



SC5412A

400 MHz to 6 GHz IQ Modulator

PXI Express Interface

Operating and Programming Manual

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# IMPORTANT INFORMATION

## Warranty

This product is warranted against defects in materials and workmanship for a period of three years from the date of shipment. SignalCore will, at its option, repair or replace equipment that proves to be defective during the warranty period. This warranty includes parts and labor.

Before any equipment will be accepted for warranty repair or replacement, a Return Material Authorization (RMA) number must be obtained from a SignalCore customer service representative and clearly marked on the outside of the return package. SignalCore will pay all shipping costs relating to warranty repair or replacement.

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SignalCore, Incorporated uses a fully RoHS compliant manufacturing process for our products. Therefore, SignalCore hereby declares that its products do not contain restricted materials as defined by European Union directive 2002/95/EC (EU RoHS) in any amounts higher than limits stated in the directive. This statement is based on the assumption of reliable information and data provided by our component suppliers and may not have been independently verified through other means. For products sold into China, we also comply with the “Administrative Measure on the Control of Pollution Caused by Electronic Information Products” (China RoHS). In the current stage of this legislation, the content of six hazardous materials must be explicitly declared. Each of those materials, and the categorical amount present in our products, are shown below:

組成名稱 Model Name	鉛 Lead (Pb)	汞 Mercury (Hg)	鎘 Cadmium (Cd)	六价铬 Hexavalent Chromium (Cr(VI))	多溴联苯 Polybrominated biphenyls (PBB)	多溴二苯醚 Polybrominated diphenyl ethers (PBDE)
SC5412A	✓	✓	✓	✓	✓	✓

A ✓ indicates that the hazardous substance contained in all of the homogeneous materials for this product is below the limit requirement in SJ/T11363-2006. An ✗ indicates that the particular hazardous substance contained in at least one of the homogeneous materials used for this product is above the limit requirement in SJ/T11363-2006.

## CE European Union EMC & Safety Compliance Declaration

The European Conformity (CE) marking is affixed to products with input of 50 - 1,000 Vac or 75 - 1,500 Vdc and/or for products which may cause or be affected by electromagnetic disturbance. The CE marking symbolizes conformity of the product with the applicable requirements. CE compliance is a manufacturer’s self-declaration allowing products to circulate freely within the European Union (EU). SignalCore products meet the essential requirements of Directives 2004/108/EC (EMC) and 2006/95/EC (product safety), and comply with the relevant standards. Standards for Measurement, Control and Laboratory Equipment include EN 61326 and EN 55011 for EMC, and EN 61010-1 for product safety.

## Warnings Regarding Use of SignalCore Products

- (1) PRODUCTS FOR SALE BY SIGNALCORE, INCORPORATED ARE NOT DESIGNED WITH COMPONENTS NOR TESTED FOR A LEVEL OF RELIABILITY SUITABLE FOR USE IN OR IN CONNECTION WITH SURGICAL IMPLANTS OR AS CRITICAL COMPONENTS IN ANY LIFE SUPPORT SYSTEMS WHOSE FAILURE TO PERFORM CAN REASONABLY BE EXPECTED TO CAUSE SIGNIFICANT INJURY TO A HUMAN.

- (2) IN ANY APPLICATION, INCLUDING THE ABOVE, RELIABILITY OF OPERATION OF THE SOFTWARE PRODUCTS CAN BE IMPAIRED BY ADVERSE FACTORS, INCLUDING BUT NOT LIMITED TO FLUCTUATIONS IN ELECTRICAL POWER SUPPLY, COMPUTER HARDWARE MALFUNCTIONS, COMPUTER OPERATING SYSTEM SOFTWARE FITNESS, FITNESS OF COMPILERS AND DEVELOPMENT SOFTWARE USED TO DEVELOP AN APPLICATION, INSTALLATION ERRORS, SOFTWARE AND HARDWARE COMPATIBILITY PROBLEMS, MALFUNCTIONS OR FAILURES OF ELECTRONIC MONITORING OR CONTROL DEVICES, TRANSIENT FAILURES OF ELECTRONIC SYSTEMS (HARDWARE AND/OR SOFTWARE), UNANTICIPATED USES OR MISUSES, OR ERRORS ON THE PART OF THE USER OR APPLICATIONS DESIGNER (ADVERSE FACTORS SUCH AS THESE ARE HEREAFTER COLLECTIVELY TERMED "SYSTEM FAILURES"). ANY APPLICATION WHERE A SYSTEM FAILURE WOULD CREATE A RISK OF HARM TO PROPERTY OR PERSONS (INCLUDING THE RISK OF BODILY INJURY AND DEATH) SHOULD NOT BE SOLELY RELIANT UPON ANY ONE COMPONENT DUE TO THE RISK OF SYSTEM FAILURE. TO AVOID DAMAGE, INJURY, OR DEATH, THE USER OR APPLICATION DESIGNER MUST TAKE REASONABLY PRUDENT STEPS TO PROTECT AGAINST SYSTEM FAILURES, INCLUDING BUT NOT LIMITED TO BACK-UP OR SHUT DOWN MECHANISMS. BECAUSE EACH END-USER SYSTEM IS CUSTOMIZED AND DIFFERS FROM SIGNALCORE' TESTING PLATFORMS, AND BECAUSE A USER OR APPLICATION DESIGNER MAY USE SIGNALCORE PRODUCTS IN COMBINATION WITH OTHER PRODUCTS IN A MANNER NOT EVALUATED OR CONTEMPLATED BY SIGNALCORE, THE USER OR APPLICATION DESIGNER IS ULTIMATELY RESPONSIBLE FOR VERIFYING AND VALIDATING THE SUITABILITY OF SIGNALCORE PRODUCTS WHENEVER SIGNALCORE PRODUCTS ARE INCORPORATED IN A SYSTEM OR APPLICATION, INCLUDING, WITHOUT LIMITATION, THE APPROPRIATE DESIGN, PROCESS AND SAFETY LEVEL OF SUCH SYSTEM OR APPLICATION.

# GETTING STARTED

## Unpacking

All SignalCore products ship in antistatic packaging (bags) to prevent damage from electrostatic discharge (ESD). Under certain conditions, an ESD event can instantly and permanently damage several of the components found in SignalCore products. Therefore, to avoid damage when handling any SignalCore hardware, you must take the following precautions:



- Ground yourself using a grounding strap or by touching a grounded metal object.
- Touch the antistatic bag to a grounded metal object before removing the hardware from its packaging.
- Never touch exposed signal pins. Due to the inherent performance degradation caused by ESD protection circuits in the RF path, the device has minimal ESD protection against direct injection of ESD into the RF signal pins.
- When not in use, store all SignalCore products in their original antistatic bags.

Remove the product from its packaging and inspect it for loose components or any signs of damage. Notify SignalCore immediately if the product appears damaged in any way.

## Verifying the Contents of your Shipment

Verify that your SC5412A kit contains the following items:

<u>Quantity</u>	<u>Item</u>
1	SC5412A IQ Modulator
1	USB Flash Drive Installation Software (may be combined with other products onto a single drive)
1	Getting Started Guide

## Setting Up and Configuring the SC5412A

The SC5412A is designed for use in a PXIe or PXIe hybrid chassis. Chassis manufacturers must provide at least the minimum required per-slot power dissipation cooling capability to be compliant with the PXIe specifications. The SC5412A is designed to be sufficiently cooled in either all-PXIe chassis or PXIe hybrid chassis (PXI Express chassis with traditional PXI slots). However, certain environmental factors may degrade performance. Inadequate cooling can cause the temperature inside the RF housing to rise above the maximum for this product, leading to improper performance and potentially reducing product lifespan or causing complete product failure. Maintain adequate air space around the chassis at all times, and keep the chassis fan filters clean and unobstructed.



*Refer to your chassis manufacturer's user manual for proper setup and maintenance of your PXIe or PXIe hybrid chassis. The SC5412A on-board temperature sensor should indicate a rise of no more than 20 °C above ambient temperature under normal operating conditions.*

The SC5412A is a PXIe-based IQ modulator with all I/O connections and indicators located on the front face of the module as shown below. Each location is discussed in further detail below.

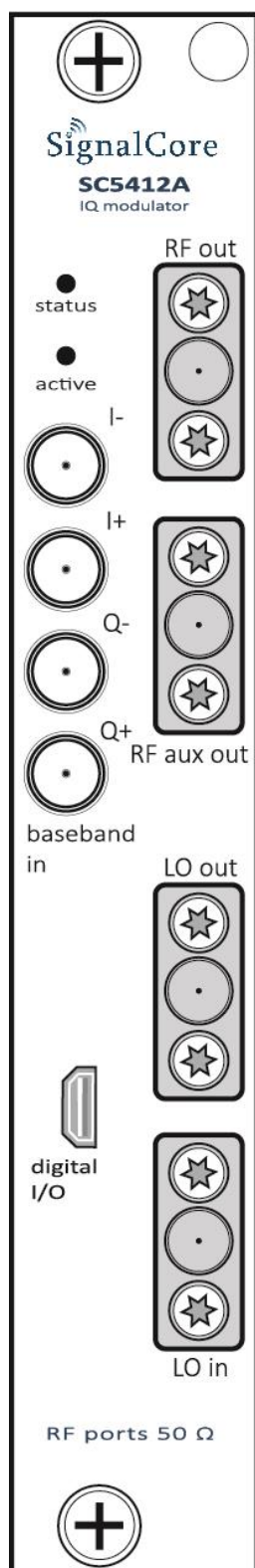


Figure 1. PXIe chassis view of the SC5412A. Module is shown installed in slot 2.



All RF signal connections (ports) on the SC5412A are SMA-type. Exercise caution when fastening cables to the signal connections. Over-tightening any connection can cause permanent damage to the device.



*The condition of your system's signal connections can significantly affect measurement accuracy and repeatability. Improperly mated connections or dirty, damaged or worn connectors can degrade measurement performance. Clean out any loose, dry debris from connectors with clean, low-pressure air (available in spray cans from office supply stores).*

*If deeper cleaning is necessary, use lint-free swabs and isopropyl alcohol to gently clean inside the connector barrel and the external threads. Do not mate connectors until the alcohol has completely evaporated. Excess liquid alcohol trapped inside the connector may take several days to fully evaporate and may degrade measurement performance until fully evaporated.*



***Tighten all SMA connections to 5 in-lb max (56 N-cm max)***

## 1 RF Signal Connections

**LO OUT** This port outputs the tunable LO signal allowing phase-coherent daisy-chaining of multiple IQ modulator modules. The connector is SMA female. The nominal output impedance is 50  $\Omega$ .

**RF OUT** This is the main RF signal output port ranging from 400 MHz to 6 GHz. The connector is SMA female. The nominal input impedance is 50  $\Omega$ .

**RF AUX OUT** This is the auxiliary RF signal output port ranging from 400 MHz to 6 GHz. This port can be used as an alternate path for system-level calibration. The connector is SMA female. The nominal input impedance is 50  $\Omega$ .

**LO IN** This port accepts a tunable LO signal from an external source to drive the modulator. The connector is SMA female. This port is AC-coupled with a nominal input impedance of 50  $\Omega$ . Maximum input power is +10 dBm.

## 2 Baseband Connections

The SC5412A has four baseband input ports, comprised of differential in-phase (I+ and I-) and differential quadrature (Q+ and Q-) inputs. Nominal differential input impedance is 100  $\Omega$ . The modulator can also be configured for single-ended or differential IF input. When configured for single-ended operation, it is recommended to terminate the other half of the differential pair using a 50  $\Omega$  terminator. All baseband connectors are MCX female.

## 3 Indicator LED

The SC5412A provides visual indication of important modes. There is one LED indicator on the unit. Its behavior under different operating conditions is shown in Table 1.

**Table 1. LED indicator states.**

LED	Color	Definition
STATUS	Green	“Power good” and device is ready.
STATUS	Off	Power fault. Contact SignalCore.
ACTIVE	Green/Off	Device is open (green) /closed (off). This indicator is also user programmable (see register map).

# SC5412A THEORY OF OPERATION

## Overview

The SC5412A is a single-stage, direct conversion Inphase-Quadrature (IQ) modulator. The modulator operates in the 400 MHz to 6 GHz RF range with a typical 3 dB IQ IF bandwidth of 320 MHz. IF signals are conditioned by input differential drivers prior to the IQ mixers. These differential drivers adjust the DC level and minimize the DC offset effects on the modulated RF signal. The RF output stage has adjustable gain to allow the user to adjust the signal levels, and to also to optimize for signal dynamic range. The SC5412A has the necessary RF amplifiers, attenuators and IF amplifiers to give the user optimal control of the device over the entire frequency range. Figure 3 shows a simplified block diagram of the SC5412A, showing only the signal conditioning components critical for the following discussion. The following sections provide more in-depth discussion on how to optimize the converter for linearity and signal-noise dynamic range. Power supply generation and regulation, and digital control functions are not covered. Should the user require more information than what is provided in this manual, please contact SignalCore.

## IF Input Section

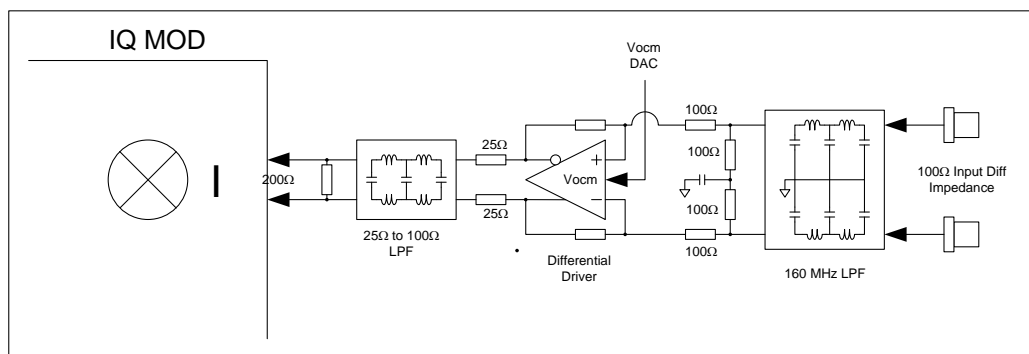
The IF inputs are typically driven differentially, however they may also be driven single-ended. The IF input is DC coupled with a differential impedance of 100  $\Omega$ . Singled-ended operation is recommended for AC-coupled operation due to the fact that DC-coupled single-ended operation may cause large DC offsets at the input driver amplifier that the DC offset compensation may not be about to overcome. A large DC offset will lead to high LO leakage, so unless the DC points of the differential inputs are bias the same, AC coupling is recommended for single-end operation. For differential DC-coupled input it is recommended to drive the common mode input voltage between 1.5 V to 2.5 V for best linearity performance. See Figure 2 for details of the input section.

From Figure 3, the IF signals are first filtered by a 160 MHz filter, and then passed to the input differential drivers before being driven into the IQ mixers. The DC characteristics of the output of each differential driver are controlled by two 14 bit DACs. One DAC controls the driver common output voltage, while a separate DAC controls the DC offset of the differential output pair. The common output voltage has a range from 0V to 2.5V (DAC code 0 to 16383), and a differential voltage range of -50 mV to +50 mV (DAC code 0 to 16383, mid code is 0V). The common output voltage controls the bias to the mixer inputs, which affects the mixer linearity. The user may need to adjust this voltage to optimize linearity (IP3 and harmonics), which is dependent on IF input power level and the operating frequency. A typical bias voltage may range between 1 V and 3 V.

DC offset to the differential modulating mixer is controlled using the DC offset DAC. This DAC provides approximately -50 mV to +50 mV of differential voltage adjustment. Adjusting the DAC offset on both the I and Q channels can minimize the LO leakage at the RF output. This is commonly known as “nulling” out the LO. The process typically involves a few adjustment steps alternating between the I-Channel DAC and the Q-Channel DAC until an optimal level of LO suppression is achieved. However, nulling of the LO is typically only effective over a small amplitude, frequency, and temperature range. Once the operating

condition changes significantly, nulling may need to be performed again. For example, if the LO is nulled at 25 °C, then it will most likely need to be nulled again at 45 °C although the frequency and input amplitude is held relatively constant. Digital data must be corrected to compensate for the modulator IQ amplitude and phase imbalances in addition to nulling out the LO leakage for best application results.

The IQ core, comprising two mixers driven at LO quadrature signals, should not be driven too hard with IF signals because the resulting IMD3 of the RF signal may be too high. It is recommended to use an IF level of 0.5 V peak-to-peak differential or less to lower the IMD3. However if the IF is too low, the RF signal-to-noise ratio may suffer. Subsequently, the user must look at the RF result to determine the optimal IF input level.



**Figure 2. IF input section.**

## RF Output Section

The output section comprises adjustable digital step attenuators (DSA), RF amplifiers (one is selectable), and a bank of low pass filters to suppress RF harmonics. These are used to condition the RF signal generated in the IQ core component. The RF signal has its best performance exiting the IQ core; therefore it is important to select a suitable RF gain to minimize further degradation of the signal. A general rule is to apply more attenuation earlier in the RF path (close to the IQ core) to improve linearity, and more gain to improve signal-to-noise performance. Generally, for RF frequencies less than 3 GHz, to vary signal levels greater than -20dBm the attenuators RF ATTEN#1, and RF ATTEN#2 should be used as controls. To lower signal levels below -20 dBm, ATTEN#3 and ATTEN#4 should then be used. Although all attenuators in the path have 30 dB of adjustment with 1 dB steps, it is not always recommended to maximize the full range of an attenuator before moving to the next one in the path. As an example, attenuation of ATTEN#1 should rarely be more than 10 dB because any further attenuation will degrade the signal-to-noise ratio at a faster rate than the improvement of IMD3. If any further IMD3 improvement is needed, ATTEN#2 or ATTEN#3 should be used to create the desired attenuation. ATTEN#4 should be fully utilized first to generate signals lower than -30 dBm.

The selectable RF amplifier is used to improve the overall gain of the device for frequencies in the 5 GHz to 6 GHz range, as the RF loss in the RF path become more significant at these higher frequencies. The gain flatness roll-off over the entire operating band is typically 15-16 dB. The RF amplifier has 14 dB of gain. If the overall gain is too excessive at the desired operating frequency, ATTEN#2 should be used to readjust the gain to the required level.

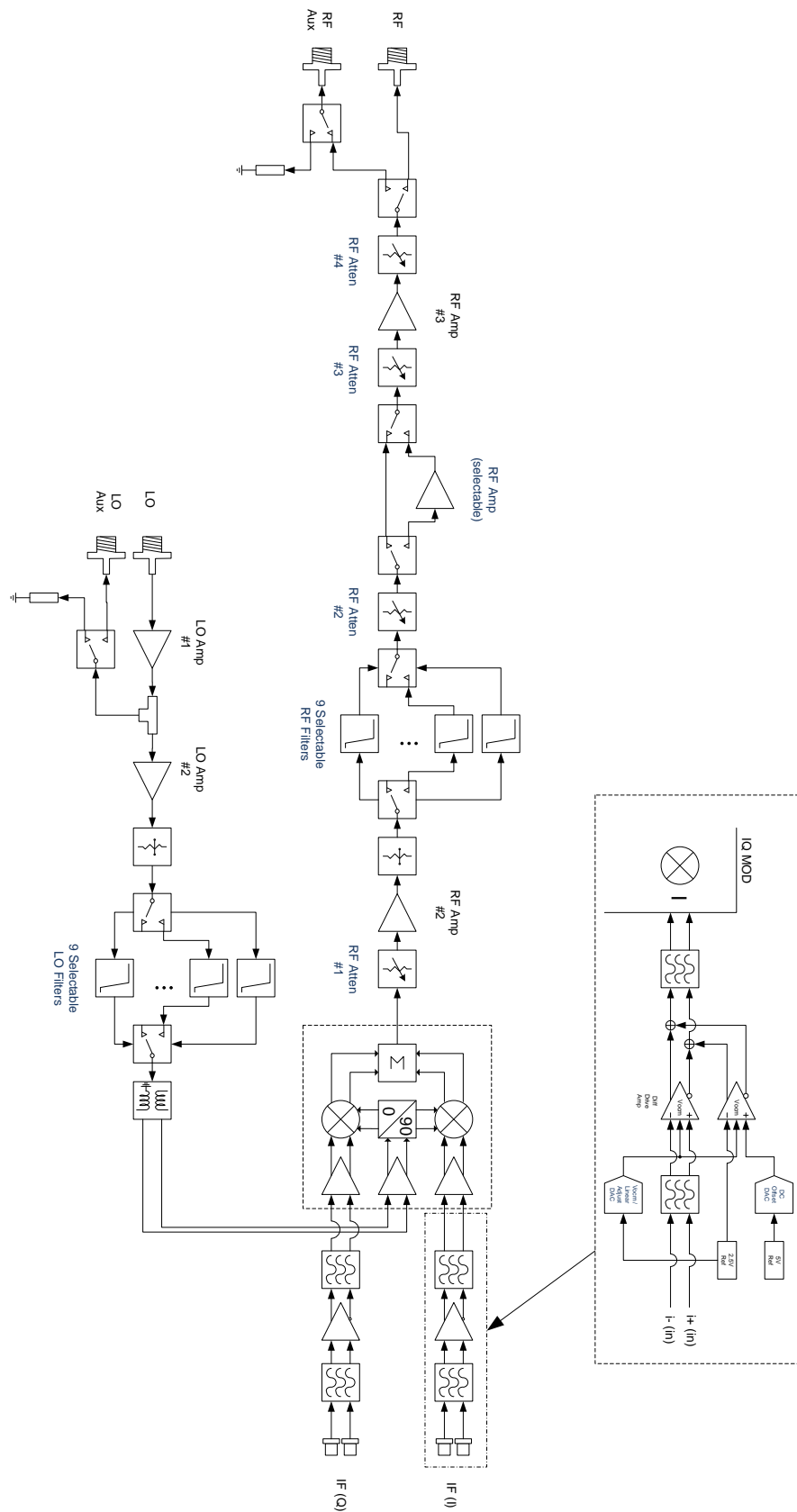


Figure 3. Simplified SC5412A block diagram.

There are nine low pass filters in the RF filter bank. These filters are automatically selected when the user enters the operating frequency. These filters can also be selected manually should the user choose to do so. As with all filters, there is generally an amplitude roll-off as the frequency nears its 3 dB cutoff point so it is important to understand that frequencies near the cutoff point may experience a slightly faster roll-off of their IF bandwidth. A typical 1 dB IQ IF bandwidth is about 160 MHz. The user may want to choose a higher frequency filter if this becomes a problem. See the section “Setting the SC5412A: Writing to Configuration Registers” for more details. The filters in both the RF and LO filter banks are identical and are listed below.

Filter Number	1 dB Cutoff Frequency
0	400 MHz
1	500 MHz
2	650 MHz
3	1000 MHz
4	1400 MHz
5	2000 MHz
6	2825 MHz
7	3800 MHz
8	6000 MHz

## LO Input Section

The SC5412A requires an external RF signal as its “Local Oscillator” (LO) for the frequency conversion process. The external RF signal must be connected to the “LO in” port. The typical required input level is -3 dBm to 3 dBm. These levels are required to sufficiently drive the IQ modulator for good linearity performance and conversion loss. The LO signal is conditioned through a bank of low-pass filters to reduce the signal harmonics. Reducing the harmonics produces a “purer” signal tone, improving the duty cycle of the LO as it drives the mixers of the modulator. Additionally, the LO signal can be passed out of the device via the “LO out” port. This output can be used as the input LO source for another modulator, for example. Driving multiple modulators (or demodulators when working with SignalCore’s SC5312A) with the same derived LO signal optimizes phase coherency between them. When this port is not in use, it is highly recommended to terminate it into a 50  $\Omega$  load.

# SC5412A PROGRAMMING INTERFACE

## Device Drivers

The SC5412A is programmed by writing to its set of configuration registers, and its data is read back through its set of query registers. The user may program directly at register level or through the API library functions provided. These API library functions are wrapper functions of the registers that simplify the task of configuring the register bytes. The register specifics are covered in the next section. Writing to and reading from the device at the register level through the API involves calls to the **sc5412a\_RegWrite** and **sc5412a\_RegRead** functions respectively.

The SC5412A is programmed by writing to its set of configuration registers, and its status read back through its set of query registers. The user may choose to program directly at register level or through the API library functions provided. These API library functions are wrapper functions of the registers that simplify the task of configuring of the register bytes. The register specifics are covered in the next section. Writing to and reading from the device at the register level through the API involves calls to the **sc5412a\_RegWrite** and **sc5412a\_RegRead** functions respectively.

For Microsoft Windows™ operating systems, The SC5412A API is provided as a dynamic linked library, *sc5412a.dll*. This API uses **NI-VISA™** to communicate with the device. Inclusion of the NI-VISA driver is required for code development in programming languages such C, C++, or LabVIEW™. For LabVIEW™ support, an additional LabVIEW API, *sc5412a.llb*, is also provided. The functions in the LabVIEW API are primarily LabVIEW VI wrappers to the standard API functions. **NI-VISA™** is available from National Instruments Corporation ([www.ni.com](http://www.ni.com)).

For other operating systems or VISA implementations such as Agilent VISA, users will need to access the device through their own proprietary PXIe driver. The VISA-based driver code is available to our customers by request. This code can be compiled with Agilent VISA with minimal or no code change. Should the user require assistance in writing an appropriate API other than that provided, please contact SignalCore for additional example code and hardware details.

## Using the Application Programming Interface (API)

The SC5412A API library functions make it easy for the user to communicate with the device. Using the API removes the need to understand register-level details - their configuration, address, data format, etc., and the additional layer between the PXIe bridge and the onboard microcontroller that must be configured prior to writing the device registers. Using the API, commands to control the device are greatly simplified. For example, to obtain the device temperature, the user simply calls the function **sc5412a\_GetDeviceTemperature**, or calls **sc5412a\_SetFrequency** to tune the frequency. The software API is covered in detail in the “Software API Library Functions” section.

# SETTING THE SC5412A: WRITING TO CONFIGURATION REGISTERS

## Configuration Registers

The users may write the configuration registers (write only) directly by calling the **sc5412a\_RegWrite** function. The syntax for this function is **sc5412a\_RegWrite(deviceHandle, registerCommand, instructWord)**. The **instructWord** takes a 64 bit-word. However, it will only send the required number of bytes to the device. Table 2 summarizes the register addresses (commands) and the effective bytes of command data.

**Table 2. Configuration registers.**

Register (Address)	Reg Code	Serial Range	MSB Bit 7	MSB Bit 6	MSB Bit 5	MSB Bit 4	MSB Bit 3	MSB Bit 2	MSB Bit 1	MSB Bit 0
INITIALIZE	0x01	[7:0]								Mode
SET_SYSTEM_ACTIVE	0x02	[7:0]								Enable SYS LED
RF_FREQUENCY	0x10	[7:0]	MHz Frequency Word [7:0]							
		[15:8]	MHz Frequency Word [15:8]							
		[23:16]	MHz Frequency Word [23:16]							
		[31:24]	MHz Frequency Word [31:24]							
		[39:32]	MHz Frequency Word [39:32]							
RF_AMPLIFIER	0x12	[7:0]							Amplifier	Mode
RF_ATTENUATION	0x13	[7:0]	Attenuation							
		[15:8]							Attenuator #	
RF_PATH	0x14	[7:0]								Path
RF_FILTER_SELECT	0x15	[7:0]					Filter [3:0]			
LO_FILTER_SELECT	0x16	[7:0]					Filter [3:0]			
LO_OUT_ENABLE	0x17	[7:0]								Enable LO Out
DC_OFFSET_DAC	0x1A	[7:0]	DAC value [7:0]							
		[15:8]			DAC value [13:8]					
		[23:16]								Channel
LINEARITY_DAC	0x1B	[7:0]	DAC value [7:0]							
		[15:8]			DAC value [13:8]					
		[23:16]								Channel
STORE_STARTUP_STATE	0x1D	[7:0]								
USER_EEPROM_WRITE	0x1F	[7:0]	Address [7:0]							
		[15:8]	Address [15:8]							
		[23:16]	Byte[7:0]							



## Initializing the Device

**INITIALIZE (0x01)** - Writing 0x00 to this register will reset the device to the default power-on state. Writing 0x01 will reset the device but leave it in the current state. The user has the ability to define the default startup state by writing to the **STORE\_STARTUP\_STATE (0x1D)** register, described later in this section.

## Setting the System Active LED

**SET\_SYSTEM\_ACTIVE (0x02)** - This register simply turns on the front panel “active” LED with a write of 0x01, or turns off the LED with a write of 0x00. This register is generally written when the device driver opens or closes the device.

## Setting the RF Frequency

**RF\_FREQUENCY (0x10)** - This register provides the device frequency information to set up the filters appropriately. Data is sent as a 40 bit word with the LSB in Hz.

## Setting RF Input RF Amplifiers

**RF\_AMPLIFIER (0x12)** - This register enables or disables the RF amplifiers. Setting bit 0 low (0) disables RF amplifier. Setting bit 0 high (1) enables RF amplifier.

## Setting the RF Attenuation

**RF\_ATTENUATION (0x13)** – Each of the attenuators is a 5 bit digital step attenuator with 1 dB per LSB. Data is sent in 2 bytes; byte1 and bits [1:0] specifies the attenuator to program, and byte0 and bit [4:0] specifies the attenuation value.

## Setting the RF Path

**RF\_PATH (0x14)** – Setting bit 0 low selects the main RF input path, while high will select the RF auxiliary path.

## Selecting the RF Filter

**RF\_FILTER\_SELECT (0x15)** – There are 9 RF filters to select from to improve RF input second harmonic suppression. Bits [3:0] are used.

## Selecting the LO Filter

**LO\_FILTER\_SELECT (0x16)** – There are 9 RF filters to select from to improve LO input second harmonic suppression. Bits [3:0] are used.

## Enabling LO Output

**LO\_OUT\_ENABLE (0x17)** – Setting bit 0 high enables the LO signal to be ported out the LO output connector. Note there is always a leakage out of this port and the levels could be as high as -30 dBm. It is recommended to terminate this port into a 50  $\Omega$  load if it is not used.

## Removing DC Offset in Differential Amplifiers

**DC\_OFFSET\_DAC (0x1A)** – The DC offsets at the input of the modulator causes LO leakage. Adjustments to both the I & Q channel differential DC offsets can minimize the LO leakage. Varying the DAC value from 0 to 16383 can correct up to approximately  $\pm 50\text{mV}$  of DC offset error. This correction resolution is less than 0.010 mV per LSB. An approximation of the DAC value-to-offset voltage is given below.

$$DAC\ Value = 16383 \left( V_{offset} + 0.05V / 0.1V \right)$$

## Setting the Output Linearity of the IQ Modulator

**LINEARITY\_DAC (0x19)** – This DAC controls the bias point of the IQ modulator. A typical value for the bias point is 1.2V, however adjustments are needed to improve linearity at different operating frequency and input IF power levels. Typically, the DAC is set around 1.2 V using the following equation:

$$DAC\ Value = 16383 \left( V_{com} / 5V \right)$$

## Storing the Startup State

**STORE\_STARTUP\_STATE (0x1D)** – Writing to this register will save the current device state as the new default power on (startup) state. All data written to this register will be ignored as only the write command is needed to initiate the save.

## Writing to the User EEPROM

**USER\_EEPROM\_WRITE (0x1B)** - There is an onboard 32 kilobyte EEPROM for the user to store data. User data is sent one byte at a time and is contained in the last (least significant) byte of the three bytes of data written to the register. The other two bytes contain the write address in the EEPROM. For example, to write user data 0x22 into address 0x1F00 requires writing 0x1F0022 to this register.

# QUERYING THE SC5412A: WRITING TO REQUEST REGISTERS

The registers to read data back from the device (such as device status) are accessed through the **sc5412a\_RegRead** function. The function and parameter format for this command is **sc5412a\_RegRead(deviceHandle, registerCommand, instructWord,\*dataOut)**. Any instructions in addition to the register call are placed into “instructWord”, and data obtained from the device is returned via the pointer value **dataOut**. The set of request registers are shown in Table 3.

**Table 3. Query registers.**

Register Name	Register Address (Hex)	Serial Range	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
GET_TEMPERATURE	0x20	[7:0]	Open	Open	Open	Open	Open	Open	Open	Open
GET_DEVICE_STATUS	0x21	[7:0]	Open	Open	Open	Open	Open	Open	Open	Open
USER_EEPROM_READ	0x23	[7:0]	EEPROM Address [7:0]							
		[15:8]	EEPROM Address [15:8]							
CAL_EEPROM_READ	0x24	[7:0]	EEPROM Address [7:0]							
		[15:8]	EEPROM Address [15:8]							

## Reading the Device Temperature

**GET\_TEMPERATURE (0x17)** - Data returned by this register needs to be processed to correctly represent data in temperature units of degrees Celsius. Data is returned in the first 14 bits [13:0]. Bit [13] is the polarity bit indicating whether it is positive (0x0) or negative (0x1). For an ENDPOINT\_IN transfer, data is returned in 2 bytes with the MSB first. The temperature value represented in the raw data is contained in the next 13 bits [12:0]. To obtain the temperature ADC code, the raw data should be masked (bitwise AND’ed) with 0x1FFF, and the polarity should be masked with 0x2000. The conversion from 12 bit ADC code to an actual temperature reading in degrees Celsius is shown below:

$$\text{Positive Temperature (bit 13 is 0)} = \text{ADC code} / 32$$

$$\text{Negative Temperature (bit 13 is 1)} = (\text{ADC code} - 8192) / 32$$

It is not recommended to read the temperature too frequently, especially once the temperature of the SC5412A has stabilized. The temperature sensor is a serial device located inside the RF module. Therefore, like any other serial device, reading the temperature sensor requires a sending serial clock and data commands from the processor. The process of sending clock pulses on the serial transfer line may cause unwanted spurs on the RF signal as the serial clock could potentially modulate the externally-supplied LO signal within the device.

## Reading the Device Status

**GET\_DEVICE\_STATUS (0x21)** - This register, summarized in Table 4, returns the device status information such as phase lock status of the PLL, current reference settings, etc. Data is contained in the first three bytes.

**Table 4. Description of the status data bits.**

Bit	Description
[4]	RF AMP#1 enable
[3]	RF AMP#2 enable
[2]	RF path selection
[1]	LO output enable
[0]	Device accessed

## Reading the User EEPROM

**USER\_EEPROM\_READ (0x23)** - Once data has been written to the user EEPROM, it can be retrieved by calling this register and using the process outlined in the next section for reading calibration data. The maximum address for this EEPROM is 0x7FFF. A single byte is returned.

## Reading the Calibration EEPROM

**CAL\_EEPROM\_READ (0x24)** - Reading a single byte from an address in the device EEPROM is performed by writing this register with the address for the instructWord. The data is returned as a byte. The CAL EEPROM maximum address is also 0x7FFF. Reading above this address will cause the device to retrieve data from the lower addresses. For example, addressing 0x8000 will return data stored in address location 0x0000. The calibration EEPROM map is shown in Table 5.

All calibration data, whether floats, unsigned 8-bit, unsigned 16-bit or unsigned 32-bit integers, are stored as flattened unsigned byte representation. A float is flattened to 4 unsigned bytes, so once it is read back it needs to be un-flattened back to its original type. Unsigned values containing more than a single byte are converted (un-flattened) simply by concatenation of the bytes through bit-shifting. Converting to floating point representation is slightly more involved. First, convert the 4 bytes into an unsigned 32-bit integer value, and then (in C/C++) type-cast a float pointer to the address of the value. In C/C++, the code would be `float Y = *(float *)&X`, where X has been converted earlier to an unsigned integer. An example written in C code would look something like the following:

```
byte_value[4]; // read in earlier
unsigned int uint32_value;
float float32_value;

int count = 0;
while (count < 4) {
    uint32_value = uint32_value | (byte_value[count] <<
(count*8));
    count++;
}

float32 value = *(float *)&uint32_value;
```

# CALIBRATION EEPROM MAP

Table 5. Calibration EEPROM map.

EEPROM ADDRESS (HEX)	NUMBER OF DATA POINTS	TYPE	DESCRIPTION
0	1	U32	Manufacturing information
4	1	U32	Product serial number
8	1	U32	RF module number
C	1	U32	Product manufacture date
24	1	F32	Firmware revision
28	1	F32	Hardware revision
2C	40	F32	Reserved
CF	33	U8	Startup state
F4	1	F32	Calibration temperature

# SOFTWARE API LIBRARY FUNCTIONS

SignalCore's philosophy is to provide products to our customers whose lower hardware functions are easily accessible. For experienced users who wish to use direct, low-level control of frequency and gain settings, having the ability to access the registers directly is a necessity. However, others may wish for simpler product integration using higher level function libraries and not having to program registers directly. The functions provided in the SC5412A API dynamic linked library or LabVIEW library are:

- **sc5412a\_ListResources**
- **sc5412a\_OpenDevice**
- **sc5412a\_CloseDevice**
- **sc5412a\_RegWrite**
- **sc5412a\_RegRead**
- **sc5412a\_InitDevice**
- **sc5412a\_SetFrequency**
- **sc5412a\_SetRfGain**
- **sc5412a\_SetRfAmplifier**
- **sc5412a\_SetRfPath**
- **sc5412a\_SetLoOut**
- **sc5412a\_SetRfAttenuation**
- **sc5412a\_SetRfFilter**
- **sc5412a\_SetLoFilter**
- **sc5412a\_SetIfGainDac**
- **sc5412a\_SetVcomDac**
- **sc5412a\_SetDcOffsetDac**
- **sc5412a\_SetLinearityDac**
- **sc5412a\_WriteUserEeprom**
- **sc5412a\_StoreCurrentState**
- **sc5412a\_GetDeviceInfo**
- **sc5412a\_GetDeviceStatus**
- **sc5412a\_GetTemperature**
- **sc5412a\_ReadCalEeprom**
- **sc5412a\_ReadUserEeprom**

Each of these functions is described in more detail on the following pages. Example code written in C/C++ is located in the *CD:\Win\Driver\src* directory to show how these functions are called and used. First, for C/C++, we define the constants and types which are contained in the C header file, *sc5412a.h*. These constants and types are useful not only as an include for developing user applications using the SC5412A API, but also for writing device drivers independent of those provided by SignalCore.

## Constants Definitions

```
// Parameters for storing data in the onboard EEPROM
#define MAXDEVICES          50    // bytes
#define MAXDESCRIPTORSIZE   25    // bytes
#define CALEEPROMSIZE       32768 // bytes
#define USEREEPROMSIZE      32768 // bytes

// Define labels
#define CH_I                0x00
#define CH_Q                0x01
#define RF_ATTEN1           0x00
#define RF_ATTEN2           0x01
#define RF_ATTEN3           0x02
#define RF_AMP1             0x00
#define RF_AMP2             0x01

// Define error codes
#define RESERVEDERROR       -1
#define NOTCORRECTDEVICE    -2
#define INPUTNULL           -3
#define COMMERROR           -4
#define INPUTNOTALLOC       -5
#define EEPROMOUTBOUNDS     -6
#define INVALIDARGUMENT     -7
#define INPUTOUTRANGE       -8
#define NOREFWHENLOCK       -9
#define NORESOURCEFOUND     -10
#define INVALIDCOMMAND      -11

// Define device registers
#define INITIALIZE           0x01  // initialize the device
#define SET_SYSTEM_ACTIVE   0x02  // set the device "active" LED
#define RF_FREQUENCY        0x10  // set the frequency
#define RF_AMPLIFIER        0x12  // enable amplifiers
#define RF_ATTENUATION      0x13  // set attenuation for digital step attenuators
#define RF_PATH             0x14  // select the RF path
#define RF_FILTER_SELECT    0x15  // manually select the RF filter
#define LO_FILTER_SELECT    0x16  // manually select the LO filter
#define LO_OUT_ENABLE       0x17  // enable LO output
#define DC_OFFSET_DAC       0x1A  // set the DC offset
#define LINEARITY_DAC       0x1B  // set the linearity DAC (0 to 0xFFF)
#define STORE_STARTUP_STATE 0x1D  // store the current state as default
#define USER_EEPROM_WRITE  0x1F  // write a byte to the user EEPROM
#define GET_DEVICE_STATUS   0x20  // read the device status
#define GET_TEMPERATURE     0x21  // get the internal temperature of the device
#define USER_EEPROM_READ   0x23  // read a byte from the USER EEPROM
#define CAL_EEPROM_READ     0x24  // read a byte from the calibration EEPROM
```

```
typedef struct
{
    unsigned int productSerialNumber;
    unsigned int rfModuleSerialNumber;
    float firmwareRevision;
    float hardwareRevision;
    unsigned int calDate; // year, month, day, hour:&(0xFF000000,0xFF0000,0xFF00,0xFF)
    unsigned int manDate; // year, month, day, hour:&(0xFF000000,0xFF0000,0xFF00,0xFF)
} deviceInfo_t;

typedef struct
{
    bool rfAmpEnable;
    bool rfPath;
    bool loEnable;
    bool deviceAccess;
} deviceStatus_t;
```

The functions listed below are found in the *sc5412a.dll* dynamic linked library for the Windows™ operating system. These functions are also provided in the LabVIEW library, *sc5412a.llb*. The LabVIEW functions contain context-sensitive help (Ctrl-H) to assist with understanding the input and output parameters.

<i>Function:</i>	<b>sc5412a_OpenDevice</b>
<i>Definition:</i>	<b>int</b> sc5412a_OpenDevice( <b>char</b> *visaResource, <b>unsigned int</b> *deviceHandle)
<i>Input:</i>	<b>char</b> *visaResource (Resource ID)
<i>Output:</i>	<b>unsigned int</b> *deviceHandle (unsigned integer number for the deviceHandle)
<i>Description:</i>	<b>sc5412a_OpenDevice</b> opens the device and turns the front panel “active” LED on if it is successful. It returns a handle to the device for other function calls.



**Function:** `sc5412a_CloseDevice`

**Definition:** `int sc5412a_CloseDevice(unsigned int deviceHandle)`

**Input:** `unsigned int deviceHandle` (handle to the device to be closed)

**Description:** `sc5412a_CloseDevice` closes the device associated with the device handle and turns off the “active” LED on the front panel if it is successful.

**Example:** Code to exercise the functions that open and close the device:

```
// Declaring
char **visaResource = (char**)malloc(sizeof(char*)*10); // 10 devices
unsigned int deviceHandle;
int devicesFound;
int i,status;
// Allocate memory for 10 device with 20 characters to hold ID
for(i = 0; i< 10; i++)
    visaResource[i] = (char*)malloc(sizeof(char)*20);

status = sc5412a_ListResources(visaResource, &devicesFound);
printf("There are %d SignalCore PXI devices found. \n", devicesFound);

if(devicesFound == 0)
//If no device are found deallocate memory and end the program
{
    for(i = 0; i<10;i++)
        free(visaResource[i]);
    free(visaResource);
    printf("No sc5412a devices detected. Press enter to continue.\n");
    return 1;
}

/** sc5412a_OpenDevice, open device 0
status = sc5412a_OpenDevice(visaResource[0], &deviceHandle);

// Free memory
for(i = 0; i<10;i++)
    free(visaResource[i]);
free(visaResource);
//
// Do something with the device
//
//Close the device
int status = sc5412a_CloseDevice(deviceHandle);
```

**Function:** `sc5412a_RegWrite`

**Definition:** `int sc5412a_RegWrite(unsigned int deviceHandle, unsigned char commandByte, unsigned long long int instructWord)`

**Input:** `unsigned int deviceHandle` (handle to the opened device)  
`unsigned char commandByte` (register address)  
`unsigned long long int instructWord` (data for the register)

**Description:** `sc5412a_RegWrite` writes the instructWord data to the register specified by the commandByte. See the register map on Table 2 for more information.

**Example:** To set the frequency to 2 GHz:

```
int status = sc5412a_RegWrite(devHandle, RF_FREQUENCY, 2000000000); // set frequency
```

**Function:** **sc5412a\_RegRead**

**Definition:** **int** sc5412a\_RegRead(**unsigned int** deviceHandle, **unsigned char** commandByte, **unsigned long long int** instructWord, **unsigned int** \*receivedWord)

**Input:** **unsigned int** deviceHandle (handle to the opened device)  
**unsigned char** commandByte (address byte of the register to write to)  
**unsigned long long int** instructWord (data for the register)  
**unsigned int** \*receivedWord (data to be received)

**Description:** **sc5412a\_RegRead** reads the data requested by the instructWord data to the register specified by the commandByte. See Table 3 for details on the registers.

**Example:** To read the status of the device:

```
unsigned int deviceStatus;

int status = sc5412a_RegRead(devHandle,
GET_DEVICE_STATUS, 0x00, &deviceStatus);
```

**Function:** **sc5412a\_InitDevice**

**Definition:** **int** sc5412a\_InitDevice(**unsigned int** deviceHandle, **bool** mode)

**Input:** **unsigned int** deviceHandle (handle to the opened device)  
**bool** mode (set the mode of initialization)

**Description:** **sc5412a\_InitDevice** initializes (resets) the device. Mode = 0 resets the device to the default power up state. Mode = 1 resets the device but leaves it in its current state.

**Function:** **sc5412a\_SetFrequency**

**Definition:** **int** sc5412a\_SetFrequency (**unsigned int** deviceHandle, **unsigned long long int** frequency)

**Input:** **unsigned int** deviceHandle (handle to the opened device)  
**unsigned long long int** frequency (frequency in Hz)

**Description:** **sc5412a\_SetFrequency** sets the RF frequency so the device can automatically use the information to set the optimal filters in the LO and RF filter banks.

**Function:** **sc5412a\_SetRfAmplifier**

**Definition:** **int** sc5412a\_SetRfAmplifier(**unsigned int** devHandle, **bool** mode)

**Input:** **unsigned int** deviceHandle (handle to the opened device)  
**bool** mode (disable/enable)

**Description:** **sc5412a\_SetRfAmplifier** enables or disables the RF amplifier.

**Function:** **sc5412a\_SetRfPath**

**Definition:** **int** sc5412a\_SetRfPath(**unsigned int** deviceHandle, **bool** mode)

**Input:** **unsigned int** deviceHandle (handle to the opened device)  
**bool** mode (0=main path, 1=aux path)

**Description:** **sc5412a\_SetRfPath** selects the RF input port.

**Function:** `sc5412a_SetLoOut`

**Definition:** `int sc5412a_SetLoOut(unsigned int deviceHandle, bool mode)`

**Input:** `unsigned int` deviceHandle (handle to the opened device)  
`bool` mode (0=disable, 1= enable)

**Description:** `sc5412a_SetLoOut` enables the LO output port. The LO input signal is replicated and made available to the “LO out” port.

**Function:** `sc5412a_SetRfAttenuation`

**Definition:** `int sc5412a_SetRfAttenuation(unsigned int deviceHandle, unsigned char attenuator, unsigned char atten)`

**Input:** `unsigned int` deviceHandle (handle to the opened device)  
`unsigned char` attenuator (selects the attenuator to program)  
`unsigned char` atten (attenuation value (0-31 dB))

**Description:** `sc5412a_SetRfAttenuation` sets the attenuation level of the RF attenuators.

**Function:** `sc5412a_SetRfFilter`

**Definition:** `int sc5412a_SetRfFilter(unsigned int deviceHandle, unsigned char filter)`

**Input:** `unsigned int` deviceHandle (handle to the opened device)  
`unsigned char` filter (select the appropriate filter number 0-8)

**Description:** `sc5412a_SetRfFilter` selects the active filter in the RF filter bank.

**Function:** `sc5412a_SetLoFilter`

**Definition:** `int sc5412a_SetLoFilter(unsigned int deviceHandle, unsigned char filter)`

**Input:** `unsigned int` deviceHandle (handle to the opened device)  
`unsigned char` filter (select the appropriate filter number 0-8)

**Description:** `sc5412a_SetLoFilter` selects the active filter in the LO filter bank.

**Function:** `sc5412a_SetDcOffsetDac`

**Definition:** `int sc5412a_SetDcOffsetDac(unsigned int deviceHandle, unsigned char channel, unsigned short dacValue)`

**Input:** `unsigned int` deviceHandle (handle to the opened device)  
`unsigned char` channel (select the I or Q channel)  
`unsigned short` dacValue (DAC value range 0 - 16383)

**Description:** `sc5412a_SetDcOffsetDac` sets the DC offset voltage at the IQ modulator core. Voltage adjust is approximately +/- 0.05 V. The default factory setting is 8038.

**Function:** **sc5412a\_SetLinearityDac**

**Definition:** **int** sc5412a\_SetLinearityDac(**unsigned int** deviceHandle, **unsigned char** channel, **unsigned short** dacValue)

**Input:** **unsigned int** deviceHandle (handle to the opened device)  
**unsigned char** channel (select the I or Q channel)  
**unsigned short** dacValue (DAC value range 0 - 16383)

**Description:** **sc5412a\_SetLinearityDac** sets the bias point of the IQ modulator, which affects the linearity of the device. A DAC value of 3935 is recommended and is also the default factory setting.

**Function:** **sc5412a\_WriteUserEeprom**

**Definition:** **int** sc5412a\_WriteUserEeprom(**unsigned int** deviceHandle, **unsigned int** memAdd, **unsigned char** byteData)

**Input:** **unsigned int** deviceHandle (handle to the opened device)  
**unsigned int** memAdd (memory address to write to)  
**unsigned char** byteData (byte to be written to the address)

**Description:** **sc5412a\_WriteUserEeprom** writes one byte of data to the memory address specified.

**Function:** **sc5412a\_StoreCurrentState**

**Definition:** **int** sc5412a\_StoreCurrentState(**unsigned int** deviceHandle)

**Input:** **unsigned int** deviceHandle (handle to the opened device)

**Description:** **sc5412a\_StoreCurrentState** stores the current state of the device as the default power-up state.

**Function:** **sc5412a\_GetDeviceInfo**

**Definition:** **int** sc5412a\_GetDeviceInfo(**unsigned int** deviceHandle, **deviceInfo\_t** \*devInfo)

**Input:** **unsigned int** deviceHandle (handle to the opened device)

**Output:** **deviceInfo\_t** \*devInfo (device info struct)

**Description:** **sc5412a\_GetDeviceInfo** retrieves device information such as serial number, calibration date, revision, etc.

**Function:** **sc5412a\_GetDeviceStatus**

**Definition:** **int** sc5412a\_GetDeviceStatus(**unsigned int** deviceHandle, **deviceStatus\_t** deviceStatus)

**Input:** **unsigned int** deviceHandle (handle to the opened device)

**Output:** **deviceStatus\_t** \*deviceStatus (deviceStatus struct)

**Description:** **sc5412a\_GetDeviceStatus** retrieves the status of the device such as phase lock status and current device settings.

**Example:** Code showing how to use this function:

```
deviceStatus_t *devStatus;
devStatus = (deviceStatus_t*)malloc(sizeof(deviceStatus_t));

int status = sc5412a_GetDeviceStatus(devHandle, devStatus);

if(devStatus->loEnable)
printf("The LO Output Port is Enabled \n");
else
printf("The LO Output Port is disabled \n");

free(deviceStatus);
```

**Function:** **sc5412a\_GetTemperature**

**Definition:** **int** sc5412a\_GetTemperature(**unsigned int** deviceHandle, **float** \*temperature)

**Input:** **unsigned int** deviceHandle (handle to the opened device)

**Output:** **float** \*temperature (temperature in degrees Celsius)

**Description:** **sc5412a\_GetTemperature** retrieves the internal temperature of the device.

**Function:** **sc5412a\_ReadCalEeprom**

**Definition:** **int** sc5412a\_ReadCalEeprom(**unsigned int** deviceHandle, **unsigned int** memAdd, **unsigned char** \*byteData)

**Input:** **unsigned int** deviceHandle (handle to the opened device)  
**unsigned int** memAdd (EEPROM memory address)

**Output:** **unsigned char** \*byteData (the read back byte data)

**Description:** **sc5412a\_ReadUserEeprom** reads back a byte from a specific memory address of the calibration EEPROM.

**Function:** **sc5412a\_ReadUserEeprom**

**Definition:** **int** sc5412a\_ReadUserEeprom(**unsigned int** deviceHandle, **unsigned int** memAdd, **unsigned char** \*byteData)

**Input:** **unsigned int** deviceHandle (handle to the opened device)  
**unsigned int** memAdd (EEPROM memory address)

**Output:** **unsigned char** \*byteData (the read back byte data)

**Description:** **sc5412a\_ReadUserEeprom** reads back a byte from a specific memory address of the user EEPROM.

## CALIBRATION & MAINTENANCE

The SC5412A does not receive a factory calibration. The SC5412A is sold as a component and users will need to perform amplitude and IQ correction as part of their system, which may minimally include a digitizer, LO source, and the SC5412A. Should users require SignalCore to perform any calibration, please contact SignalCore support directly.