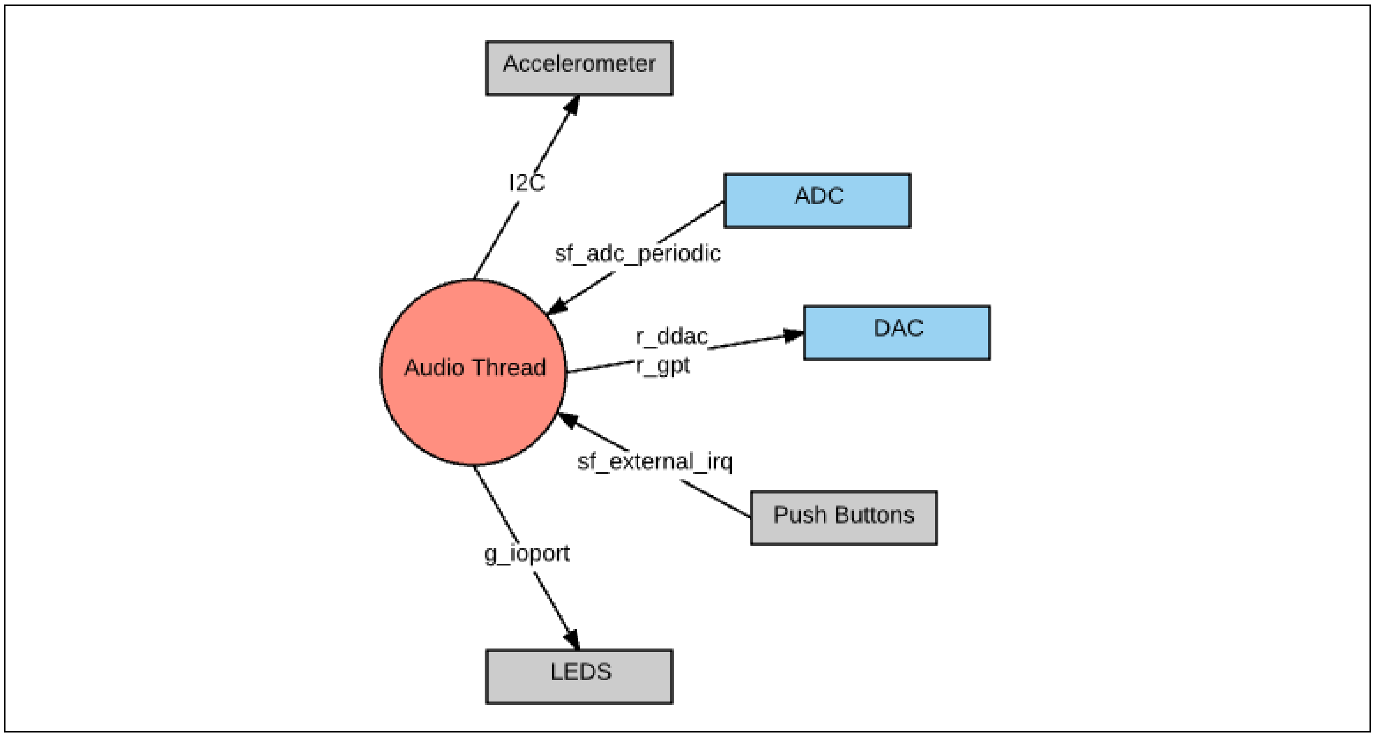


Figure 8 Conceptual diagram of the Tone Generator application

3.4 Audio thread logic

The code in the audio thread, or other threads, can be divided into three separate sections:

- Any initialization code that executes prior to entering the main thread loop
- Code that executes each time the main thread loop executes
- Code that executes inside callback routines, which are executed in response to an interrupt

The tone generator example application is special because the only code that actually executes in the main thread loop is the `tx_thread_sleep()`. This is the call that suspends the thread execution allowing other threads to run.

The audio thread contains four callback routines that do all the work:

- A separate callback routine for each switch (**S1** and **S2**)
- A callback routine for the ADC period framework that samples analog data from the on-board potentiometer (POT1) at regular intervals, and then uses this data to determine the output volume
- Another callback routine associated with the General Purpose Timer (GPT) interrupt, is used to play back the sine wave data at a set rate. This rate determines the frequency of the tone you hear. The rate changes in response to one of the switch interrupts, to rotate through all the pre-defined frequencies.

In the following figure it shows the logic implemented in the main thread loop. To be responsive, the audio thread samples the button states every 50 ns. Normal button presses of **S1** and **S2** result in a few variables (for example, `cur_freq` or `amp_enable`) being set. These variables are examined inside the other callback routines if necessary.

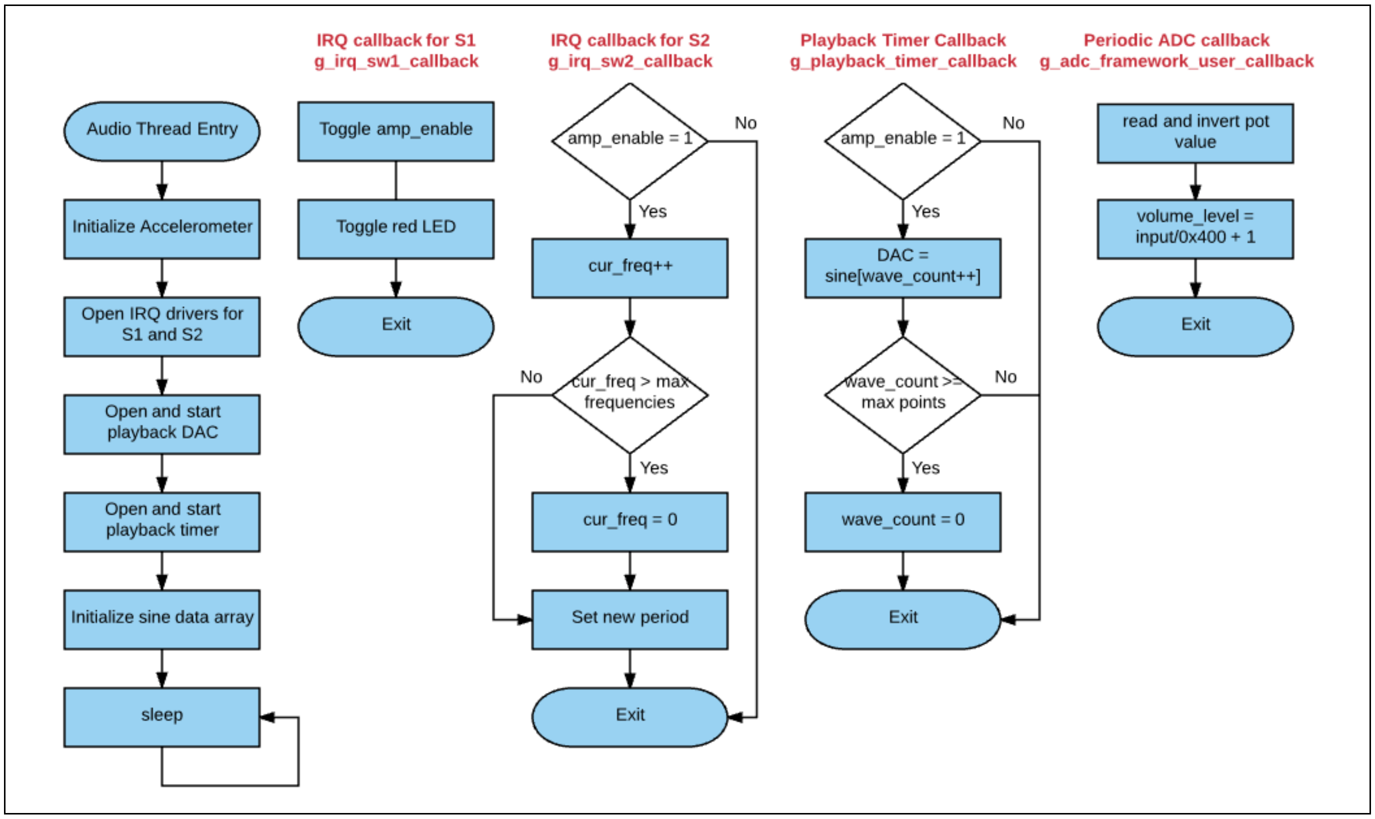
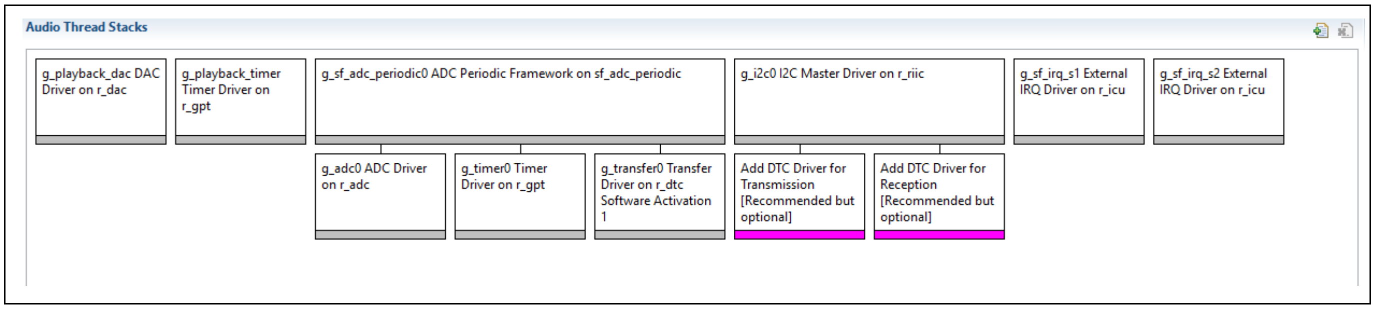


Figure 9 Simplified flowchart of the inputs thread logic

3.5 Threads and modules

As is the case with all Renesas Synergy™ Platform applications, module drivers are added to threads and their properties are configured using the e^2 studio ISDE Configurator. The configurator is opened by double clicking on the `configuration.xml` file from inside the project explorer in e^2 studio. For more information on Synergy modules and drivers, refer to the *SSP User's Manual*.

To configure interfaces to external peripherals, you must understand how a peripheral is connected to the S124 MCU. As mentioned previously, for example, it is necessary to initialize the accelerometer to free up **S1** for our use. The S124 MCU communicates with accelerometer over an I^{2}C bus. It is therefore necessary to add an I^{2}C driver to the thread that communicates with the accelerometer. As shown in the following figure, the `r_riic` driver has been added.


Audio Thread Stacks

g_playback_dac DAC Driver on r_dac

g_playback_timer Timer Driver on r_gpt

g_sf_adc_periodic0 ADC Periodic Framework on sf_adc_periodic

g_i2c0 I2C Master Driver on r_riic

g_sf_irq_s1 External IRQ Driver on r_icu

g_sf_irq_s2 External IRQ Driver on r_icu

g_adc0 ADC Driver on r_adc

g_timer0 Timer Driver on r_gpt

g_transfer0 Transfer Driver on r_dtc Software Activation 1

Add DTC Driver for Transmission [Recommended but optional]

Add DTC Driver for Reception [Recommended but optional]

Figure 10 Audio thread stacks

The Synergy MCU Group contains two different peripherals for I^{2}C communication, a dedicated I^{2}C peripheral, and the Serial Communications Interface (SCI), that may act as either a simple I^{2}C, simple SPI, or UART (Synchronous or Asynchronous). The SSP supports both types of I^{2}C peripherals. The same scenario is true for SPI peripherals.

Choosing which peripheral to use depends on the complexities of your system. In many cases, you may not need all the power available on the dedicated SPI or I^{2}C peripherals. You may need to use the pins assigned to the dedicated I^{2}C peripheral for another use. The decision on which peripheral to use must typically be made during the hardware design phase since it affects which physical processor pins are connected to the peripheral.

One consideration to make when designing the system are the types of peripherals your design requires and how many of each type will be needed. While the S124 MCU only has two dedicated SPI and I^{2}C peripherals, it has nine SCI peripherals which can be configured as either simple SPI or I^{2}C.

The reason that the Tone Generator application uses the dedicated I^{2}C peripheral, rather than one of the nine SCI peripherals, is simply because these are the pins that the hardware designers chose to connect the S124 MCU to the accelerometer.

3.6 Using the Periodic ADC Framework

The Tone Generator application uses the ADC Periodic Framework component to sample the analog value present on the potentiometer (POT1). The value read is then scaled appropriately and used to set one of four volume levels as you rotate the potentiometer. The ADC Periodic Framework component provides the ability to sample analog data at a prescribed rate. You define a callback function to process the data each time a new sample is complete.

The ADC periodic framework can be a bit confusing to get working. If you already have experience using this framework component, you can skip ahead to the next section. If not, study this section carefully and review the application code for the callback function associated with it to understand how to configure and handle scan data in the callback.

Note: One of the key strengths of the Periodic ADC Framework component is the ability to sample multiple analog channels. You can even configure the ADC Periodic Framework component to take multiple samples of each channel during each iteration. This application note does not explore that functionality but other application notes such as the Simple Record Example use additional features of the Periodic ADC Framework.

The ADC Periodic Framework component, in the following figure is essentially a framework layer built on top of the `r_adc` ADC driver, a `r_gpt` timer driver, and the `r_dtc` transfer driver. You need to configure a few parameters in each of these components except for the transfer driver (`r_dtc`), whose role is completely transparent to the user.

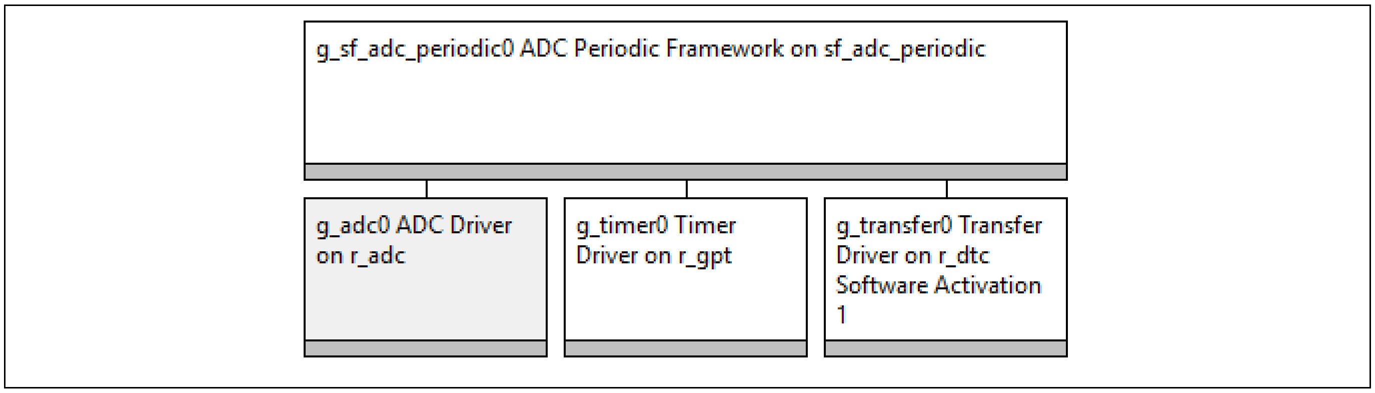
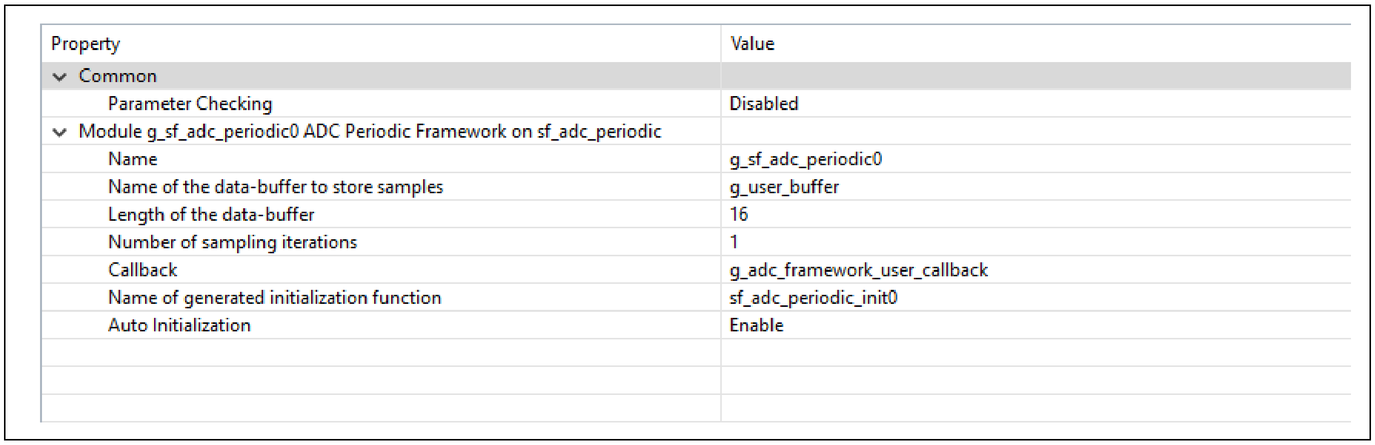

g_sf_adc_periodic0 ADC Periodic Framework on sf_adc_periodic
g_adc0 ADC Driver on r_adc
g_timer0 Timer Driver on r_gpt
g_transfer0 Transfer Driver on r_dtc Software Activation 1

Figure 11 ADC Periodic Framework Stack

As is the case with configuring all SSP components, you click on the appropriate box and then define the properties using the **Properties** tab. The ADC Periodic Framework component contains numerous properties and the default values are acceptable for many of them. Once you have imported and built the application, as outlined in section 4, Design Demonstration, you can browse all the properties for each of the components used in the applications. A few of the properties are reviewed in this section.

As you can see in the following figure, the buffer `g_user_buffer` that holds the samples is 16 bytes deep. A single sample is taken at each scan iteration and the GPT timer channel 0 is used to trigger the scan. The callback name is `g_adc_framework_user_callback`. You may choose any name for the callback function if the callback function in your code matches the name you define here.

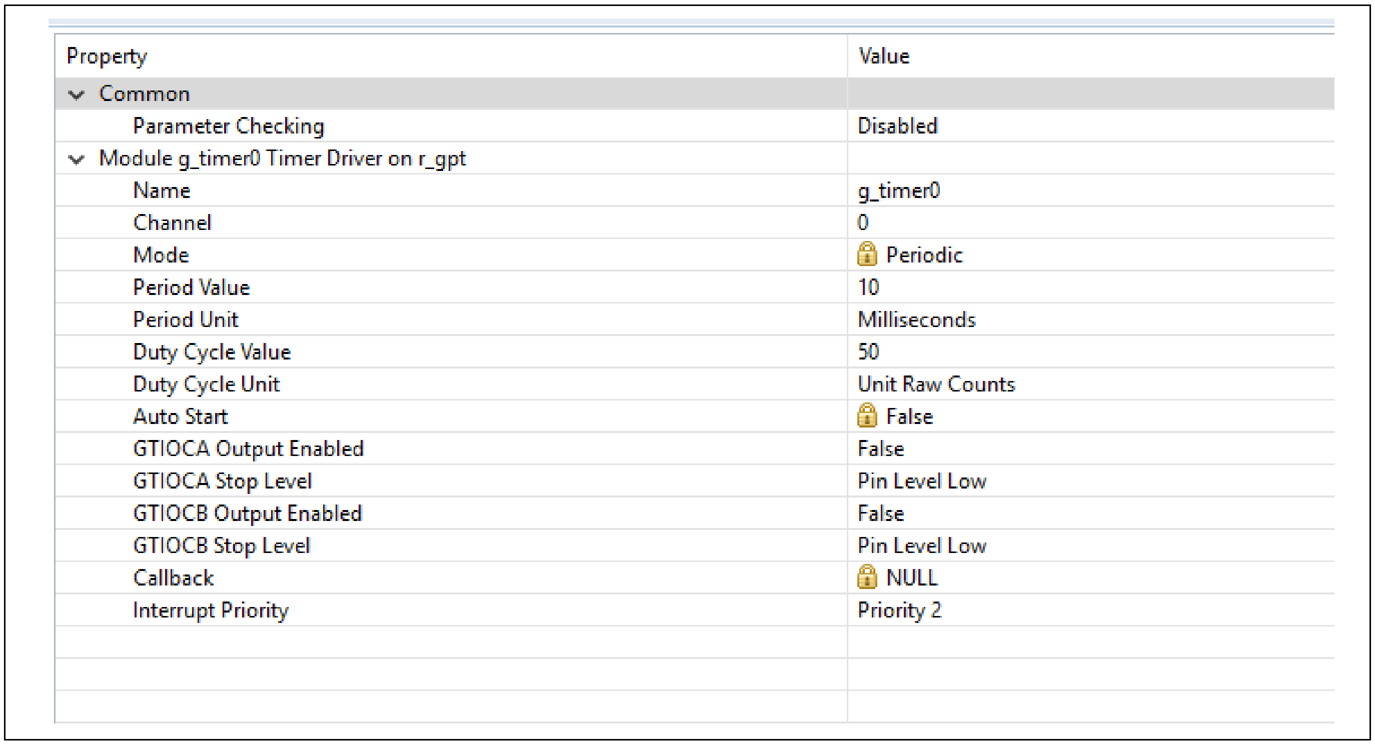


Property	Value
Common	
Parameter Checking	Disabled
Module g_sf_adc_periodic0 ADC Periodic Framework on sf_adc_periodic	
Name	g_sf_adc_periodic0
Name of the data-buffer to store samples	g_user_buffer
Length of the data-buffer	16
Number of sampling iterations	1
Callback	g_adc_framework_user_callback
Name of generated initialization function	sf_adc_periodic_init0
Auto Initialization	Enable

Figure 12 Properties for sf_adc_periodic

The data-buffer (`g_user_buffer`) used to store the samples will be defined for you in the auto-generated `audio_thread.c` file. We will reference this buffer in the callback routine to read the data associated with each scan. An important consideration here is the GPT channel selection. In this case, we must use channel 0 since the channel used by the GPT timer module is locked at channel 0, shown in the following figure.

The key parameters for the `r_rgpt` module are outlined in the following figure. You must enable and pick a priority for the GPT0 COUNTER OVERFLOW IRQ (interrupt) for the scan to work. Additionally, the sample rate of 50 ms is defined by setting the **Period Value** to 50 and the **Period Unit** to **Milliseconds**. This means that the ADC framework samples the analog value present on the potentiometer and call the callback function we defined in the `sf_adc_periodic` component every 50 ms.



Property	Value
Common	
Parameter Checking	Disabled
Module g_timer0 Timer Driver on r_gpt	
Name	g_timer0
Channel	0
Mode	🔒 Periodic
Period Value	10
Period Unit	Milliseconds
Duty Cycle Value	50
Duty Cycle Unit	Unit Raw Counts
Auto Start	🔒 False
GTIOCA Output Enabled	False
GTIOCA Stop Level	Pin Level Low
GTIOCB Output Enabled	False
GTIOCB Stop Level	Pin Level Low
Callback	🔒 NULL
Interrupt Priority	Priority 2

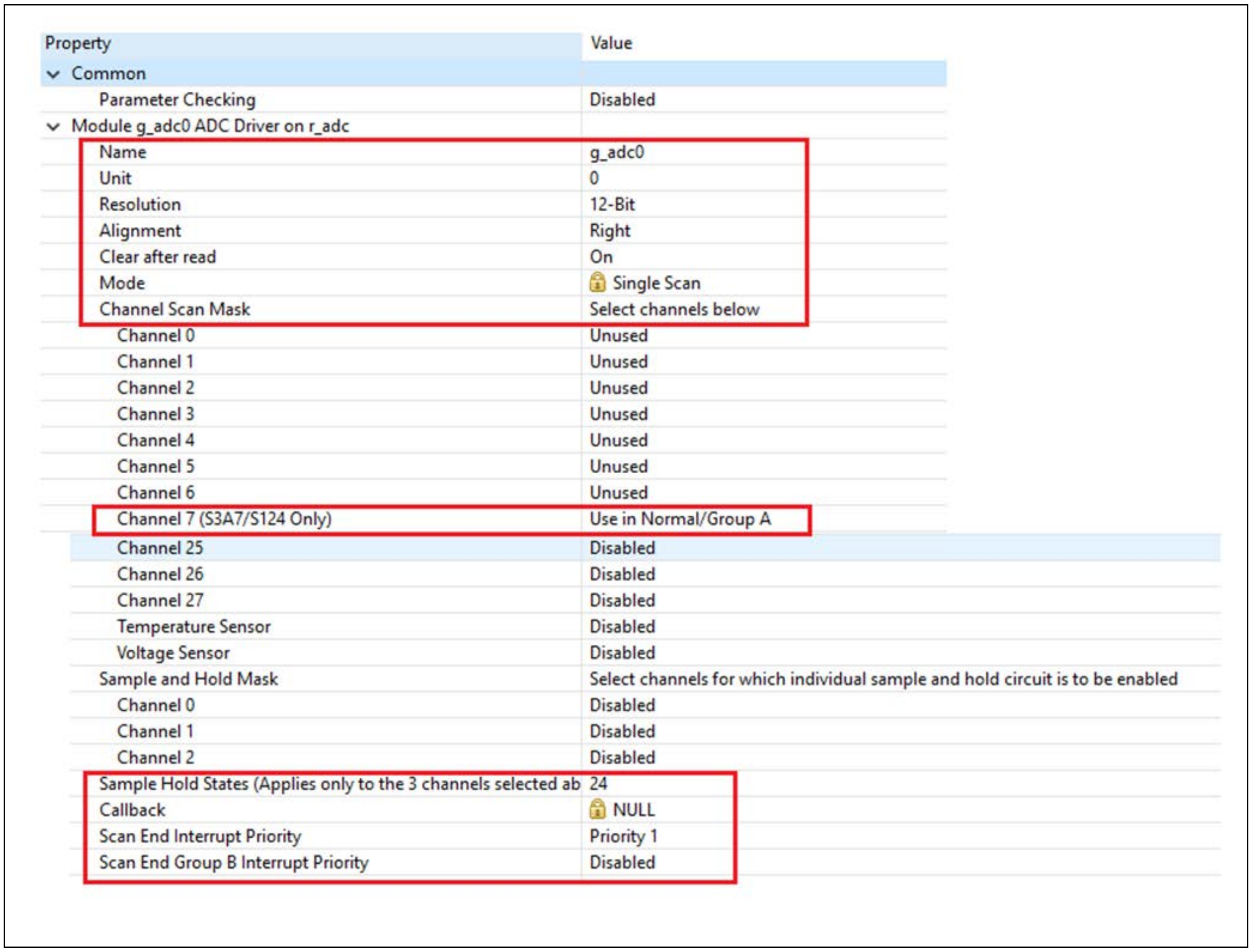
Figure 13 r_rgpt properties for ADC Periodic Framework

Note: You can select from a large range for the **Period Unit** based on the specific needs of your application. The options currently include **Raw Count**, **Nanoseconds**, **Microseconds**, **Milliseconds**, **Seconds**, **Hertz**, and **Kilohertz**.

3.7 Configuring the ADC Unit

The component with the largest number of properties is the `r_adc` component, which is used to configure the ADC unit. Most of the default values are acceptable. Since no changes to the lower half of the properties are necessary, the focus is only on the highlighted properties shown in the following figure. As with many SSP components, you must enable the IRQ associated with it. Here, the ADC0 SCAN END interrupt is set to Priority 1. This interrupt priority could be lower since the analog sampling in this application is only used to set the volume control. In other applications, such as the Simple Record example, audio data is being sampled in real time so a higher priority interrupt id is justified.

As is the case with many SSP components, you may optionally assign your own name to the component. That name would then be used in the various API calls used to access the component inside your code. Here, the default name of `g_adc0` is used. A name such as `g_adc_volume_control` could have been easily selected to make the code more readable. Many of these decisions will either be based on personal preference or your coding standards used.

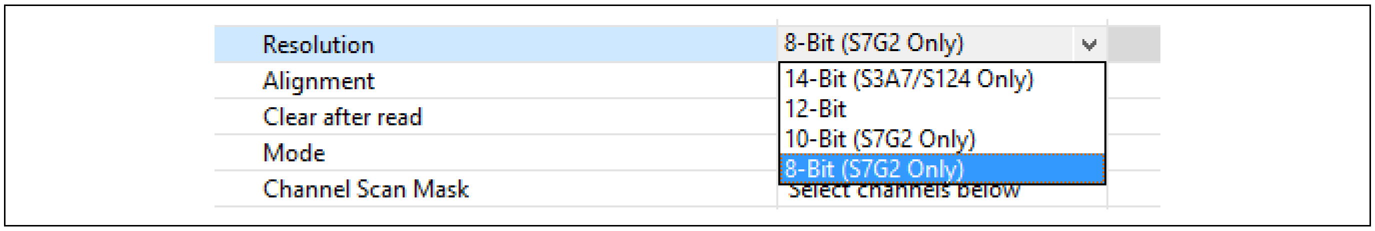


Property	Value
Common	
Parameter Checking	Disabled
Module g_adc0 ADC Driver on r_adc	
Name	g_adc0
Unit	0
Resolution	12-Bit
Alignment	Right
Clear after read	On
Mode	Single Scan
Channel Scan Mask	Select channels below
Channel 0	Unused
Channel 1	Unused
Channel 2	Unused
Channel 3	Unused
Channel 4	Unused
Channel 5	Unused
Channel 6	Unused
Channel 7 (S3A7/S124 Only)	Use in Normal/Group A
Channel 25	Disabled
Channel 26	Disabled
Channel 27	Disabled
Temperature Sensor	Disabled
Voltage Sensor	Disabled
Sample and Hold Mask	Select channels for which individual sample and hold circuit is to be enabled
Channel 0	Disabled
Channel 1	Disabled
Channel 2	Disabled
Sample Hold States (Applies only to the 3 channels selected ab	24
Callback	NULL
Scan End Interrupt Priority	Priority 1
Scan End Group B Interrupt Priority	Disabled

Figure 14 Properties for r_adc component of ADC periodic framework

One of the most important properties that needs to be set correctly in the `r_adc` component is **Resolution**. At the time writing this application note, the default for this field is 8 bit (S7G2 MCU only), that will not work for the S124 MCU as seen in the following figure.

Note: If you are working on an S124 MCU and forget to select either 12 bit or 14 bit (S3A7/S124 MCU only), you will receive an invalid parameter error at run time, which can be a bit confusing to track down at run time.



Resolution	8-Bit (S7G2 Only)
Alignment	
Clear after read	
Mode	
Channel Scan Mask	Select channels below

Figure 15 ADC resolution defaults to 8 bit (S7G2 MCU only)

The actual channels to be sampled each time an ADC scan occurs need to be configured. You can see that only channel 7 has been selected, which is the analog channel connected to the potentiometer. Other application notes, such as the Simple Record example show how to sample multiple channels, for example, the potentiometer and the microphone input at the same time.

3.7.1 Callback for ADC Periodic Framework

Once you have defined all the properties and built your code, you will see a section of code like that shown below in the `audio_thread.h` file:

```
/** Buffer where the sampled data will be stored for application usage */
extern uint16_t g_user_buffer[16];
#ifdef g_adc_framework_user_callback
#define ADC_PERIODIC_ON_ADC_PERIODIC_CALLBACK_USED_g_sf_adc_periodic0 (0)
#else
#define ADC_PERIODIC_ON_ADC_PERIODIC_CALLBACK_USED_g_sf_adc_periodic0 (1)
#endif
#if ADC_PERIODIC_ON_ADC_PERIODIC_CALLBACK_USED_g_sf_adc_periodic0
/** Declaration of user callback function. This function MUST be defined in the user application.*/
void g_adc_framework_user_callback(sf_adc_periodic_callback_args_t * p_args);
#endif
```

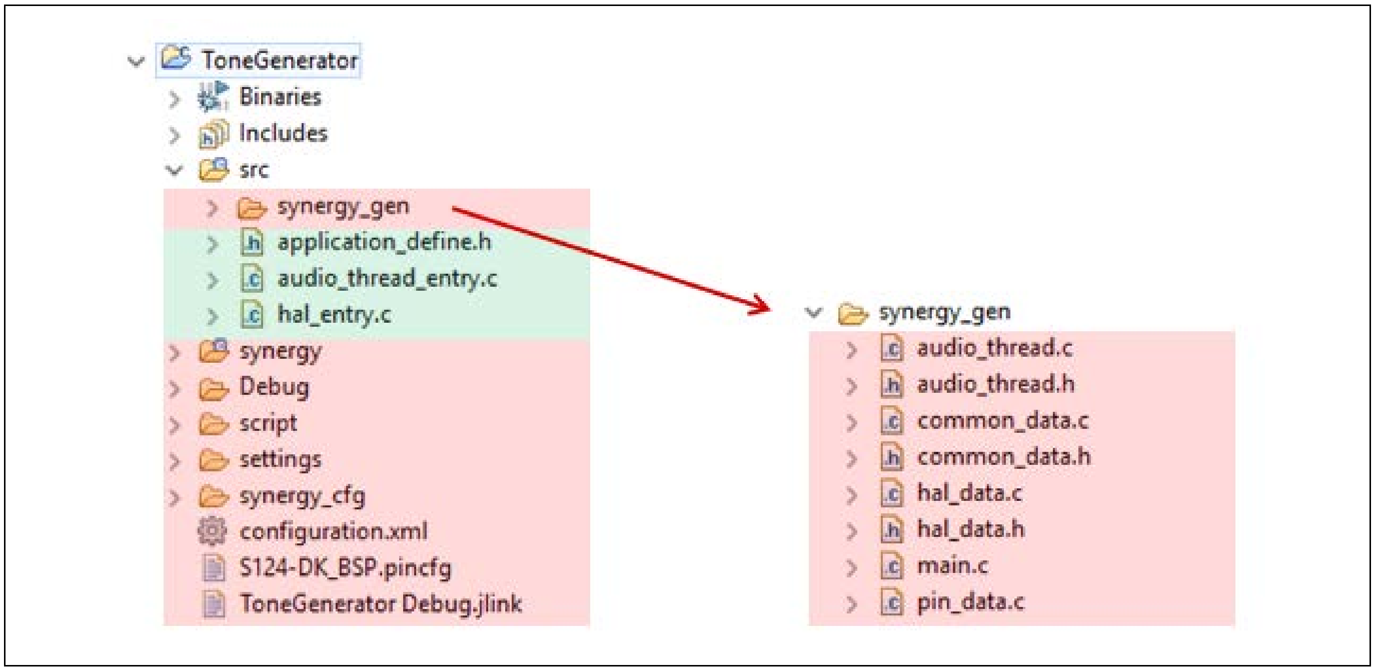
This code defines the function prototype of the call back for you. It also says this code must be defined in your application. You will find the code for `g_adc_framework_user_callback()` at the bottom of the `audio_thread_entry.c` file. The flowchart in Figure 9, highlights the functionality of each callback routine.

3.8 Source Code Layout

This section gives a brief overview of the source code layout that you would expect to see when you build the Tone Generator project with e^2 studio. If you are already experienced writing Synergy applications, you are probably familiar with how e^2 studio organizes a standard project, and can skip ahead to the next section.

After you have imported the Tone Generator application into the e^2 studio and built the project, you should see a directory structure like the one shown in the following figure. The first time you import the project, you may notice that the `synergy_gen`, `synergy`, `debug`, `synergy` and `synergy_cfg` folders do not exist. These folders are built automatically by the framework when you compile the project. To reduce size, these subfolders are normally not included when applications are distributed.

The only files you typically need to work with (for example, add/delete code) in your project are the files highlighted in green.


ToneGenerator
Binaries
Includes
src
synergy_gen
application_define.h
audio_thread_entry.c
hal_entry.c
synergy
Debug
script
settings
synergy_cfg
configuration.xml
S124-DK_BSP.pincfg
ToneGenerator Debug.jlink

synergy_gen
audio_thread.c
audio_thread.h
common_data.c
common_data.h
hal_data.c
hal_data.h
main.c
pin_data.c

Figure 16 Source code layout for DK-S124 OOB v1.0 program

4. Design Demonstration

The DK-S124 Synergy MCU Group comes preloaded with the Out-of-Box application software, that displays the values of the various analog sensors on the PMOD LCD screen. Prior to running the tone generator example code, you need to reprogram the board with the Tone Generator firmware. Before doing this, you should first configure the board shown in the following section.

4.1 Configure the DK-S124 for the Tone Generator Example

The steps to configure the DK-S124 Synergy MCU Group are:

1. Verify that all headers near the battery are configured with all jumpers to make connections as shown in the top portion of the following figure.
2. Connect the JLink®-OB on J18 of the DK-S124 MCU to the PC using a micro USB cable, as shown in the bottom portion of the following figure.
3. Connect speakers or headphones to J16 using a 3.5 mm jack plug as shown in Figure 18 following.

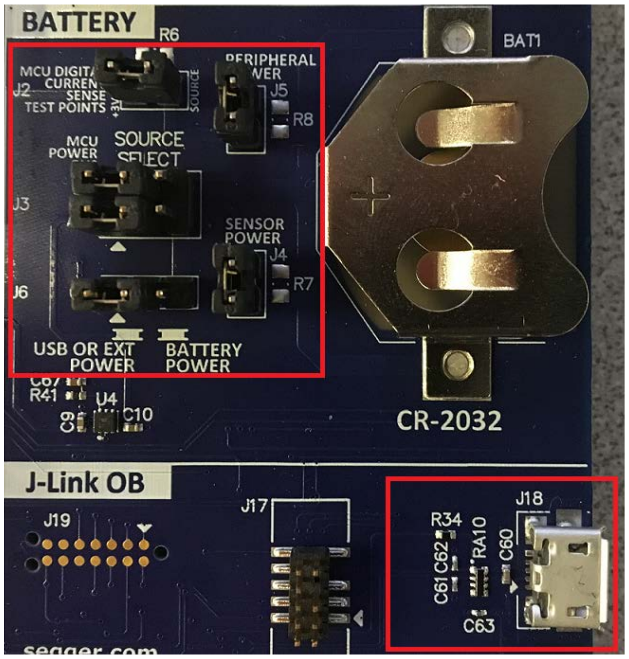


Figure 17 Power setup (top) and J-Link OB connection (bottom)

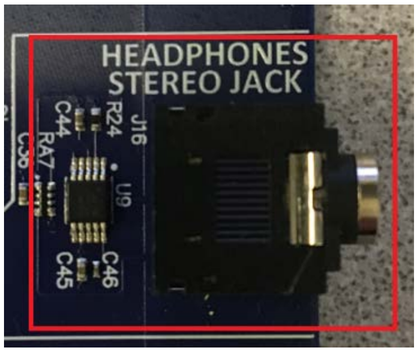


Figure 18 Connecting headphones or external speaker

Now that you have configured the board, you need to import the Tone Generator application into e^2 studio, compile it, and load it onto your DK-S124 board.

On power up, the Tone Generator program defaults to outputting a tone and playing the first tone in its list of pre-defined frequencies. The following section describes how to interact with the program.

4.2 Interacting with the Test Generator Example Program

The steps to interact with the Test Generator program are:

1. **S1** enables/disables the output. When enabled, the red LED (LED1) lights up, and the tone generator outputs the currently selected frequency. When disabled, the red LED turns off and no sound is passed to the earphone jack. On power up, the program defaults to the output being enabled.
2. **S2** increments through the list of frequencies that the tone generator is programmed to play if the output is enabled. If the output is disabled (using **S1**) **S2** has no effect.
3. **POT1** acts as a volume control, where rotating clockwise increases the volume.
   CAUTION: Listening to excessive volume levels can damage your hearing.

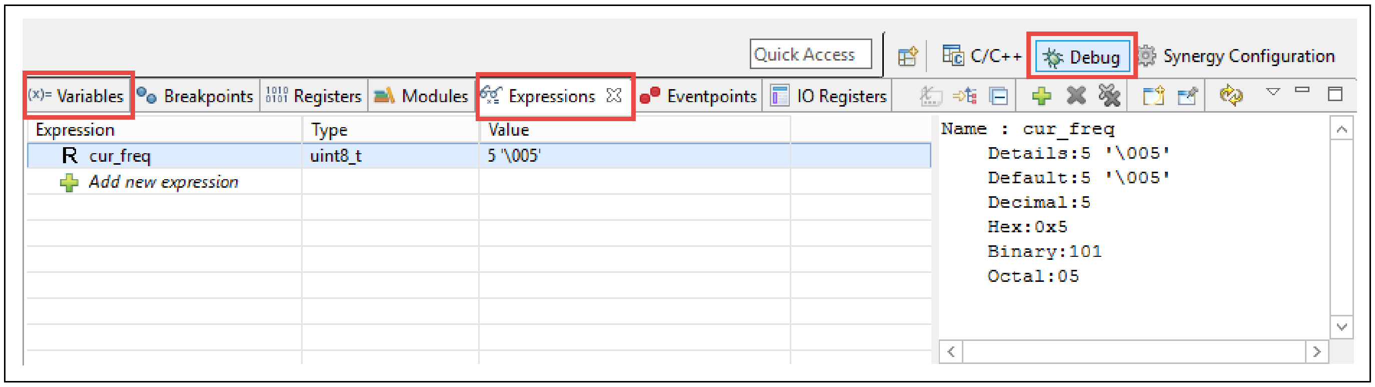
5. Importing and Building the Project

Follow the procedure in the *SSP Import Guide* (r11an0023eu0119-synergy-ssp-import-guide.pdf) to import the project into the e^2 studio ISDE, and to build and debug the project. For the debug configuration, select **ToneGenerator Debug** (under **Renesas GDB Hardware Debugging**).

6. e^2 studio Tricks - Examining Variables

When debugging your applications, you often need to examine the values of certain variables as you step through your code in the debugger. The e^2 studio provides several ways to do this. Once you have compiled your project and loaded it onto your board, e^2 studio asks you if you want to switch to the **Debug** view. The next few images assume you are in the **Debug** perspective.

You can change to the **Debug** perspective at any time by choosing **Window** > **Perspective** > **Open Perspective** > **Other** and then choosing the **Debug** perspective.



Expression	Type	Value
cur_freq	uint8_t	5 '\005'

```
Name : cur_freq
    Details:5 '\005'
    Default:5 '\005'
    Decimal:5
    Hex:0x5
    Binary:101
    Octal:05
```

Figure 19 Variables and Expressions tab

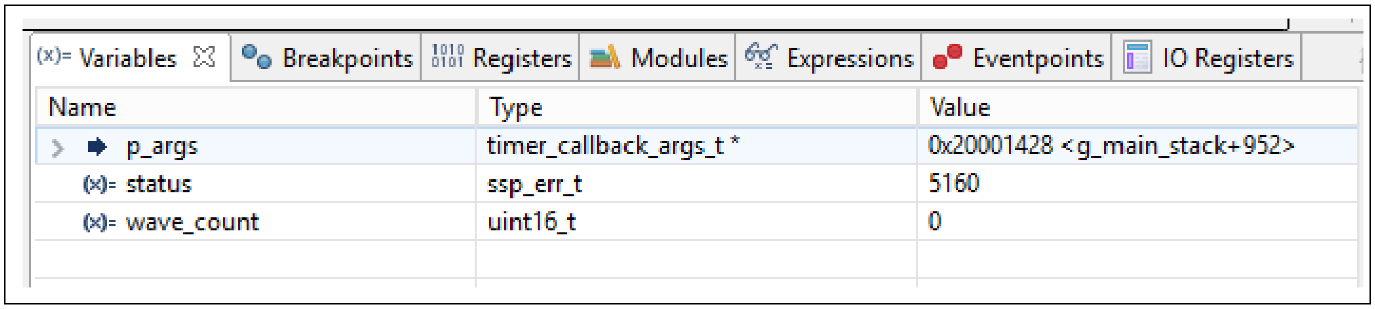
The most common way of examining variables is to use either the **Variables** tab or the **Expressions** tab (as highlighted in the figure above. While these two tabs can often give you the same information, the functionality of each is somewhat different. The **Variables** tab automatically populates variables for you in the function currently executing when you hit a break point.

For example, if you set a breakpoint on the highlighted line in the `g_playback_timer_callback()` routine (below) the **Variables** tab automatically displays the contents of the **status** and **wave count** variables. At the time of writing of this application note, a disadvantage of the **Variables** tab is that it does not display global variables.

```
void g_playback_timer_callback(timer_callback_args_t * p_args)
{
    SSP_PARAMETER_NOT_USED (p_args);
    ssp_err_t status;
    static  uint16_t wave_count = 0;

    /* If the output is enabled, write the current data point for the sine wave to the DAC */
    if(amp_enable){
        /* Write out the sine wave data */
        status = g_playback_dac.p_api->write(g_playback_dac.p_ctrl,
                                             (dac_size_t)(sine[wave_count++] << volume_level));
        APP_ERR_TRAP(status);
        if (wave_count >= SINE_POINTS) { wave_count = 0;}
    }
}
```

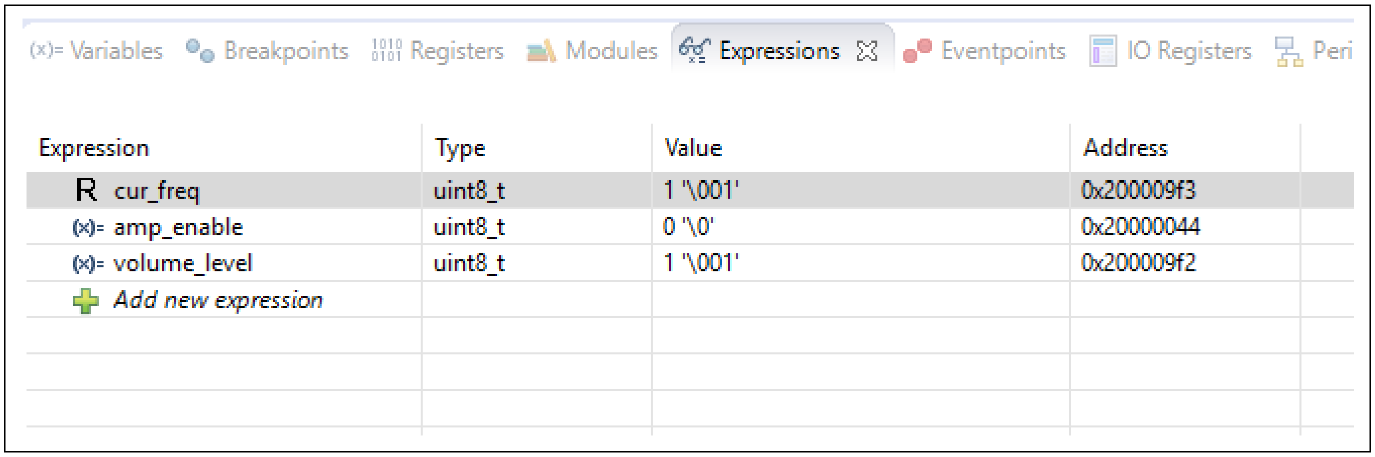
This is where the **Expressions** tab comes into play. The **Expressions** tab allows you to enter variable names or even expressions that use variable names. You are not restricted to only seeing the local variables of the function you are currently in. It does not populate its view automatically with the contents of any variables.



Name	Type	Value
p_args	timer_callback_args_t *	0x20001428 <g_main_stack+952>
status	ssp_err_t	5160
wave_count	uint16_t	0

Figure 20 Variable tab automatically displays function variables

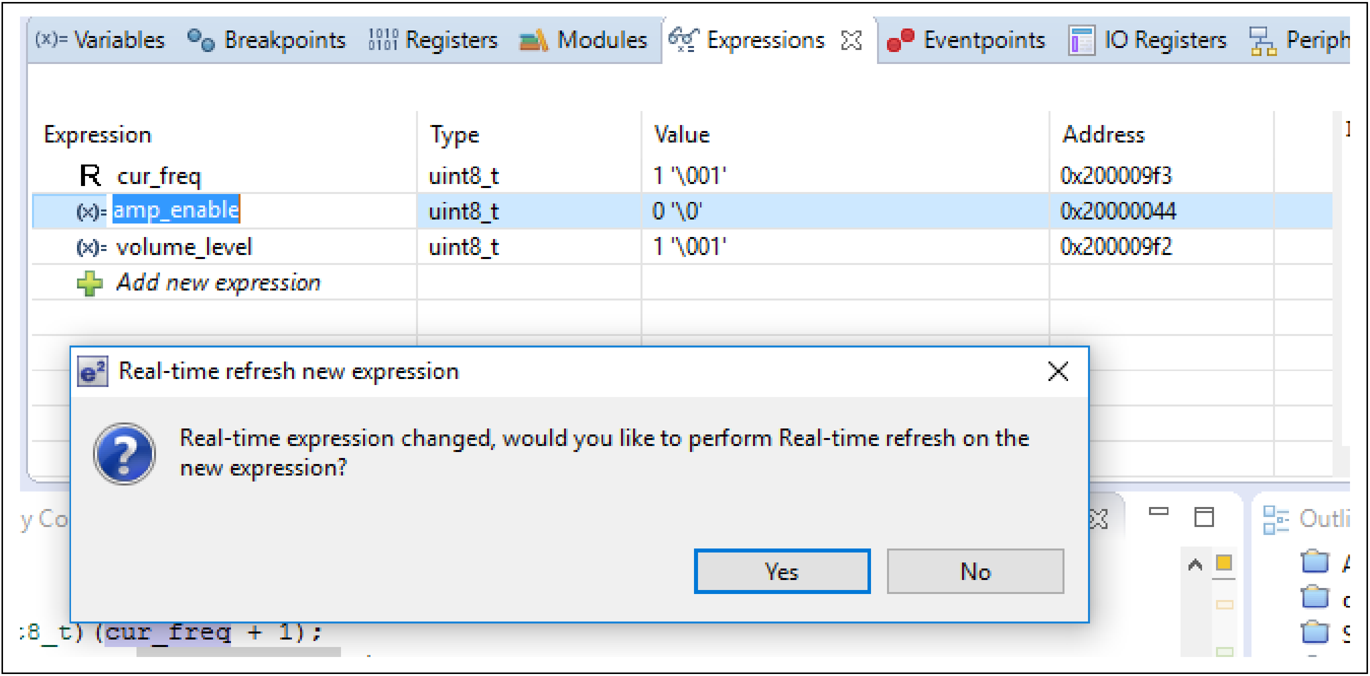
To display a variable, you click on the green arrow next to the prompt that says **Add New Expression** and enter the name of your variable. This is illustrated in the following figure, by adding the variables, `cur_freq`, `amp_enable` and `volume_level`. The associated display shows columns for the **Expression**, **Type**, and **Value** of the expression. In this case, the expression is just the variable name. Clicking on any of the expressions shows you the differing views of the data (for example, hex or decimal) in the pane to the right of the **Expressions** tab.



Expression	Type	Value	Address
R cur_freq	uint8_t	1 '\001'	0x200009f3
amp_enable	uint8_t	0 '\0'	0x20000044
volume_level	uint8_t	1 '\001'	0x200009f2
Add new expression			

Figure 21 Expressions tab displaying content of three variables

Notice in the above figure, that the `cur_freq` variable has an upper case R just to the left of it. By default, the values of the expressions in the **Expressions** tab are only updated when you hit a break point. One of the benefits of the **Expressions** tab is the ability to display the contents of your variables in real time. There are several ways of accomplishing this. The first way is to click on the (x)= next to the variable you are interested in, while your application is running. This presents the dialog you see in the following figure, asking if you want to change this expression to be refreshed in real time.



Expression	Type	Value	Address
R cur_freq	uint8_t	1 '\001'	0x200009f3
(x)= amp_enable	uint8_t	0 '\0'	0x20000044
(x)= volume_level	uint8_t	1 '\001'	0x200009f2
Add new expression			

Real-time refresh new expression

Real-time expression changed, would you like to perform Real-time refresh on the new expression?

```
:8_t) (cur_freq + 1);
```

Figure 22 Dialog prompting to change to real-time refresh

The second way is to right click on the variable and select **Real-time refresh** from the dropdown menu as shown in the following figure. You may also use this dropdown menu to disable real-time refresh, change the expression associated with the current item selected, delete the expression, and so on.

Once you have enabled real-time refresh on a specific expression, you do not need to hit a breakpoint and pause execution of your application to see the value of the variable.

Note: Some variables are easier to examine at run time compared to others. If you have a variable that changes too fast, it will be difficult to see all its values as it changes. In this case, it is better to set a break point to examine the variable value at specific points in your program execution.

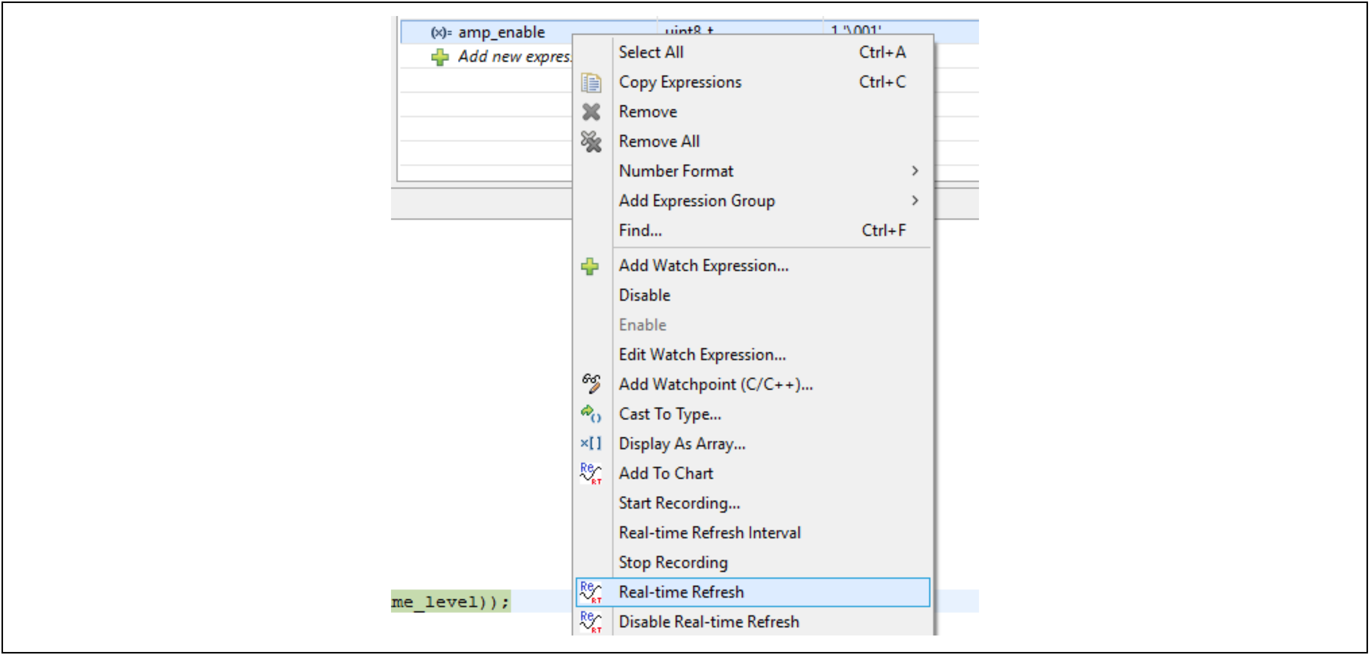


Figure 23 Enabling real-time refresh

6.1 Visual Expressions

One final way of examining variables is using **Visual Expressions**. The e^2 studio provides several graphical ways of representing your data. These are accessed through the **Visual Expressions** tab. If you do not see the **Visual Expressions** tab displayed, you may access it by selecting **Window** >**Show View**>**Other** and then selecting **Visual Expressions** under the **Debug** folder.

The following figure shows an example of the type of display that you can make inside the **Visual Expressions** tab.

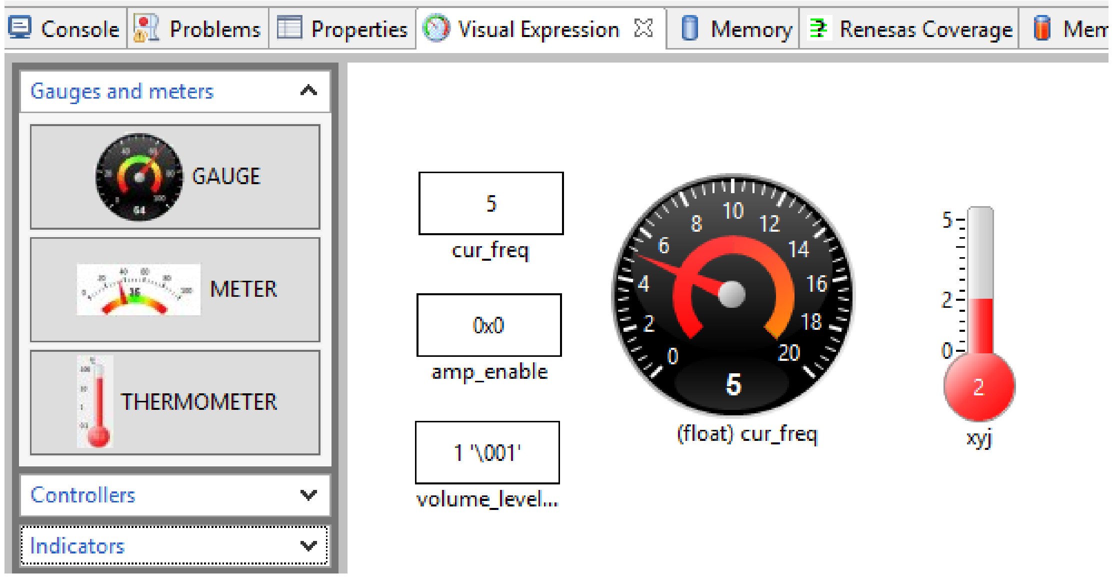


Figure 24 Visual Expressions

We will refer to these graphical representations of your data as widgets. You drag and drop a widget from **Gauges**, **Controllers**, or **Indicators** column in the left selection pane on to the canvas (right pane) and then configure their properties.

From left to right, we have three labels, the small square boxes, followed by a Gauge and a Thermometer. Right clicking on an item presents a dropdown list of operations that allows you to configure it as shown in the following figure.

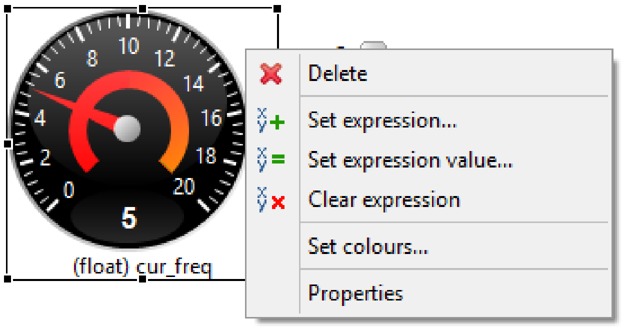


Figure 25 Configuring the gauge

To associate a visual expression with a variable, choose the **Set expression** option and simply type in the variable name or an expression.

Note: At the time of writing this application note, certain visual expressions such as the Gauge seem to only recognize float type values. To display integer variables, you must cast the value to a float before it is displayed.

As shown in the figure below, label widgets have an additional option that allows you to choose the number format.

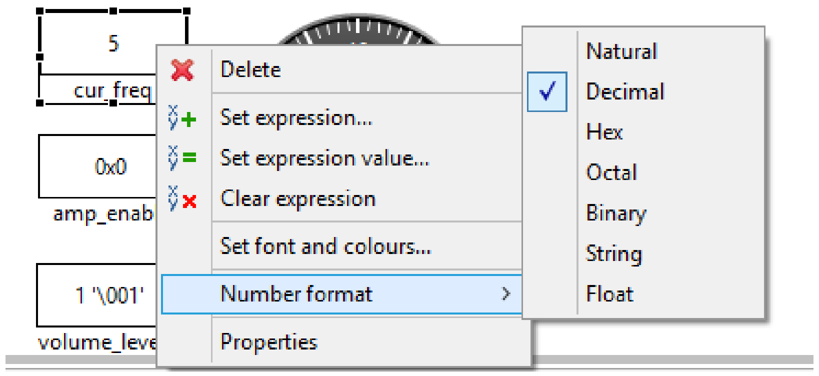


Figure 26 Choosing the number format of a Label widget

7. Next Steps

After you run the example application, you can learn more about how the application works, and the API calls involved by examining the application source code.

Some experiments you might try are:

1. Explore the result of disabling the digital filtering on **S1** (see section 4.1). With the digital filtering disabled, you may hear the frequency increase by more than one increment as you push **S1**. This is because the IRQ is responding to the switch bounce causing the IRQ callback (that increments the current frequency) to be called multiple times for a single switch press.
2. Increase/decrease the number of data points used to represent the sine wave. This can be done by changing the value of `SINE_POINTS` in `audio_thread_entry.c` and rebuilding the project. An increase in the number of points used to represent the sine wave results in a decrease in the frequency of the tone produced. A decrease in the number of points used to represent the sine wave results in an increase in the tone you hear.

If you have access to an oscilloscope, you can monitor the output of the DAC at P0_14, which is connected to pin 7 of the header J6 for easy access. Below are two different captures of ~1 kHz. The first capture uses more data points to represent the sine wave, and the second uses about half the data points.

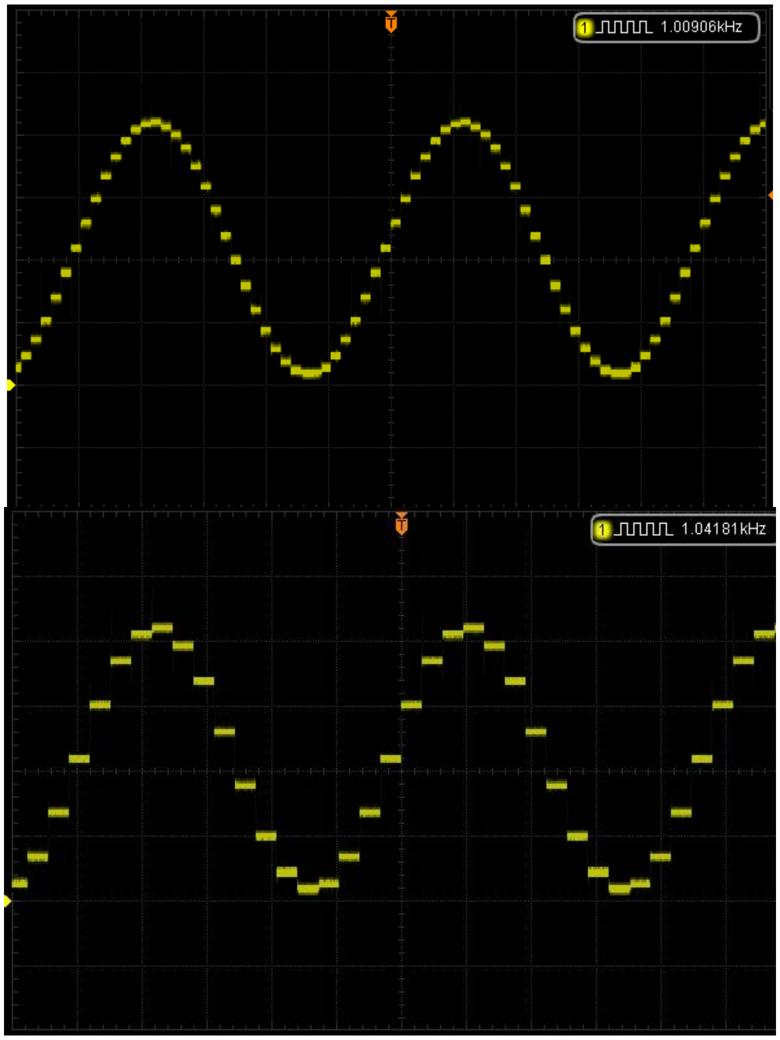


Figure 27 Effect of different number of data points

Note: According to the Nyquist the orem, multiplying a given frequency by 2 gives the minimum number of data points necessary to represent that frequency. In practice, many designers will want at least 4 to 10 data points. The more points sampled, the better the fidelity of the captured waveform.

Website and Support

Support: https://synergygallery.renesas.com/support

Technical Contact Details:

- America: https://www.renesas.com/en-us/support/contact.html
- Europe: https://www.renesas.com/en-eu/support/contact.html
- Japan: https://www.renesas.com/ja-jp/support/contact.html

Revision History

Rev.	Date	Description	
		Page	Summary
1.00	Aug 11, 2016	-	Initial version
1.01	Feb 16, 2017	-	Upgraded to SSP 1.2.0
1.02	Jul 06, 2017	-	Upgraded to SSP 1.3.0
1.03	Sep 27, 2017	-	Final edit to SSP 1.3.0
		2	Required resources of SSP version changed
1.04	Feb 9, 2018	-	Updated for SSP v1.4.0

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