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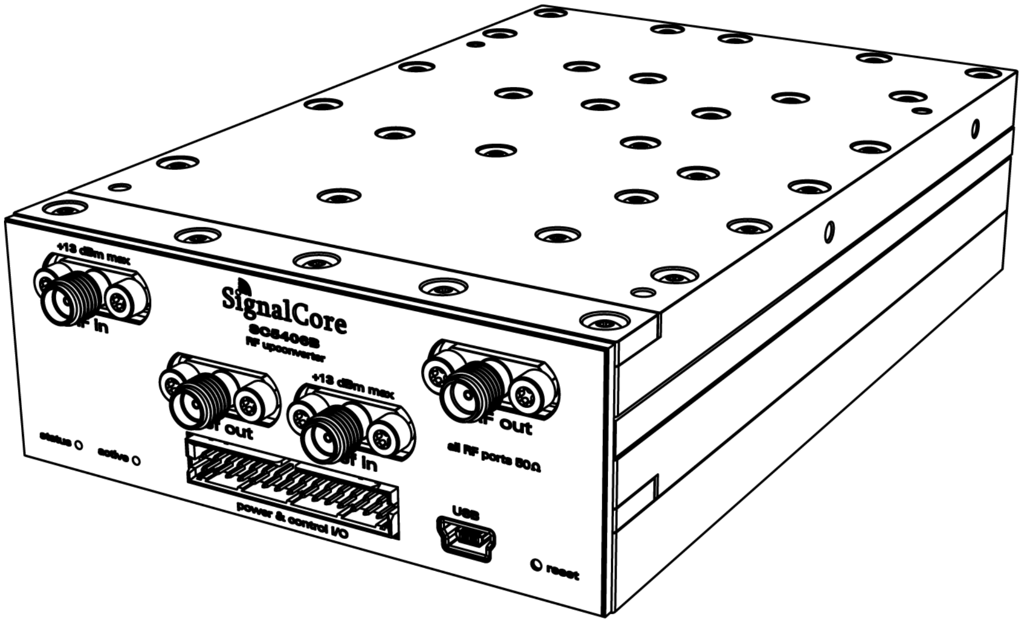

SC5406B
1 MHz to 3.9 GHz RF Upconverter
Core Module with USB and RS232/SPI

Operating & Programming Manual

support@signalcore.com

Contents

IMPORTANT INFORMATION

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組成名稱 **Model Name**	鉛 **Lead (Pb)**	汞 **Mercury (Hg)**	镉 **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)**
SC5406B USB/RS-232/SPI	✓	✓	✓	✓	✓	✓

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 **X** 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.

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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

In addition to this User Guide, verify that your SC5406B kit contains the following items:

Quantity	Item
1	SC5406B USB RF Upconverter
1	USB flash drive with installation software

Setting Up and Configuring the SC5406B

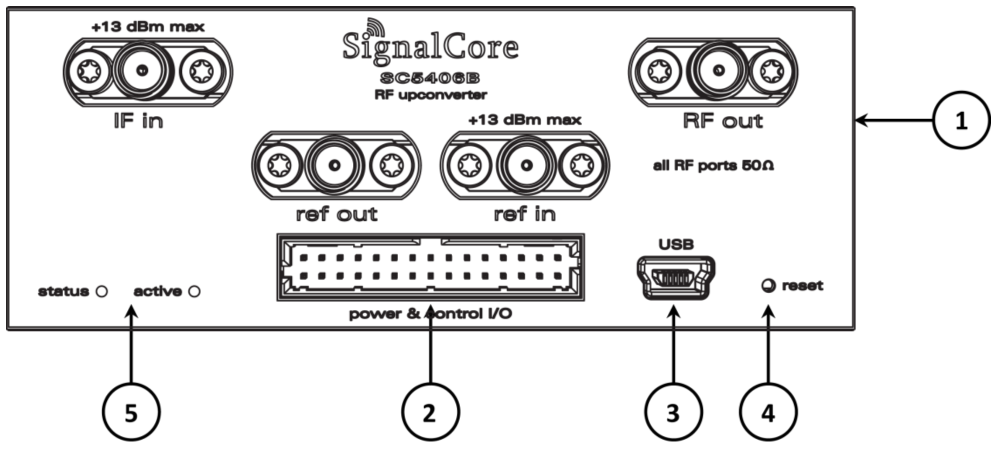


Figure 1 Front view of the SC5406B connectors

The SC5406B is a core module-based RF upconverter with all user I/O located on the front face of the module as shown in Figure 1. Each location is discussed in further detail below.

1 Signal Connections

All signal connections (ports) to the SC5406B are SMA-type. Exercise caution when fastening cables to the SMA connections. Over-tightening any connection can cause permanent damage to the device.

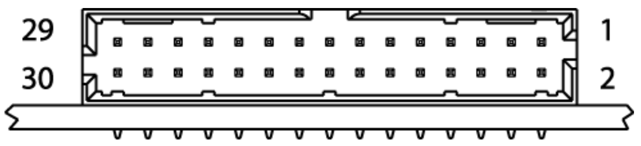
The condition of your system's signal connections can significantly affect measurement accuracy and repeatability. Improperly mated connections or dirty, damaged or worn connectors can degrade measurement performance. Clean out any loose, dry debris from connectors with clean, low-pressure air (available 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 with 3 in-lb min to 5 in-lb max (56 N-cm max)

RF OUT	This port accepts input signals from 1 MHz to 3.9 GHz to the upconverter. The nominal output impedance is 50 Ω.
IF IN	This port outputs the 70 MHz IF signal from the downconverter. The nominal input impedance is 50 Ω. Maximum input power is +23 dBm
REF IN	This port accepts an external 10 MHz reference signal, allowing an external source to synchronize the internal reference clock. This port is AC-coupled with a nominal input impedance of 50 Ω. Maximum input power is +13 dBm.
REF OUT	This port outputs the internal 10 MHz or 100 MHz reference clock. If the internal reference clock is synchronized to an external reference clock through the 10 MHz "**ref in**" port, this output port will also be synchronized. This port is AC-coupled with a nominal output impedance of 50 Ω.

2 Communication and Supply Connection

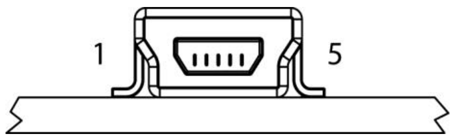


Power and communication and to the device is provided through a Molex **Milli-Grid**^{M} 2.00mm, 30 position, male header connector, whose part number is 87833-3020. A suggested receptacle female connector is the crimp terminal type 51110-3051 or ribbon type 87568-3093 from Molex. The pin definitions of this I/O connector are listed Table 1 below.

Table 1 Communication IO connector pin definitions

PIN #		21	Device Active
1,3	12V Supply rail	22	Device Status
2,4,10,16, 20,24,28	GND	23	Baudrate/Spi Mode
5,6,7,8,9, 15,18,21	Reserved, do not connect	25	CTS/$\overline{\text{CS}}$. This pin is CTS for RS232 or device select for SPI
11	USB+	26	SPI Clock
13	USB-	27	TX/MISO. This pin is TX for RS232 or MISO for SPI
14	USB_VBUS	29	RX/MOSI. This pin is RX for RS232 or MOSI for SPI
17	Reserved, pull high to 3.3V or DNC	30	RTS/SRDY. This pin is RTS for RS232 or serial ready for SPI
19	$\overline{\text{Reset}}$, logic 0 to reset device		

3 Mini-USB Connection



Pin	USB Function	Description
1	VBUS	Vcc (+5 Volts)
2	D -	Serial data
3	D +	Serial data
4	ID	Not used
5	GND	Device ground (also tied to connector shell)

The SC5406B uses a mini-USB Type B connector for USB communication with the device using the standard USB 2.0 protocol (full speed) found on most host computers. The pinout of this connector, viewed from the board edge, is shown in the table above.

4 Reset Button (Pin Hole)

Behind this pin hole is the reset button. Using a pin and lightly depressing this momentary-action push button switch will cause a hard reset to the device, putting it back to its default settings. All user settings will be lost. System reset capability can also be accessed through the communication header connector.

5 Indicator LEDs

The SC5406B provides visual indication of important modes. There are two redundant pairs of LED indicators on the device, two to the left of the micro-D connector and two on the opposite side of the module. The LED closest to the micro-D connector indicates STATUS. The LED to the left of the STATUS LED indicates ACTIVE. The pair of LEDs on the opposite side of the module are oriented the same way. Their behavior under different operating conditions is shown in the table below.

SC5406B - Theory of Operation

Overview

The SC5406B operates on the principle of heterodyning, a process whereby an incoming RF/IF signal is mixed with specific oscillator frequencies in stages, producing both sum and difference frequency products. At each stage the summed frequency product (or image) is removed through low-pass filtering, allowing the difference frequency product to continue through the signal path. Repeating this process several times using carefully selected local oscillators (LOs) and well-designed band-pass filtering, the original signal is translated, or "up-converted" in frequency from low IF to higher RF. Using a tunable LO as the final mixing oscillator allows the upconverter to translate a fixed IF input frequency to a broad range of RF frequencies.

The SC5406B is a three-stage superheterodyne upconverter that delivers superior image rejection over single stage conversion and offers both high signal-to-noise dynamic range and high spurious-free dynamic range. The RF input ranges from 1 MHz to 3.9 GHz, and the IF output is fixed at 70 MHz. When the input frequency is lower than the intermediate frequency, the device technically behaves as an upconverter. The SC5406B up-converts when the input frequency ranges from 1 MHz to 70 MHz. The converted spectrum polarity may be inverted or non-inverted by programming the device accordingly.

Fundamentally, each conversion stage consists of a frequency mixer that mixes two input signals and producing a wanted third. The *wanted* third component is selected, via a frequency filter, among other signals generated in the mixing process. The three primary components of the signals in each conversion mixer are commonly known as the local oscillator (LO), radio frequency (RF), and the intermediate frequency (IF) as shown in Figure 3.

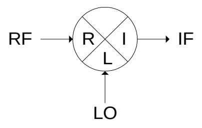


Figure 2. Frequency conversion stage using a mixer.

Where R represents the RF component, L represents the LO component, and I represents the IF component. The LO is resident in the upconverter and is either frequency tunable or fixed in frequency depending on the stage.

The final IF stage (IF1) is a down-conversion stage – the RF signals are down converted from this IF and it is higher than the highest output RF frequency specified. The second and third stages successively convert the 70 MHz IF up to the final IF1, which is at 4675 MHz. Having a high final IF allows the upconverter to suppress internal IF frequencies from appearing at the RF output port.

The SC5406B exhibits very low phase noise of -107 dBc/Hz at 10 kHz offset on a 1 GHz RF carrier with a typical noise floor of -150 dBm/Hz. The noise floor can be further reduced below -165 dBm/Hz by

enabling the internal preamplifier. With gain control between -60 dB to +50 dB, a measurement signal-to-noise dynamic range greater than 180 dB is achievable. Using high reverse isolation devices and sharp cutoff filters, LO leakages and other spurious contents at the input connectors are well below -120 dBm. Inter-stage LO leakages are also kept very low through sophisticated circuit and shielding design to ensure that spurious in-band signals remain less than -80 dBc. The excellent spurious free dynamic range is achieved using low noise linear amplifiers, low loss mixers, and high performance solid state attenuators. State-of-the-art solid state attenuators have improved linearity over earlier designs. Their attenuation level changes settle under a microsecond, and for applications that involve frequent range changing, they offer a vastly superior lifetime over mechanical attenuators.

The real-time bandwidth is shaped primarily by the final 70 MHz IF surface acoustic wave (SAW) filter. The final IF filter has two programmatically selectable paths, switching either between two filter paths with different bandwidths or between one filter and one bypass (no filter) path. Filters in the first and second IF stages are not as selective as the final IF filter but they ensure good isolation between local oscillators (LO). Keeping each LO isolated helps to suppress unwanted spurious signals.

Frequency accuracy is provided by an onboard 10 MHz temperature compensated crystal oscillator (TCXO) which can be phase-locked to an external reference source if required, and it is recommended to do so in applications that may require a more stable and accurate base reference.

Signal Path Description

Figure 3 depicts an overall block diagram of the SC5406B. Starting from the upper right, the IF3 input of the SC5406B is AC coupled, followed by a switch that either selects the IF port as the input of the internal signal generator. This switch is by default set to switch in the IF port, but it will switch to the signal generator path when the device enables internal signal generation. When internal signal generation is not selected, the signal generator is powered down to prevent possible leakages into the IF path. It is strongly recommended that the IF source be disconnected when internal generation is selected to prevent external leakages. Furthermore, the internal switch does not terminate the external port to a load, and this could possibly cause unwanted signal reflections.

Following the switches are two digital step attenuators that are cascaded together to form a 60 dB attenuation range with 1 dB step increment. These attenuators control the signal level to the IF2 mixer, determining the linearity and noise dynamic ranges of the device. For better linearity the input levels should be lower, and to improve the signal-to-noise ratio (SNR) the levels should be higher. For a compromise, the level at the mixer should be about -16 dBm to -18 dBm, so for a 0 dBm IF input the IF3 attenuator(s) should be set to 16 – 18 dB attenuation respectively.

After the attenuators, the IF3 filter shapes the bandwidth of the device. It is the most selective of all the IF stages. This filter has significant loss so a linear LNA is required to boost up the signal prior to passing it through the filter. Following the filter is the IF2 mixer, driven by local oscillator LO3. This LO frequency switches between 745 MHz and 605 MHz to convert the 70 MHz IF to 675 MHz, which the center frequency of IF2. The default LO2 frequency is 745 MHz, which preserves the spectral polarity of the IF at the RF. Selecting 605 MHz will invert the spectral content of the RF with respect to the IF. This could be useful for some systems, especially those where the IF is digitally sampled on even Nyquist zones and is spectrally inverted.

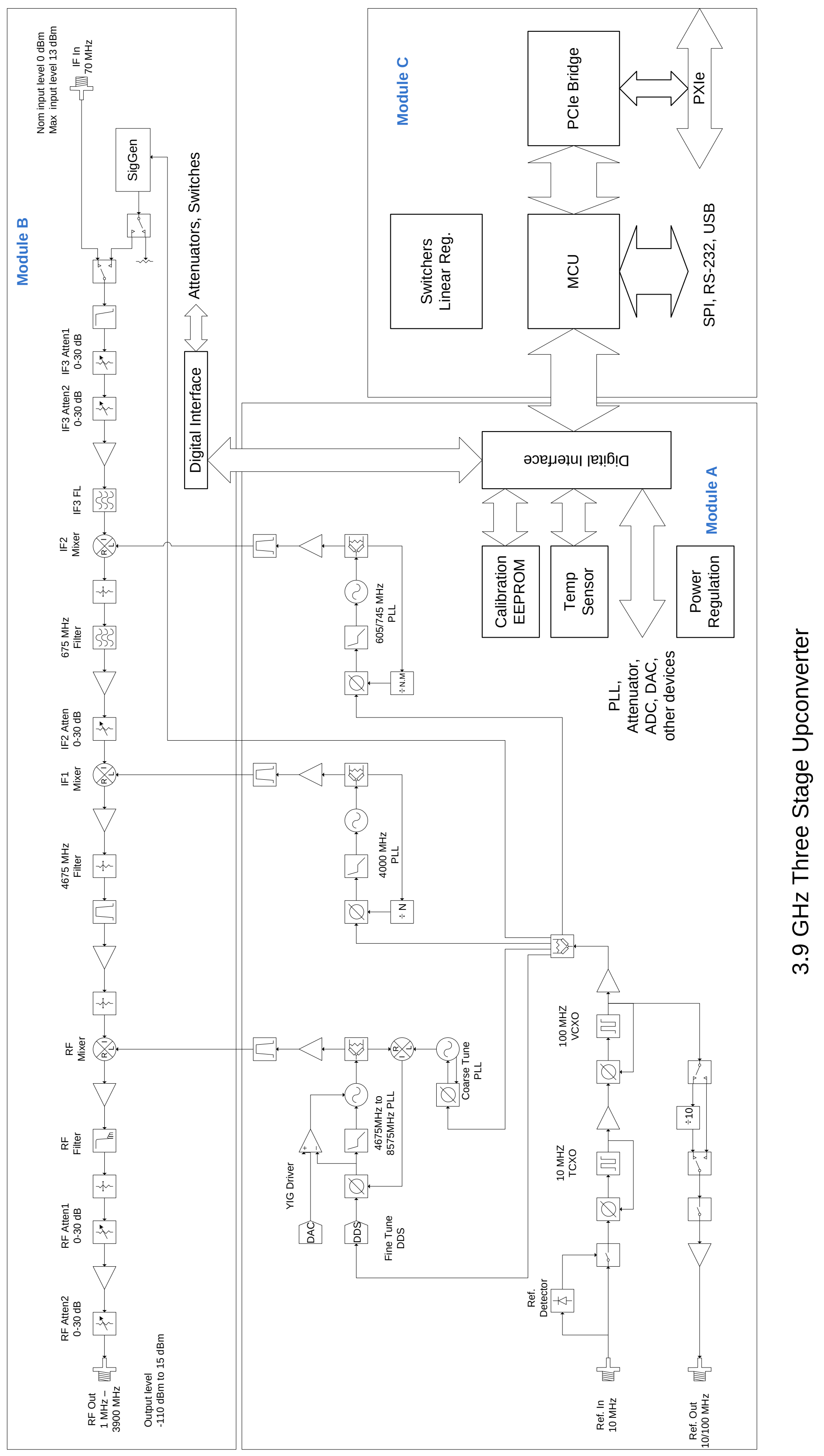


Figure 3. Block diagram of SignalCore 3.9 GHz upconverters.

The second IF (IF2) is filtered to remove LO leakages and images and well conditioned by the use of linear LNA to keep the signal levels at an optimum so that SNR is not lost. There is another digital step attenuator in this IF to balance device to device gain variation. It is also used when large amount of attenuation is required by the device to produce extremely low level signals such as -100 dBm. IF2 is mixed with LO2 at the IF1 mixer to obtain the IF1 frequency of 4675 MHz, which is in turn "downconverted" by LO1 and the RF mixer to obtain the RF frequency range of 1 MHz to 3.9 GHz.

The RF mixer, due to its non ideal nature, leaks IF1 and LO1 signals through to the RF port. So at the RF port of the mixer, all components as well as their harmonics are present. Although IF1 and LO1 signals are relative low compared to the RF component and they are well filtered at the output port, their harmonics could intermodulate with each other and with the RF to produce unwanted spurious products inside the RF band. It is important to keep IF1 at the RF mixer low enough but not too low, so that these spurious products are kept to at least -65 dBc below the RF level. The API functio**n** **sc5406B_CalcAutoAttenuation** has an input parameter call "perfSelect" (short for performance selection) that computes the attenuation requirement for all the attenuators to meet the performance selected. For best signal-to-noise ratio the IF at the RF mixer is high, causing larger in-band spurs but greatly improves the close-in signal to noise power.

Following the RF mixer is an elliptic low-pass filter to suppress both IF1 and LO1 leakages from exiting at high levels out of the RF port. The final two RF attenuators are used to control the RF output levels.

Local Oscillator Description

The signal path circuit is separate from the local oscillator generation circuits to maximize isolation between the RF/IF signals and the local oscillators, except for the LO injection paths into the mixers. Although the both circuits reside within the same module, well-designed shielding and circuit layouts ensures leakages between them are keep to a minimum.

The first local oscillator, LO1, is an agile, tunable phase-lock synthesizer. The synthesizer tunes from 4675 MHz to 8575 MHz, a tuning range of 3900 MHz. The minimum step size is 1 Hz, and is accomplished through a multiple phase-locked loop and DDS hybrid architecture. The use of a hybrid tuning architecture is important for improved phase noise and improved close-in phase spurious responses. Operating LO1 at such high frequencies internally to obtain a 1 MHz to 3.9 GHz RF range requires that the phase noise at these frequencies is sufficiently low so that the converted RF signal phase noise is not degraded significantly. For example, to produce a 100 MHz RF signal, LO1 is tuned to 4775 MHz, which is about 48 times higher in frequency than the output frequency. To further ensure phase noise remains low farther away from the carrier, especially at 100 kHz and 1 MHz offsets, a YIG oscillator is used. It important to realize that having a phase noise "plateau" out to several tens of MHz, which is a very common phenomenon with VCO-based synthesizers, is not acceptable for many applications.

Another reason for a hybrid tuning architecture is to reduce the phase spurs associated with phase-locked loops. A simple fractional PLL may provide resolution to 1 Hz, but it cannot provide 1 Hz frequency tuning steps with low fractional phase spurs. By using two DDS circuits to provide the 1 Hz tuning steps and mathematically ensuring that DDS-generated spurs are suppressed within the architecture, LO1 is made to fine tune to exact frequencies, that is, the frequency synthesized is an exact integer multiple or division of the reference signal.

The second local oscillator, LO2, is fixed at 4.0 GHz, synthesized using an integer PLL and a fixed narrow tune VCO with very low phase noise. The typical raw phase noise of the second stage oscillator is less than -150 dBc/Hz @ 1 MHz offset. LO2 phase noise contribution to the overall phase noise of the device is less than 1 dB. LO1 dominates the phase noise of the device.

The third local oscillator, LO3, is synthesized using a fractional PLL and has phase noise lower than both LO1 and LO2, and is switchable between two frequencies: 605 MHz and 745 MHz, the later frequency being the default. Both of these frequencies will set the output IF center frequency at 70 MHz. However, at the default frequency the final 70 MHz IF output spectral polarity is the same as that of the input RF, whereas the 605 MHz frequency will create an inverted IF spectrum. If LO3 is set to 605 MHz by calling the **sc5406B_SetIfInversion** function or register, the IF output spectral content will be inverted with respect to the input RF spectrum. See Figure 4 for a graphical representation of this process.

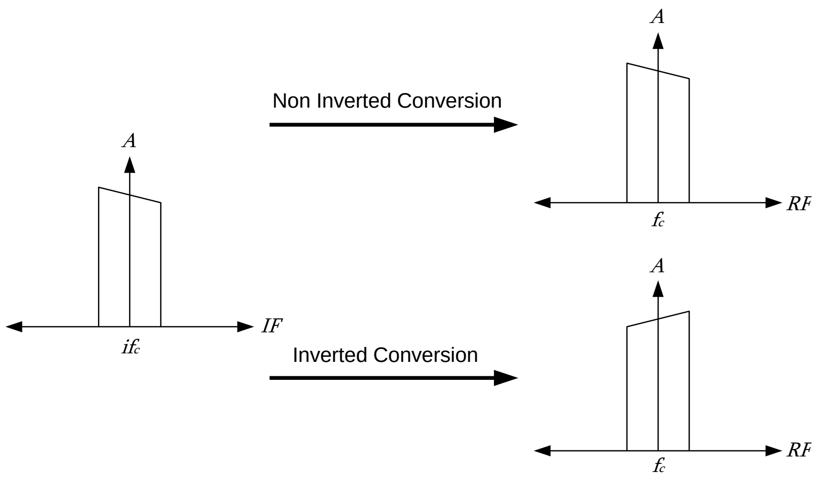


Figure 4. Graphical representation of RF inversion.

All local oscillators are phase-locked to an internal 100 MHz voltage controlled crystal oscillator (VCXO), which sets their close-in phase noise performance. The 100 MHz VCXO is in turn phase-locked to the internal 10 MHz TCXO for frequency accuracy and stability. For better frequency accuracy and stability than the TCXO onboard the SC5406B, or for frequency synchronization, the user can programmatically set the device to phase lock the TCXO to an external 10 MHz reference source by programming the REFERENCE_SETTING register. It is important to note that the TCXO will only attempt to lock to an external source if one is detected. A typical external reference source minimum level of -10 dBm is required for detection to be successful. A reference source level of 0 dBm to +3 dBm is recommended for normal operation. The reference source is fed into the device through the **"ref in"** port. The device can also export a copy of its internal reference through the **"ref out"** port. The output reference frequency is selectable for either 10 MHz or 100 MHz output. By default, routing of the reference signal to the "**ref out**" port is disabled. It can be enabled by programming the REFERENCE_SETTING register. This reference frequency is sourced from the internal 100 MHz OCXO, and the default output selection is 10 MHz, which is divided down from the 100 MHz VCXO. The output reference level is typically +3 dBm.

Frequency Tuning Modes

Tuning of SC5406B superheterodyne upconverter is accomplished through the tuning of LO1. LO1 has two sets of control parameters that can be explored to optimize the device for any particular application. The first set of parameters, TUNE SPEED, set the tuning and phase lock time as the frequency is changed. TUNE SPEED consists of two modes - Fast Tune mode and the Normal mode; both of these modes directly affect the way the YIG oscillator is configured. The Fast Tune mode deactivates a noise suppression capacitor across the tuning coil of the YIG oscillator, and doing so increases the rate of current flow through the coil, correspondingly increasing the rate of frequency change. In Normal mode the capacitor is activated, slowing down the rate of frequency change. The advantage of activating the capacitor is that it shunts the noise developed across the coil, decreasing close-in phase noise. Refer to Appendix A for specifications regarding tuning speed.

The other set of control parameters, FINE TUNE, sets the tuning resolution of the device. There are three modes: 1 MHz, 25 kHz, and 1 Hz tuning step sizes. The first two modes use only fractional phase detectors to tune the frequency of the LO1 synthesizer, while the third mode enables the DDS to provide 1 Hz resolution. The PLL-only modes (1 MHz and 25 kHz) provide the ability to realize exact frequencies with tuning as fine as 25 kHz. Use of these modes offers several advantages - lower phase spurs and less computational burden to set a new frequency. These modes have the lowest phase spurious signals, below the levels published in the product specification. The DDS mode also tunes to exact frequencies, however it requires many more computing cycles and additional register-level writes in order to set a new frequency. Comparing times, the device requires up to 175 microseconds to compute and change to a new frequency in PLL only modes, but requires up to 350 microseconds in the DDS tuning mode. At first glance it may seem that these differences would directly impact frequency tuning times. However, tuning times are predominantly set by the physical parameters of the YIG oscillator. Computation and register writes typically account for less than 25% of the total tune time of a 10 MHz step change in frequency.

It is important to note that although the synthesized frequencies are exact frequencies, there are observable random phase drifts in the upconverted signals. These drifts are due to PLL non-idealities rather than a frequency error in the DDS tuning circuit. Having exact frequency synthesis is important for many applications. Published phase noise and spurs specifications are based on the 1 Hz (DDS) mode.

Setting the SC5406B to Achieve Best Dynamic Range

The SC5406B is designed with a focus on having a high dynamic range, not just low in noise or having high output compression points. It is designed as a receiver for signal analyzers, which require that it handle larger signals well. The design ensures the SFDR dynamic range specification is met when the IF signal is at 0 dBm, 18 dB of IF3 attenuation, and the RF level is at 0 dBm.

For applications where the SNR must be maximized, such as an optimal sine tone, little to no IF3 attenuation should be applied, setting most of the attenuation in the RF attenuators. The IF2 attenuator should be adjusted to lower in-band intermodulation spurs.

The SC5406B is designed for a nominal input IF level of 0 dBm. Depending on the application, the user will need to set the appropriate gain of the device (via attenuation), and hence the output level, to suit the particular application. For broadband signals, where the absolute noise power is relatively high, the upconverter should be adjusted for improvement in the SNR; that is, decrease IF3 attenuation and increase RF attenuation as necessary to adjust for the desired output level. The optimal setting occurs when the total in-band noise power is at the same level as the IMD products.

For applications that require better linearity to improve close-in intermodulated products, the IF3 attenuation should be increased. The user should adjust these IF attenuators carefully so that the noise does not dominate.

SignalCore provides a simulation tool that mimics the behavior of the SC5406B. The user may run the simulator to get an understanding of what the parameters need to be set on the upconverter to achieve certain performance. Additionally, the function **sc5406B_CalcAutoAttenuation** helps the user obtain the necessary attenuator parameters to setup the device for the best compromise of linearity and noise performance for a given set of input and output parameters.

Operating the SC5406B Outside Normal Range

The SC5406B is capable of tuning below 1 MHz and above 3.9 GHz. These frequencies however, lie outside of the specification range and performance will be degraded if operated in these outer margins. For some applications, the reduced dynamic range or elevated spurious levels in these ranges may not pose an application concern. The lowest tunable frequency is 0 MHz (DC). However, for input frequencies below 1 MHz, the AC coupling capacitors in the circuit limit/attenuate the signal significantly. On the upper end of the spectrum, the input low-pass filter will attenuate the signal rapidly as the frequency increases above 3.9 GHz. Calibration stored on the device EEPROM does not account for these out-of range-frequencies, so applying any correction using the stored calibration is not valid.

SC5406B Programming Interface

Device Drivers

The SC5406B is programmatically controlled 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 the 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 involves calls to the **sc5406B_RegWrite** and **sc5406B_RegRead** functions respectively. These functions are accessible in the API library.

For USB communication, there are many USB drivers available that can be used to directly access the registers of the device - WinUSB, libusb-1.0, libusb-win32, and NI-VISA are a few examples. The SC5406B API is based on the libusb-1.0 driver and is provided as a Microsoft Windows dynamic linked library (*sc5406B.dll*) or Linux shared library (*libsc5406B.so*). For more information on the libusb driver, visit www.libusb.org. For the Windows platform, libusb-1.0 relies on WinUSB at the kernel level. For libusb-1.0 to function properly on Windows platforms, WinUSB must be installed on the host.

For LabVIEW support on Windows operating systems, SignalCore provides two types of APIs - an API consisting of simple wrapper VIs that make calls to the libusb-based sc5406B.dll, and a separate API with all device functions written as native G-code VIs based on NI-VISA.

For other operating systems or embedded systems, users will need to access the registers through their own proprietary USB driver or through one of the drivers mentioned above. Should the user require additional assistance in writing an appropriate API other than that provided in the software installation, please contact SignalCore.

The SC5406B USB Configuration

The SC5406B USB interface is USB 2.0 compliant running at Full Speed, capable of 12 Mbits per second. It supports 3 transfer or endpoint types:

- Control Transfer
- Interrupt Transfer
- Bulk Transfer

The endpoint addresses are provided in the C-language header file and are listed below.

```
//  Define SignalCore USB Endpoints
#       define   SCI_ENDPOINT_IN_INT           0x81
#       define   SCI_ENDPOINT_OUT_INT          0x02
#       define   SCI_ENDPOINT_IN_BULK          0x83
#       define   SCI_ENDPOINT_OUT_BULK         0x04

// Define for Control Endpoints
#       define   USB_ENDPOINT_IN               0x80
#       define   USB_ENDPOINT_OUT              0x00
#       define   USB_TYPE_VENDOR               (0x02 << 5)
#       define   USB_RECIP_INTERFACE           0x01
```

The buffer lengths are sixty-four bytes for all endpoint types. The user should not exceed this length or the device may not respond correctly. Furthermore, all registers require five bytes or less with the exception of registers 0x24 (GET_CAL_EEPROM_BULK) and 0x25 (GET_USER_EEPROM_BULK). These two registers return sixty-four bytes of valid data upon executing a device read.

Writing the Device Registers Directly

Device commands for the SC5406B vary between two bytes and five bytes in length. The most significant byte (MSB) is the command register address that specifies how the device should handle the subsequent configuration data. The configuration data likewise needs to be ordered MSB first, that is, transmitted first. For configuration commands, an output buffer of five bytes long is sufficient. To ensure that a configuration command has been fully executed by the device, reading a few bytes back from the device will confirm a proper command write because the device will only return data upon full execution of a command. A map of the configuration registers for the SC5406B is provided in Table 2. Details for writing the registers are provided in the next section.

Reading the Device Registers Directly

Valid data is only available to be read back after writing one of the query registers. With the exception of registers 0x24 (GET_CAL_EEPROM_BULK) and 0x25 (GET_USER_EEPROM_BULK), where sixty-four bytes of valid data are returned, only the first two bytes of the device IN endpoints contain valid data. When querying the device, the MSB is returned as the first byte. A map of the query registers for the SC5406B is provided in Table 3. Details for reading the registers are provided in the next section.

Using the Application Programming Interface (API)

The SC5406B 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. Furthermore, the user does not need to understand the different transfer types of the USB interface. For example, to obtain the device temperature the user simply calls the function **sc5406B_GetTemperature**, or calls **sc5406B_SetFrequency** to set the device frequency. The software API is covered in detail in the "Software API Library Functions" section.

Setting the SC5406B - Writing USB Configuration Registers Directly

Configuration Registers

The configuration registers to control the SC5406B are summarized in Table 2. The size of a command is based on the sum of the register address byte and the number of data bytes. For example, setting the frequency would require five bytes with the first byte being the register address 0x10. The user may send more data bytes than required for a command without incurring a device error. “Extra” bytes will be ignored.

Table 2: Configuration registers.

Register (Address)	Data Bytes	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Default
INITIALIZE (0x01)	[7:0]	Open	Open	Open	Open	Open	Open	Open	Mode	0x00
SET_SYSTEM_ACTIVE (0x02)	[7:0]	Open	Open	Open	Open	Open	Open	Open	Enable SYS LED	0x00
POWER_SHUT_DOWN (0x05)	[7:0]	Open	Open	Open	Open	Open	Open	Open	Enable	0x00
RF_FREQUENCY (0x10)	[7:0]	Frequency Word [7:0]								0x00
	[15:8]	Frequency Word [15:8]								0x00
	[23:16]	Frequency Word [23:16]								0x00
	[31:24]	Frequency Word [31:24]								0x00
ATTENUATOR_SETTING (0x11)	[7:0]	Attenuator Value								0x00
	[15:8]	Attenuator								0x00
RF_MODE_SETTING (0x13)	[7:0]	Open	Open	Open	Open	Open	Fast Tune Enable	Fine Tune		0x00
IF_BAND_SELECT (0x15)	[7:0]	Open	Open	Open	Open	Open	Open	Open	Band	0x00
SIG-GEN_ENABLE (0x1B)	[7:0]	Open	Open	Open	Open	Open	Open	Open	Enable	0x00
REFERENCE_SETTING (0x16)	[7:0]	Open	Open	Open	Open	Reserv	100 MHz Out Sel	Ref Out Enable	Lock Enable	0x00
REFERENCE_DAC (0x17)	[7:0]	DAC word [7:0]								0x00
	[15:8]	DAC word [15:8]								0x00
IF_INVERT_SETTING (0x1D)	[7:0]	Open	Open	Open	Open	Open	Open	Open	Enable	
WRITE_USER_EEPROM (0x23)	[7:0]	EEPROM DATA [7:0]								
	[15:8]	EEPROM Address [7:0]								
	[23:16]	EEPROM Address [15:8]								
PHASE_SETTING (0x32)	[7:0]	Units Value[7:4]				Tenths Value				0x00
	[15:8]	Open	Open	Units Value [13:8]						0x00

Tuning the RF Frequency

The frequency of the first local oscillator (LO1) is set by writing the RF_FREQUENCY register (0x10). This register requires the address byte plus four data bytes, these data bytes being the bytes comprising an unsigned 32-bit integer. The data bytes contain the frequency tuning word in Hertz. For example, to tune to a frequency of 2.4 GHz, the data word would be d2400000000 in decimal or 0x8F0D1800 in hexadecimal. Breaking this command down to the five bytes sent via the USB interface, the command bytes would be [0x10] [0x8F] [0x0D] [0x18] and [0x00], with [0x10] being the first byte sent.

Changing the Attenuator Settings

The ATTENUATOR_SETTING (0x11) register has two data bytes needed to set the value of a specific attenuator. The MSB sets the target attenuator, and the least significant byte (LSB) contains the attenuation value. The MSB values and corresponding attenuator locations are as follows:

MSB value	Attenuator
0x00	IF3_ATTEN2
0x01	IF3_ATTEN1
0x02	RF_ATTEN1
0x03	RF_ATTEN2
0x04	IF2_ATTEN

The LSB contains the attenuation value in 1 dB steps for the attenuator specified in the MSB. For example, to set the RF attenuator to 15 dB, the command bytes would be [0x11] [0x02] [0x0F].

Enabling and Disabling the Internal Tone Generator

The SIG-GEN_ENABLE (0x1B) register has one data byte that enables or disables the internal sine tone generator. Setting the LSB of the data byte high or low will enable or disable this feature, respectively. For example, to turn it on the command bytes would be [0x1B] [0x01].

Changing the RF Synthesizer Mode

The RF_MODE_SETTING (0x13) register has one data byte that provides two tuning modes for the device: Fast Tune and Fine Tune. By default the Fast Tune mode is disabled (Normal mode). Asserting high bit 3 of the data byte will enable Fast Tune mode. Fast Tune enables the device to achieve faster lock and settling times between frequency changes. Please refer to Appendix A for more information regarding Fast Tune mode. The second mode, Fine Tune mode, has three options: 1 MHz (PLL), 25 kHz (PLL), and 1 Hz (DDS). Selection of these options requires setting the first two bits of the data byte to 0, 1, and 2 respectively. See the Local Oscillator Description section for more information. For example, to set the device for Fast Tune and a 1 Hz tuning step resolution, the command bytes would be [0x13] [0x06].

Selecting the IF Filter Path

The IF_FILTER_SELECT (0x15) register has one data byte that selects between two installed IF filters; IF3_FILTER0 and IF3_FILTER1. Setting bit 0 high will select IF_FILTER1. The exact bandwidths of the filters depend on the available installed options and are stored in the device calibration EEPROM. This function does not work for converters without addition filters.

Enabling the Internal IF Signal Generator.

Setting bit 0 to high of the SIG-GEN_ENABLE (0x1B) register will enable the a 70 MHz tone at the IF input. The SC5406B can be configured as a signal generator would amplitude is controlled by setting the attenuators to the settings generated by calling the **sc5406B_CalcAutoSigGenAttenuation** function.

Setting the Reference Clock Behavior

The REFERENCE_SETTING (0x16) register has one data byte which sets the reference clock behavior of the device. The default state of this register is 0x00, which disables the export of the internal reference clock, and disables phase locking to an external source. Asserting bit 0 high enables the device to lock to an external clock source. However, the device will not attempt to phase lock until it successfully detects the presence of a clock source at the "**ref in**" port. Asserting bit 1 low disables export of the internal clock. Asserting bit 1 high enables the device to export a 10 MHz signal through the "**ref out**" port. Asserting high bit 1 and bit 2 exports a 100 MHz signal.

Adjusting the Reference Clock Accuracy

The frequency precision of the SC5406B's 10 MHz TCXO is set by the device internally. The device writes the factory calibrated value to the reference DAC on power-up. This value is an unsigned 16-bit number stored in the EEPROM (see the calibration EEPROM map). The user may choose to write a different value to the reference DAC by accessing the REFERENCE_DAC (0x17) register. This register has two data bytes to hold the 16-bit word.

Setting Spectral Inversion in the RF

The default RF spectral polarity is the same as that of the IF input. However, should there be a need to invert the RF spectrum with respect to the IF spectrum, the register IF_INVERT_SETTING (0x1D) is used for that purpose. This register contains one data byte. Setting bit 0 high will enable inversion.

Storing Data into the User EEPROM Space

There is an on-board 16k byte EEPROM available to the user to store user data information such as user calibration, settings, etc. Writing to the user accessible EEPROM space is accomplished through the register WRITE_USER_EEPROM (0x23). This register has three data bytes: bytes 2 and 1 contain the address of the EEPROM; byte 0 is the byte value to be written. **NOTE:** The user may need to add 1-5 millisecond delay between consecutive writes if data is not written correctly. There is no delay required in read mode. For example, to write 123 to address 1234 of the user EEPROM the command bytes would be [0x23] [0x04] [0xD2] [0x7B].

Setting the Phase of the RF Signal

When the device is tuned to a fixed RF frequency, some applications may need to change the phase of the down-converted signal for various reasons. The RF output phase can be programmatically adjusted in 0.1 degree increments from 0 to 360 degrees. Changing the phase is accessed through the register PHASE_SETTING (0x32), which has two data bytes. The first four bits contain the tenths value, while bits [13:4] hold the units value.

Querying the SC5406B - Writing USB Request Registers Directly

The request set of registers shown in Table 3 are used to retrieve data from the device. They are accessed by calling the **sc5406B_RegRead** function. The parameters this function passes are listed in the "**Error! Reference source not found.**" section, which is repeated here for convenience:

int sc5406B_RegRead(deviceHandle *devHandle, unsigned char commandByte,

unsigned int instructWord, unsigned int *receivedWord)

Table 3: Query registers.

Register (Address)	Data Byte	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Default
GET_DEVICE_STATUS (0x18)	[7:0]	Open	Open	Open	Open	Open	Open	Open	Open	0x00
Read Byte 1	[7:0]	Device status [7:0]								
Read Byte 0	[15:8]	Device status [15:8]								
GET_TEMPERATURE (0x19)	[7:0]	Open	Open	Open	Open	Open	Open	Open	Open	0x00
Read Byte 1		Temp data [7:0]								
Read Byte 0		Open	Open	Sign	Temp data [12:8]					
READ_CAL_EEPROM (0x20)	[7:0]	EEPROM Address [7:0]								0x00
	[15:8]	EEPROM Address [15:8]								0x00
Read Byte 1		Cal EEPROM byte data								
Read Byte 0		Open	Open	Open	Open	Open	Open	Open	Open	
READ_USER_EEPROM (0x22)	[7:0]	EEPROM Address [7:0]								0x00
	[15:8]	EEPROM Address [15:8]								0x00
Read Byte 1		User EEPROM byte data								
Read Byte 0		Open	Open	Open	Open	Open	Open	Open	Open	
READ_CAL_EEPROM_BULK (0x24)	[7:0]	EEPROM Start Address [7:0]								
	[15:8]	EEPROM Start Address [15:8]								
Read Byte 63		Cal EEPROM data @ Start Address + 63								
:					:					
Read Byte 0		Cal EEPROM data @ Start Address								
READ_USER_EEPROM_BULK (0x25)	[7:0]	EEPROM Start Address [7:0]								
	[15:8]	EEPROM Start Address [15:8]								
Read Byte 63		User EEPROM data @ Start Address + 63								
:					:					
Read Byte 0		User EEPROM data @ Start Address								

Reading Device Status Data

To obtain the device status, write request register GET_DEVICE_STATUS (0x18) with 0x00 in the data byte, followed by querying the two bytes of data at the corresponding USB endpoint. The returned data are summarized in Table 4. It is important to note that the first local oscillator has three phase detectors in the synthesizer, so all three phase detectors must be ANDed to indicate the proper phase-locked status. The three bits that indicate the status of the three phase detectors are [13], [10] and [9].

Table 4. Description of the status data bits.

Bit	Description
[15]	10 MHz TCXO PLL lock status
[14]	100 MHz VCXO PLL lock status
[13]	LO1 PLL Main lock status
[12]	LO2 PLL lock status
[11]	LO3 PLL lock status
[10]	LO1 PLL1 lock status
[9]	LO1 PLL2 lock status
[8]	Internal SigGen PLL lock status
[7]	External reference detected
[6]	Reference output enabled
[5]	Reference lock enabled
[4]	IF3_FILTER1 selected
[3]	Hi freq path selected (RF section)
[2]	Device standby enabled
[1]	Reserved
[0]	SigGen enabled

Reading Temperature Data

To obtain temperature data, write request register GET_TEMPERATURE (0x19) with 0x00 in the data bytes, followed by reading two bytes. Once data is received, the two bytes of data need to be processed to correctly represent the 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 a positive (0x0) or negative (0x1) value. 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 (logically 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:

$$\text{Positive Temperature} = \text{ADC code} / 32$$

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

It is not recommended to read the temperature too frequently, especially once the SC5406B has stabilized in temperature. The temperature sensor is a serial device located inside the RF module. Therefore, like any other serial device, reading the temperature sensor requires 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 potentially modulates the local oscillators. Furthermore, once the SC5406B stabilizes in temperature, repeated readings will likely differ by as little as 0.25 ^{O}C over extended periods of time. Given that the gain-to-temperature coefficient is on the order of 0.1 dB/^{O}C, gain changes between readings will be negligible.

Reading Calibration EEPROM Data

To read a single byte from an address in the device EEPROM write the READ_CAL_EEPROM register with the address in the two data bytes, followed by reading back 2 bytes of data. The data is returned on the last byte, byte 1; byte 0 contains invalid data. The EEPROM maximum address is 0x3FFF. Reading above this address will cause the device to retrieve data starting from the lowest addresses. For example, addressing 0x4000 will return data stored in address location 0x0000. The calibration EEPROM map is discussed in detail in the "

Working With Calibration Data" section.

For faster reading of the entire calibration EEPROM, the READ_CAL_EEPROM_BULK (0x24) register should be written with the starting address of the 64 byte memory read. Data is return in 64 byte chunks where the first byte corresponds to the starting memory address. There are 237 chunks of 64 byte data.

All calibration data, whether floats or unsigned 32-bit integers, are stored as flattened unsigned 32-bit words. Each data point is comprised of four unsigned bytes, so data must be read back in multiples of four bytes, with the *least significant byte stored in the lower address*. After the data are read back, they need to be un-flattened back to their original type. Since the four bytes constitutes the four bytes of an unsigned 32-bit integer, converting (un-flattening) to an unsigned value simply involves concatenation of the bytes through bit shifting. To convert to floating point representation is a little more involved. First, convert the four bytes into an unsigned 32-bit integer value, and then (in C/C++, etc.) 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:

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

int count  =  0;
while (count  <  4) {
       uint32_value  =  unit32_value  |  (byte_value[count]  <<
(count*8));
       count++;
}

float32_value = *(float *)&uint32_value;
```

Reading User EEPROM Data

Once data has been written to the User EEPROM, it can be retrieved using the process outlined above for reading calibration data, but calling the READ_USER_EEPROM or READ_USER_EEPROM_BULK registers instead.

Working With Calibration Data

The device EEPROM on board has capacity for 16k bytes data. The EEPROM stores both device information and calibration data, which the user may choose to use to correct for conversion gain. Users are not required to use the onboard calibration to compensate for the gain errors associated with temperature, attenuator settings, frequency, pass-band ripple, and filter path selection. Alternatively, users can perform their own system calibration to remove these errors if the unit is integrated into a larger system whose external factors affect the gain significantly. Furthermore, the calibration data provided are raw measured data, and it is in the discretion of the user to decide on the appropriate methods of applying the calibration. For example, the user may choose to fit the measured data to a polynomial and use the polynomial coefficients to compute the necessary correction. Alternatively, the user may choose to perform correction through the use of interpolation. The methods outlined in this section only serve as guides on how to use the calibration data for correction, and these are the methods used by SignalCore in deriving published specifications that indicate the use of calibration. The function **sc5406B_CalcGain** utilizes the methods outlined here and may be used to compute the device gain for any particular setting of the device.

Table 5. EEPROM memory map of device attributes and raw calibration data.

EEPROM ADD (HEX)	# DATA POINTS	# BYTES	TYPE	Array matrix	DESCRIPTION
0X00	1	4	U32	[1x1]	Manufacturing Information
0X04	1	4	U32	[1x1]	Product Serial Number
0X08	1	4	U32	[1x1]	RF Module Number
0X0C	1	4	U32	[1x1]	Product Manufacture Date
0x10	1	4	U32	[1x1]	Last Calibration Date
0X2C	1	4	F32	[1x1]	Firmware Revision
0x30	1	4	F32	[1x1]	LO Hardware Revision
0x34	1	4	F32	[1x1]	SC Hardware Revision
0x50	1	4	F32	[1x1]	Calibration Temperature
0x54	1	4	U32	[1x1]	TCXO DAC Value
0x58	2	8	F32	[1x2]	Reserved
0x64	72	288	F32	[3x24]	YIG Calibration (Reserved)
0x184	1	4	F32	[1x1]	IF Filter 0 Bandwidth
0x188	1	4	F32	[1x1]	IF Filter 1 Bandwidth
0x1A0	24	96	F32	[3x8]	Temperature Coefficients
0x204	153	612	F32	[3x51]	IF3_FILTER0 Response Calibration
0x46C	153	612	F32	[3x51]	IF3_FILTER1 Response Calibration
0x788	1	4	F32	[1x1]	Reserved
0x78C	1	4	F32	[1x1]	IF Invert Gain
0x790	1	4	F32	[1x1]	IF3_FILTER1 Gain
0x798	90	360	F32	[3x30]	IF Attenuator Calibration
0x9F8	1650	6600	R32	[33x50]	RF Calibration

Table 5 lists the calibration EEPROM map of the SC5406B, indicating how and where board information and calibration data are stored. Since there are only 16k bytes on the EEPROM, SignalCore recommends that all data be read into host memory on initialization of the device and parsed for further mathematical manipulation. Having it available on host memory at all times during an application will greatly increase the speed of data manipulation. Another recommendation is to store the data to a file and have the application read the file rather than the EEPROM to retrieve data on each execution because of the relative slow EEPROM read rate. The **sc5406B_ConvertRawCalData** function is helpful to convert EEPROM data to their original format and types.

EEPROM Data Content

The following list describes the data contents of the EEPROM in detail. All addresses shown are the starting offset positions in the EEPROM, and are the starting address for block of data.

Manufacturing Information *(0x00).* This is an unsigned integer value that contains information used by the factory for production purposes.

Product Serial Number *(0x04).* This is an unsigned integer value that contains the SC5406B serial number. It is unique for every product produced. It is used for the purpose of tracking the history of the product.

RF Module Serial Number *(0x08).* This is the serial number of the shielded RF metal enclosure containing the analog and RF circuitry. All calibration data are stored on the EEPROM within the enclosure. Calibration data are written to this EEPROM at the factory are tracked using the RF module serial number for the SC5406B.

Product Manufacture Date *(0x0C).* This is an unsigned integer: byte 3 is the Year, byte 2 is the Month, byte 1 is the day of the month, and byte 0 is the hour of the day.

Last Calibration Date *(0x10).* This is an unsigned integer: byte 3 is the Year, byte 2 is the Month, byte 1 is the day of the month, and byte 0 is the hour of the day.

Firmware Revision *(0x2C).* This is a float 32 value containing the firmware revision.

LO Hardware Revision *(0x30).* This is a float 32 value containing the local oscillator hardware revision.

SC Hardware Revision *(0x34).* This is a float 32 value containing the signal chain hardware revision.

Calibration Temperature *(0x50).* This is a float 32 value containing the temperature at which the device was calibrated.

TCXO DAC Value *(0x54).* This is an unsigned integer containing the value for the reference DAC to adjust the precision of the temperature-compensated crystal oscillator (TCXO).

YIG Calibration (0x64). Data is reserved for device use.

IF Filter Bandwidths (0x184, 0x188). These two float 32 data points contain the filter bandwidths of IF3_FILTER0 and IF3_FILTER1, respectively. These are only available if the product contains non-standard filters, different from those provided with the base product.

Gain/temperature coefficients (0x1A0). This is a 3x8 float matrix, where data is concatenated by rows, that is, data is read back row by row. These coefficients, derived during calibration, are needed to compute for gain as a function of temperature. They are 2nd order polynomial coefficients and are measured over eight different frequencies. See “Gain Correction” section for more information on gain correction factors. **Table 6** is an example of the coefficient data and its format. Variables a_1 and a_2 are the first and second order coefficients.

Table 6. An example of gain-temperature coefficients data and format.

Frequency (MHz)	50.0	250	500	1000	1500	2500	2800	3800
a_1	-0.04500	-0.04800	-0.05600	-0.05000	-0.04500	-0.04800	-0.05600	-0.05000
a_2	-0.00038	-0.00035	-0.00029	-0.00038	-0.00038	-0.00035	-0.00029	-0.00038

IF3_FILTER0 Response Calibration (0x204). This is a 3x51 float matrix, and data is read back row by row. This set of data measures pass-band amplitude variation with respect to the center IF, and phase deviation from linear phase of filter IF3_FILTER0. There are a total of 51 offset frequency points from the center IF frequency measured inside the bandwidth of the filter. Table 7 is an example of the data and format.

IF3_FILTER1 Response Calibration (0x46C). This is a 3x51 float matrix, and data is read back row by row. This set of data measures pass-band amplitude variation with respect to the center IF, and phase deviation from linear phase of filter IF3_FILTER1. There are a total of 51 offset frequency points from the center IF frequency measured inside the bandwidth of the filter. Table 7 is an example of the data and format.

Table 7. Relative IF gain and phase response calibration and format.

Frequency Offset (MHz)	-12	-11.5	. . .	-5	. . .	-.5	0	.5	. . .	5	. . .	11.5	12
Gain Error	-58.2	-20.6	. . .	0.9	. . .	0.2	0.0	0.3	. . .	-0.2	. . .	-12.8	-30.4
Phase Error(radians)	0	0	. . .	0	. . .	0	0	0	. . .	. . .	. . .	0	0

IF Invert Gain Correction (0x788). This is a float that contains the change in IF gain when the device is switched to invert the IF spectrum. The default gain in the IF is the non-inverted mode gain.

IF3_Filter1 Gain Correction (0x790). This is a float that contains the change in IF gain when the device is switched to the IF3_FILTER1 path. The default gain in the IF is the IF3_FILTER0 path gain.

IF Attenuator Calibration (0x798). This is a 3x30 float matrix, containing the calibrated attenuation values of the three IF attenuators. Data is read in row by row. Each attenuator has 30 attenuation steps, and each row correspond to one attenuator. The first row is the attenuation values of IF3_ATTEN2, the second row contains the values or IF3_ATTEN1, and the third row contains the values of IF1_ATTEN. Table 8 is an example of the data and its format. Since the IF bandwidth is typically less than 40 MHz wide and centered at a fixed frequency, it is sufficient to perform the calibration at the center IF as attenuation variation is insignificant over its range.

Table 8. An example of IF attenuation calibration.

IF3_Attenuator 2	0.973	1.927	2.948	3.912	.	.	.	.	28.630	29.634
IF3_Attenuator1	0.989	1.970	2.998	3.989					28.890	29.874
IF1_ Attenuator	0.995	2.028	3.038	4.023	.	.	.	.	28.868	29.854

RF calibration (0x9F8). This is a 33x50 float matrix. Table 9 is an example of the data and format for the RF calibration data. RF calibration contains data for preamplifier gain, gain with zero RF and IF attenuation, and attenuation values of the RF attenuator for fifty frequency points that span the operational frequency range of the SC5406B. Data is read in concatenation of rows. For example, all the frequency values are read in first, then the preamplifier gain values, followed by the zero attenuation-setting gain, etc. There are a total of 1650 values read that must be read from the EEPROM to form the full set of calibration.

Table 9. Example of the RF calibration data and its format.

Frequency (MHz)	3	5	10	.	500	.	.	.	3875	3900
Preamp Gain	20.564	20.643	20.456	.	20.003	.	.	.	19.654	19.231
Gain	33.223	33.423	33.213	.	33.102	.	.	.	29.980	29.450
RF_ATTEN 1 dB	0.988	0.955	1.093	.	0.973	.	.	.	1.008	0.995
RF _ATTEN 2 dB	1.921	2.001	2.045	.	2.056	.	.	.	1.932	2.051
.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.
RF_ATTEN 30 dB	29.645	29.854	30.065	.	29.588	.	.	.	29.260	29.572

Frequency Correction

On power-up, The SC5406B automatically applies the calibration value to the on-board reference DAC that controls the TCXO, which is the primary frequency reference of the device. The user may choose to reprogram the DAC with the 16 bit code obtained from the EEPROM at starting address 0x54, or with another value, by writing the REFERENCE_DAC register (0x17).

Gain Correction

The SC5406B has seven dynamic variables that affect its gain, namely, pre-amplifier state (on/off), IF attenuator settings, RF attenuator setting, filter path, inversion gain, input frequency, and temperature. Correction of gain needs to take into account five main factors. The pre-amplifier gain, through gain (no attenuation, no pre-amplification), RF attenuation, and gain-over-temperature variation are calibrated over the span of the SC5406B frequency range. These are the frequency dependent parameters that are combined with the IF attenuation to make the total gain calculation.

Let us start by writing the gain equation with no dependence on temperature or frequency, and with the pre-amplifier turned on. We get the following equation.

$$G_{dev} = G_{preamp} + G + \Delta G_{fil} + \Delta G_{inv} - A_{rf} - A_{if} \qquad \text{Equation 1}$$

G_{dev} is the total gain of the device, G_{preamp} is the gain of the pre-amplifier, G is the through gain, A_{rf} is the attenuation of the RF attenuator, ΔG_{fil} is the gain change of IF3_FILTER1 path (the SC5406B does not have an alternative filter path so this term is 0 or ignored), ΔG_{inv} is the gain change in spectral inversion mode, and A_{if} is the attenuation of the the IF attenuators. If the preamplifier is off, no inversion, default filter path, and no attenuation applied then $G_{dev} = G$. Writing Equation 1 with dependency on temperature we add on the temperature dependent gain factor $\Delta G(T)$ and obtain the following:

$$G_{dev}(T) = G_{preamp}(T_0) + G(T_0) + \Delta G_{fil}(T_0) + \Delta G_{inv}(T_0) - A_{rf}(T_0) - A_{if}(T_0) + \Delta G(T) \qquad \text{Equation 2}$$

where T is the temperature of the device and T_0 is the fixed temperature at which calibration was performed. The section “Reading Temperature Data” provides information on how unsigned raw temperature data is converted to Celsius, a floating point type. Taking the frequency dependence of the measured parameters into consideration, Equation 2 may be rewritten as

$$G_{dev}(f,T) = G_{preamp}(f,T_0) + G(f,T_0) - A_{rf}(f,T_0) + \Delta G(f,T) + \Delta G_{fil}(T_0) + \Delta G_{inv}(T_0) - A_{if}(T_0) \qquad \text{Equation 3}$$

Note that the IF attenuation values, $A_{if}(T_0)$ do not need to be frequency dependent as discussed earlier. Using the IF attenuator calibration is as simple as substituting the intended value with the calibrated value. From Table 8, one would use 29.854 dB for an intended 30 dB attenuation. The other 2 variables, $\Delta G_{fil}(T_0)$ and $\Delta G_{inv}(T_0)$, are also frequency independent as they are only referred to at the center of the IF band, and their values are simply summed in the total gain equation. Only those parameters that depend on frequency and/or temperature are treated below.

To obtain calibrated gain values from the parameters that are a function of frequency, interpolation is required to provide the best estimated values. A natural cubic Spline interpolation is suggested for $G_{preamp}(f,T_0)$, $G(f,T_0)$, and $A_{rf}(f,T_0)$. The important input parameters for a cubic spline interpolation are the 2 arrays $[X]$ and $[Y]$, and an arbitrary point x. The output of the interpolation is some interpolated value y based on the inputs. $[X]$ is the set of independent values, $[Y]$ is the set of $[X]$ dependent values, and x is an arbitrary independent value to obtain the interpolated value y. For example, Table 10 lists the input and output parameters to obtain the gain $G(f = 1000\ MHz, T_0)$.

Table 10. Parameters to a Spline interpolation.

Frequency (MHz); $[X]$	3	5	19	…	…	950	1050	…	3875	3900
Measured Gain; $[Y]$	33.223	33.423	33.213	…	…	32.652	32.482	…	29.980	29.450
$f; x$	1000									
$G(f,T_0); y$	32.453									

From experience, having a large [X] and [Y] array of points does not necessarily provide the best interpolated value due the nature of trying to fit a function over many points and over many octaves of frequency. Better results are obtained from a set of localized calibrated points around the point of interest. The function **sc5406B_CalcGain** uses six localized [X] points to compute the interpolated point. Using localized points, the example in Table 10 is re-tabulated in Table 11. Similarly, frequency dependent preamplifier gain and RF attenuation may be derived.

Table 11. Localized parameters to a Spline interpolation.

Frequency (MHz); $[X]$	850	900	950	1050	1100	1150
Gain; $[Y]$	32.681	32.673	32.652	32.482	32.419	32.418
$f; x$	1000					
$G(f, T_0); y$	32.532					

To find the change in gain with respect to change in temperature involves a couple of steps; first determine the array values of $[\Delta G(f_i, T)]$, where f_i is the frequency point at which a measurement was made, and then as a second step, use interpolation to determine the $\Delta G(f, T)$ at some frequency f. Again, natural cubic spline interpolation is recommended in the second step. Let us outline a method to determine $\Delta G(f_i, T)$ at frequency f_i; there are a total of 8 frequency points for this calibration.

The calibration values retrieved from the EEPROM are second order polynomial coefficients fitted to measured data. In other words, at each frequency point gain variation as a function of temperature is provided as a second polynomial. Writing the general form of the gain function using coefficients, we have:

$$G(f_i, T) = a_0(f_i) + a_1(f_i)T + a_2(f_i)T^2 \qquad \text{Equation 4}$$

Here $a_j(f_i)$ is the j^{th} order coefficient measured some frequency f_i. The gain deviation at temperature T from the gain measured at the calibration temperature T_0 can be written as

$$\begin{aligned}\Delta G(f_i, T) &= G(f_i, T) - G(f_i, T_0) \qquad \text{Equation 5}\\ &= a_1(f_i)[T - T_0] + a_2(f_i)\left[T^2 - {T_0}^2\right]\end{aligned}$$

Using equation 5 and the temperature coefficients of **Table 6**, we obtain the following:

Table 12. Calculated gain changes at the measured frequency points

Frequency (MHz) (f_i)	50.0	250	500	1000	1500	2500	2800	3800
$\Delta G(f_i, T = 45^O)$ dB	-0.340	-0.343	-0.351	-0.348	-0.354	-0.351	-0.355	-0.357

After determining the set of gain deviations at some temperature T, we apply spline interpolation to the set of $\Delta G(f_i, T)$ values to obtain $\Delta G(f, T)$, change in gain with respect to both temperature and frequency. Using Table 12 and the convention developed here, the Spline parameters are $[X] = [f_i]$, $[Y] = [\Delta G(f_i, T)]$, $x = f$, and $y = \Delta G(f, T)$.

IF Response Correction

The gain correction procedure outlined above only applies to a signal that is centered in the 70 MHz IF band. The device's Fine-Tune mode (1 Hz) is able to place any RF signal at the center of the IF, so for narrow bandwidth signals (typically less than a MHz), applying the center IF gain correction and assuming no deviation from linear phase is sufficient. However, for a large bandwidth signal that spans several MHz, it is important to apply gain and phase correction to the offset frequencies; those that are offset from the center IF. Although SignalCore performs calibration of the amplitude and phase over the bandwidth of the IF filters (available on the device calibration EEPROM), it is recommended that the user perform in-situ system equalization for digital broadband applications for improved performance.

Measured IF gain and phase error response is available for both filter paths; the user simply needs to properly select the path of interest. The measurement is made using a vector network analyzer in the frequency domain, covered by fifty-one evenly spaced frequency points. The amplitude (gain) error values are measured with respect to the center frequency and are given in decibels, while the phase error values are in radians. The phase errors are deviations from linear phase. Each set of calibrated points consists of a 3x51 floating point array (see Table 7 as an example). There are several ways to apply the frequency domain calibration:

1. Determine a fitted polynomial function for the amplitude error (gain) and multiply this function with the uncorrected amplitude spectrum. Add the two values if dealing in decibels. Additionally, determine a fitted polynomial function for the phase error and add values derived from this function with the uncorrected phase. To derive, let $X(e^{i\omega})$ be the measured uncorrected value, $E(e^{j\omega})$ be the fitted polynomial to the calibrated error values, and $Y(e^{j\omega})$ be the corrected measured value. Also let $Arg[\cdot]$ denote the principle value of the phase of the above terms, and we can relate all the terms as

$$Y\left(e^{j\omega}\right) = E\left(e^{j\omega}\right)X\left(e^{j\omega}\right)$$
$$\left|Y(e^{j\omega})\right|e^{jArg[Y(e^{j\omega})} = \left|E(e^{j\omega})\right|\left|X(e^{j\omega})\right|e^{j(Arg\left[Y\left(e^{j\omega}\right)\right]+Arg\left[Y\left(e^{j\omega}\right)\right])}$$

   From the above equation, we see that the magnitude terms are multiplied and the phase terms added. In the discrete sense (digitized) for every frequency value, ω_i, we apply the above equation to correct for the non-ideality of the IF filter.

2. The other method finds the magnitude and error points through interpolation methods such as Spline, then multiplying the error magnitude with the uncorrected magnitude and adding the error and uncorrected phases. This is similar to method 1, but instead of using a fitted function to obtain the error values, interpolation is used. Interpolation is generally a slower process. This is the method implemented in the library function **sc5406B_CalcIfResponseCorrection**.

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 device registers directly. The functions provided in the SC5406B API dynamic-linked, shared, or LabVIEW libraries are:

- **sc5406B_SearchDevices**
- **sc5406B_OpenDevice**
- **sc5406B_CloseDevice**
- **sc5406B_RegWrite**
- **sc5406B_RegRead**
- **sc5406B_InitDevice**
- **sc5406B_SetStandby**
- **sc5406B_SetFrequency**
- **sc5406B_SetSignalChain**
- **sc5406B_SetSynthesizerMode**
- **sc5406B_SetIfFilterPath**
- **sc5406B_SetReferenceClock**
- **sc5406B_SetReferenceDac**
- **sc5406B_SetIfInversion**
- **sc5406B_SetSignalPhase**
- **sc5406B_SetSigGenEnable**
- **sc5406B_WriteUserEeprom**
- **sc5406B_GetDeviceStatus**
- **sc5406B_GetTemperature**
- **sc5406B_ReadCalEeprom**
- **sc5406B_ReadUserEeprom**
- **sc5406B_ReadUserEepromBulk**
- **sc5406B_GetRawCalData**
- **sc5406B_GetCalData**
- **sc5406B_CalcAutoAttenuation**
- **sc5406B_CalcAutoSigGenAttenuation**
- **sc5406B_CalcGain**
- **sc5406B_CalcIfResponseCorrection**
- **sc5406B_ConvertRawCalData**
- **sc5406B_ConvertRawTempData**
- **sc5406B_Spline**
- **sc5406B_SplineInterp**

Each of these functions is described in more detail on the following pages. To program in C/C++, SignalCore defines the following constants and types which are contained in the C header file, **sc5406B.h.** These constants and types are useful not only as an include file for developing applications using the sc5406B libraries, but also for writing device drivers independent of those provided by SignalCore.

Constants Definitions

```
/* 2-D parameters for storing calibration data */
#define RFCALPARAM                    33    //rows of caldata
#define RFCALFREQ                     50    // frequency points
#define IFATTENUATOR                   3    // total number of IF attenuators
#define IFATTENCALVALUE               30    // attenuation steps 1-30 dB
#define IFRESPONSEPARAM                3    // freq,amp,phase
#define IFRESPONSEFREQ                51    // freq points over the bandwidth
#define TEMPCOPARAM                    3    // freq, coeff(1) , coeff(2)
#define TEMPCOFREQ                     8    // freq points

/* Attenuator assignment */
#define IF3ATTENUATOR2                 0
#define IF3ATTENUATOR1                 1
#define RFATTENUATOR                   2
#define IF1ATTENUATOR                  3

#define CALEEPROMSIZE              15168
#define USEREEPROMSIZE             16384

/* Tune mode parameters */
#define FASTTUNEENABLE                 1
#define DISABLEDFINEMODE               0    //1 MHz tuning steps, PLL implementation
#define PLLFINEMODE                    1    //25 KHz tuning steps, PLL implementation
#define DDSFINEMODE                    2    //1 Hz tuning steps, DDS implementation

/* ERROR Set */
#define SUCCESS                        0
#define DEVICEERROR                   -1
#define TRANSFERERERROR               -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
```

Type Definitions

```
typedef         unsigned char   bool;

typedef struct deviceAttribute_t
{
        unsigned int productSerialNumber;
        unsigned int rfModuleSerialNumber;
        float firmwareRevision;
        float loHardwareRevision;
        float scHardwareRevision;
        unsigned int *calDate; //size of 4 year,month,day,hour
        unsigned int *manDate; //size of 4 year,month,day,hour
}       deviceAttribute_t;

typedef struct calibrationData_t
{
        float **rfCal;    // RF gain calibration
        float **ifAttenCal; // IF attenuators calibration
        float **ifFil0ResponseCal; // IF filter 0 response calibration
        float **ifFil1ResponseCal; // IF filter 1 response calibration
        float **tempCoeff; // temperature coefficients
        float rfCalTemp; // temperature T0 at which calibration was done
        float ifFilter1GainError; // Gain error when switched to filter 1 path
        float ifFilter0Bw; // filter 0 BW in MHz
        float ifFilter1Bw; // filter 1 BW in MHz
        float invertGainError;  // gain error when spectral inversion enabled
        unsigned int tcxoDac;  // The TCXO dac value at T0
}       calibrationData_t;

typedef struct attenuator_t
{
        unsigned int if3Atten1Value;
        unsigned int if3Atten2Value;
        unsigned int rfAtten1Value;
        unsigned int rfAtten2Value;
        unsigned int if2AttenValue;
}       attenuator_t;


typedef struct deviceStatus_t
{
        bool tcxoPllLock;
        bool vcxoPllLock;
        bool lo1Pll3Lock;
        bool lo2PllLock;
        bool lo3PllLock;
        bool lo1Pll1Lock;
        bool lo1Pll2Lock;
        bool sigGenPllLock;
        bool extRefDetected;
        bool refClkOutEnable;
        bool extRefLockEnable;
        bool ifBandSelect;
        bool hiFreqSelect;
        bool standbyEnable;
        bool sigGenEnable;
}       deviceStatus_t;

typedef struct ifResponseCorrect_t
{
        float ampCorrect;
        float phaseCorrect;
}       ifResponseCorrect_t;

typedef  struct
{
        libusb_device_handle *handle;
        libusb_context *ctx;  //need to carry the session context for libusb_exit
} deviceHandle;  //using deviceHandle rather deviceHandle_t for back compatibility
```

Programming the USB interface

The functions listed below are found in the **sc5406B.dll** dynamic linked library for Windows operating systems or in the **libsc5406B.so** shared library for the Linux operating system. These functions are also provided in the LabVIEW library; **sc5406B.llb**. The LabVIEW functions contain context help (Ctrl-H) to provide further clarification of each function.

Function:	**sc5406B_SearchDevices**	
Definition:	**int sc5406B_SearchDevices(char **serialNumberList)**	
Return:	The number of devices found	
Output:	char **serialNumberList	(pointer list to serial numbers)
Description:	**sc5406B_SearchDevices** searches for SignalCore SC5406B devices connected to the host computer and returns an array containing their serial numbers. The user can use this information to open the device(s) with their serial numbers. See **sc5406B_OpenDevice** function for information on how to open a device.	

Function:	**sc5406B_OpenDevice**	
Definition:	**deviceHande sc5406B_OpenDevice(char *devSerialNum)**	
Return:	device handle to the opened device	
Output:	char *devSerialNum	(char pointer to a serial number, serial numbers are not limited to numerical values)
Description:	**sc5406B_OpenDevice** opens the device and turns on the front panel access LED if successful. This function returns a handle of USB type to the device for other function calls.	

Function:	**sc5406B_CloseDevice**	
Definition:	**int sc5406B_CloseDevice(deviceHandle *devHandle)**	
Return:	The status of the function	
Input:	deviceHandle *devHandle	(handle to the device to be closed)
Description:	**sc5406B_CloseDevice** closes the device associated with the device handle and turns off the access LED of the front panel if it is successful.	

Example:

To exercise the functions that open and and close the USB device:

```
// Declaring
char **deviceList;
deviceHandle devHandle;
int devicesFound;
int i;
// Allocate memory
deviceList  =  (char**)malloc(sizeof(char*)*MAXDEVICES);  //  MAXDEVICES=50  serial
numbers to search
for (i=0;i<MAXDEVICES; i++)
       deviceList[i] = (char*)malloc(sizeof(char)*SCI_SN_LENGTH); // SCI SN has 8 char

devicesFound = sc5406B_SearchDevices(deviceList);
printf("There are %d SignalCore USB devices found. \n", devicesFound);

i=0;
while ( i < numOfDevices)
       {
              printf("     Device %d has Serial Number: %s \n", i+1, deviceList[i]);
              i++;
       }

devHandle = sc5406B_OpenDevice(deviceList[0]); // get a handle to the first device on
the List

// Free memory
for(i = 0; i<MAXDEVICES;i++) free(deviceList[i]);
free(deviceList);
//
// Do something with the device
//
//Close the device
int status = sc5406B_CloseDevice(devHandle);
```

Function:	**sc5406B_RegWrite**
Definition:	**int sc5406B_RegWrite(deviceHandle *devHandle, unsigned char commandByte, unsigned int instructWord)**
Return:	The status of the function
Input:	deviceHandle *devHandle (handle to the opened device)
	unsigned char commandByte (the address byte of the register to write to)
	unsigned int instructWord (the data for the register)
Description:	**sc5406B_RegWrite** writes the instructWord data to the register specified by the commandByte. See the register map in Table 2 for more information. This function should rarely be used.
Example:	To set the RF attenuator value to 10 dB:

```
int status = sc5406B_RegWrite(devHandle, 0x11, 0x020A);
```

Function:	**sc5406B_RegRead**	
Definition:	**int sc5406B_RegRead(deviceHandle *devHandle,**	
	unsigned char commandByte,	
	unsigned int instructWord,	
	unsigned int *receivedWord)	
Return:	The status of the function	
Input:	deviceHandle *devhandle	(handle to the opened device)
	unsigned char commandByte	(the address byte of the register to write to)
	Unsigned int instructWord	(the data for the register)
	Unsigned int *receivedWord	(data to be received)
Description:	**sc5406B_RegRead** reads the data requested by the instructWord data to the register specified by the commandByte. See the register map in Table 3 for more information.	
Example:	To read the status of the device:	

```
unsigned int deviceStatus;

int status = sc5406B_RegRead(devHandle,0x18,0x00,&deviceStatus);
```

Function:	**sc5406B_SetStandby**	
Definition:	**int sc5406B_SetStandby(**	
	deviceHandle *devHandle,	
	bool standbyStatus)	
Return:	The status of the function	
Input:	deviceHandle *devhandle	(handle to the opened device)
	Bool standbyStatus	(set to true (1) to set device in standby mode)
Description:	**sc5406B_SetStandby** puts the device in standby mode where the power to the analog circuits is disabled, conserving power.	

Function:	**sc5406B_SetFrequency**	
Definition:	**int sc5406B_ SetFrequency(deviceHandle *devHandle, unsigned int frequency)**	
Return:	The status of the function	
Input:	deviceHandle *devhandle	(handle to the opened device)
	unsigned int frequency	(frequency in Hz)
Description:	**sc5406B_SetFrequency** sets the RF frequency.	

Function: **sc5406B_SetAttenuator**

Definition: **int sc5406B_SetAttenuator(**
deviceHandle *devHandle,
unsigned int attenValue,
unsigned int attenuator)

Return: The status of the function

Input:	deviceHandle *devhandle	(handle to the opened device)
	unsigned int attenValue	(the value assigned to the attenuator)
	unsigned int attenuator	(the designated attenuator, see header file)

Description: **sc5406B_SetAttenuator** sets the value of the designated attenuator.

Function: **sc5406B_SetSignalChain**

Definition: **int sc5406B_SetSignalChain (**
deviceHandle *devHandle,
attenuator_t *atten
)

Return: The status of the function

Input:	deviceHandle *devhandle	(handle to the opened device)
	unsigned int atten	(values to the attenuators)

Description: **sc5406B_SetSignalChain** sets all the attenuators. This simplifies the programming flow when used with **sc_5406B_CalcAutoAttenuation**, which returns the attenuator_t structure.

Example: Define attenuator_t atten and use it in the function:

```
attenuator_t *atten;
bool preamp = 0;
atten = (attenuator_t*)malloc(sizeof(attenuator_t)); //casting may not
be necessary
atten->if3Atten2Value = 10;
atten->if3Atten1Value = 10;
atten->rfAtten1Value = 10;
atten->rfAtten2Value = 0;
atten->if2AttenValue = 0;

int status = sc5406B_SetSignalChain(devHandle, atten);
free(atten);
```

Function:	**sc5406B_SetSynthesizerMode**
Definition:	**int sc5406B_SetSynthesizerMode(deviceHandle *devHandle, bool fastTuneEnable, unsigned int fineTuneMode)**
Return:	The status of the function
Input:	deviceHandle *devhandle (handle to the opened device) bool fastTuneEnable (enable/disable faster frequency stepping) unsigned int fineTuneMode (selection of 1 MHz, 25 kHz, 1 Hz step resolution)
Description:	**sc5406B_SetSynthesizerMode** enables/disables fast tuning, and sets the step resolution of the upconverter.

Function:	**sc5406B_ SetIfFilterPath**
Definition:	**int sc5406B_SetIfFilterPath(deviceHandle *devHandle, bool ifFilterPath)**
Return:	The status of the function
Input:	deviceHandle *devhandle (handle to the opened device) Bool ifFilterPath (selection of IF filter 0 or filter 1)
Description:	**sc5406B_**SetIfFilterPath selects the IF filter**.**

Function:	**sc5406B_SetReferenceClock**
Definition:	**int sc5406B_SetReferenceClock(deviceHandle *devHandle, bool lockExtEnable, bool RefOutEnable, bool Clk100Enable)**
Return:	The status of the function
Input:	deviceHandle *devhandle (handle to the opened device) bool lockExtEnable (enables phase locking to an external source) bool RefOutEnable (enables the clock to driven out the REF OUT port) bool Clk100Enable (changes REF OUT between 10MHz to 100 MHz)
Description:	sc5406B_**SetReferenceClock** configures the reference clock behavior of the device**.**

Function:	**sc5406B_SetReferenceDac**
Definition:	**int sc5406B_SetReferenceDac(deviceHandle *devHandle, unsigned int dacValue)**
Return:	The status of the function
Input:	deviceHandle *devhandle (handle to the opened device) Unsigned int dacValue (16-bit value for the reference DAC)
Description:	**sc5406B_SetReferenceDac** set the value of the DAC that tunes the internal reference TXCO. The user may choose to override the value stored in memory to improve frequency accuracy.

Function:	**sc5406B_SetIfInversion**
Definition:	**int sc5406B_SetIfInversion(deviceHandle *devHandle, bool ifInvertEnable)**
Return:	The status of the function
Input:	deviceHandle *devhandle (handle to the opened device)
	Bool ifInvertEnable (enable spectral inversion)
Description:	**sc5406B_SetIfInversion** enables the down-converted signal to be spectrally inverted with respect the RF input. This may be beneficial for some applications.

Function:	**sc5406B_SetSignalPhase**
Definition:	**int sc5406B_SetSignalPhase(deviceHandle *devHandle, float phase)**
Return:	The status of the function.
Input:	deviceHandle *devhandle (handle to the opened device)
	float phase (phase in degrees, 0-360 deg, 0.1 resolution)
Description:	**sc5406B_SetSignalPhase** increases the phase of the signal by the amount specified.

Function:	**sc5406B_SetSigGenEnable**
Definition:	**int sc5406B_ SeSigGenEnable (unsigned int *deviceHandle, bool sigGenEnable)**
Return:	The status of the function.
Input:	unsigned int *deviceHandle (handle to the opened device)
	bool sigGenEnable (1 to enable, default 0)
Description:	**sc5406B_ SetSigGenEnable** when set to 1 enables an internal 70 MHz signal generator to be switched into the input IF path, while disabling any external input. The upconverter is turned into a CW signal generator, not requiring any external IF sources.

Function:	**sc5406B_WriteUserEeprom**
Definition:	**int sc5406B_WriteUserEeprom(deviceHandle *devHandle, unsigned int memAdd, unsigned char byteData)**
Return:	The status of the function
Input:	deviceHandle *devhandle (handle to the opened device)
	unsigned int memAdd (memory address to write to)
	unsigned char byteData (byte to be written to the address)
Description:	**sc5406B_WriteUserEeprom** writes one byte of data to the memory address specified.

Function:	**sc5406B_GetDeviceStatus**
Definition:	**int sc5406B_GetDeviceStatus(deviceHandle *devHandle, deviceStatus_t *deviceStatus)**
Return:	The status of the function
Input:	deviceHandle *devhandle (handle to the opened device)
Output:	deviceStatus *deviceStatus (outputs the status of the device such as PLL lock)
Description:	**sc5406B_GetDeviceStatus** retrieves the status of the device such as LO 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 = sc5406B_GetDeviceStatus(devHandle, devStatus);

if(devStatus->vcxoPllLock)
printf("The 100 MHz is phase-locked \n");
else
printf("The 100 MHz is not phase-locked \n");

free(deviceStatus);
```

Function:	**sc5406B_GetTemperature**
Definition:	**int sc5406B_GetTemperature (deviceHandle *devHandle, float *temperature)**
Return:	The status of the function
Input:	deviceHandle *devhandle (handle to the opened device)
Output:	float *temperature (temperature in degrees C)
Description:	**sc5406B_GetTemperature** retrieves the internal temperature of the device.

Function:	**sc5406B_ReadCalEeprom**
Definition:	**int sc5406B_ReadCalEeprom(deviceHandle *devHandle, unsigned int memAdd, unsigned char *byteData)**
Return:	The status of the function
Input:	deviceHandle *devhandle (handle to the opened device)
	unsigned int memAdd (EEPROM memory address)
Output:	unsigned char *byteData (the read byte data)
Description:	**sc5406B_ReadCalEeprom** reads back a byte from the memory address of the calibration EEPROM.

Function:	**sc5406B_ReadUserEeprom**	
Definition:	**int sc5406B_ReadUserEeprom(** **deviceHandle *devHandle,** **unsigned int memAdd,** **unsigned char *byteData)**	
Return:	The status of the function	
Input:	deviceHandle *devhandle	(handle to the opened device)
	unsigned int memAdd	(EEPROM memory address)
Output:	unsigned char *byteData	(the read byte data)
Description:	**sc5406B_ReadUserEeprom** reads back a byte from the memory address of the user EEPROM.	

Function:	**sc5406B_ReadUserEepromBulk**	
Definition:	**int sc5406B_ReadUserEepromBulk(** **deviceHandle *devHandle,** **unsigned int startMemAdd,** **unsigned char *byteDataArray)**	
Return:	The status of the function	
Input:	deviceHandle *devhandle	(handle to the opened device)
	unsigned int memAdd	(EEPROM start memory address)
Output:	unsigned char *byteData	(the read 64 bytes of data)
Description:	**sc5406B_ReadUserEepromBulk** reads back 64 bytes beginning at the start memory address of the user EEPROM.	
Example:	Code to read back 512 bytes of data starting at address 1024 into eepromData:	

```
unsigned char eepromData = (unsigned char*)malloc(512);
unsigned char *bufferIn = (unsigned char*)malloc(64);
int i = 0;
int bufferCount = 0;
unsigned int add = 1024;

while(bufferCount < 8){
       int status = sc5406B_ReadUserEepromBulk(devHandle, add+bufferCount*64,
                                               bufferIn);
       for (i = 0; i < 64; i++)
       eepromData[i + bufferCount*64] = bufferIn[i];
       bufferCount ++;
}

free(bufferIn);
```

Function:	**sc5406B_GetRawCalData**
Definition:	**int sc5406B_GetRawCalData(deviceHandle *devHandle, unsigned char *rawCalDataArray)**
Return:	The status of the function
Input:	deviceHandle *devhandle (handle to the opened device)
Output:	unsigned char *rawCalDataArray (the entire calibration EEPROM contents)
Description:	**sc5406B_GetRawCalData** reads the entire calibration EEPROM into the rawCalDataArry. The array must be allocated for at least 15168 bytes.
Example:	See code block example below for using **sc5406B_ConvertRawCalData**.

Function:	**sc5406B_GetCalData**
Definition:	**int sc5406B_GetCalData(deviceHandle *devHandle, deviceAttribute_t *deviceAttributes, calibrationData_t *calData)**
Return:	The status of the function
Input:	deviceHandle *devhandle (handle to the opened device)
Output:	deviceAttribute_t *deviceAttributes (device attributes)
	calibrationData_t *calData (structured calibration data)
Description:	**sc5406B_GetCalData** returns the device attributes such as serial number, calibration date, and also structured calibration data used for gain calculation and correction.
Example:	See code block example for **sc5406B_ConvertRawCalData**.

Function:	**sc5406B_ConvertRawCalData**
Definition:	**int sc5406B_ConvertRawCalData (unsigned char *rawCalData, deviceAttribute_t *deviceAttributes, calibrationData_t *calData)**
Input:	unsigned char *rawCalData (entire cal EEPROM data in raw byte format)
Output:	calibrationData_t *calibrationData (current calibration data)
	deviceAttribute_t *deviceAttributes (device attributes)
Description:	**sc5406B_ConvertRawCalData** organizes/decodes the entire 15168 bytes of raw calibration data read from the EEPROM and returns two data formats - deviceAttribute_t and calibrationData_t. The array rawCalData must contain valid calibration data, obtained by reading the EEPROM, and rawCalData, calData and deviceAttributes must have memory allocated.

Example: Allocating memory for the input and output parameters in C, and calling the function. Similarly, allocated memory must be de-allocated when no longer used or when the program quits.

```c
//Declaring
calibrationData_t* calData;
deviceAttribute_t* devAttr;
unsigned char *rawCal;

//allocate memory for raw calibration
rawCal = (unsigned char*)malloc(sizeof(char)*CALEEPROMSIZE);

// Allocate memory; the user may use malloc() instead of calloc()
devAttr->calDate = (unsigned int*)calloc(4,sizeof(unsigned int));
devAttr->manDate = (unsigned int*)calloc(4,sizeof(unsigned int));

calData->rfCal = (float**)calloc(RFCALPARAM,sizeof(float*));
for(i = 0;i<RFCALPARAM;i++)
	calData->rfCal[i] = (float*)calloc(RFCALFREQ,sizeof(float));

calData->ifAttenCal = (float**)calloc(IFATTENUATOR,sizeof(float*));
for(i = 0;i<IFATTENUATOR;i++)
	calData->ifAttenCal[i] = (float*)calloc(IFATTENCALVALUE,sizeof(float));

calData->ifFil0ResponseCal = (float**)calloc(IFRESPONSEPARAM,sizeof(float*));
for(i = 0;i<IFRESPONSEPARAM;i++)
	calData->ifFil0ResponseCal[i] =
(float*)calloc(IFRESPONSEFREQ,sizeof(float));

calData->ifFil1ResponseCal = (float**)calloc(IFRESPONSEPARAM,sizeof(float*));
for(i = 0;i<IFRESPONSEPARAM;i++)
	calData->ifFil1ResponseCal[i] =
(float*)calloc(IFRESPONSEFREQ,sizeof(float));

calData->tempCoeff = (float**)calloc(TEMPCOPARAM,sizeof(float*));
for(i = 0;i<TEMPCOPARAM;i++)
	calData->tempCoeff[i] = (float*)calloc(TEMPCOFREQ,sizeof(float));

//read in raw calibration
int status = sc5406B_GetRawCal(devHandle, rawCal);
//Calling the function to structure the calibration data
status = sc5406B_convertRawCalData(rawCal, devAttr, calData);

//alternatively instead of calling the above 2 functions
status = sc5406B_GetCalData(devHandle, devAttr, calData);
```

Function:	**sc5406B_CalcAutoAttenuation**
Definition:	**int sc5406B_CalcAutoAttenuation(**

```
int     sc5406B_CalcAutoAttenuation(
                    unsigned int frequency,
                    float rfOutLevel,
                    float ifInLevel,
                    float perfSelect,
                    bool if3Filter1Enable,
                    float temperature,
                    calibrationData_t *calData,
                    attenuator_t *attenuator);
```

Input:	unsigned int frequency	(input RF frequency in Hz)
	float rfOutLevel	(output RF level in dB)
	float ifInLevel	(input IF level in dB)
	bool perfSelect	(performance select)
	bool if3Filter1Enable	(Enable Filter 1 path in IF3)
	float temperature	(current device temperature)
	calibrationData_t * calData	(structured calibration data for the device)
Output:	attenuator_t *attenuator	(attenuation settings for RF, IF1, and final IF3 attenuators)

Description: **SC5406B_CalcAutoAttenuation** returns the set of attenuation settings for all the attenuators that will configure the SC5406B for best dynamic range operation based on user input parameters such as frequency, mixer level, etc. The values are calculated to maintain a good balance between the signal-to-noise dynamic range and the linearity dynamic range. The perfSelect input has 0=Optimized for linearity, 1=Best balance between linearity and noise, and 2=Optimize for SNR. Each attenuator must have memory allocated before calling this function. *SC5406B_ConvertRawCalData* must be called or valid structure calibration data must be entered before calling this function.

Example: Code showing how to properly use this function:

```
//Declaring
Attenuator_t *atten;
float deviceTemp;

//call a function to return the device temperature
function_to_sc5406B_GetTemperature( &deviceTemp);

unsigned int rfFreq = 1000000000;  // 1.0 GHz
float rfLevel = 0;  // expecting a 0 dBm input signal
float mixerLevel = -20;  //set the mixer level requirement
bool preamp = 0;    // since input level is 0 dB, no need for a preamp
float ifLevel = 0; // to obtain a level clost to 0 dBm at the IF
bool filterPath = 0; // use the default filter path in the IF
float temp = deviceTemp;

//Calling the function
int status = sc5406B_CalcAutoAttenuation(rfFreq,
rfLevel,mixerLevel,preamp,ifLevel,filterPath,temp, atten);
```

Function: **sc5406B_CalcAutoSigGenAttenuation**

Definition:
```
int     sc5406B_CalcAutoSigGenAttenuation(
                        unsigned int frequency,
                        float rfOutLevel,
                        float perfSelect,
                        bool if3Filter1Enable,
                        float temperature,
                        calibrationData_t *calData,
                        attenuator_t *attenuator);
```

Input:	unsigned int frequency	(input RF frequency in Hz)
	float rfOutLevel	(output RF level in dB)
	bool perfSelect	(performance select)
	bool if3Filter1Enable	(Enable Filter 1 path in IF3)
	float temperature	(current device temperature)
	calibrationData_t * calData	(structured calibration data for the device)
Output:	attenuator_t *attenuator	(attenuation settings for RF, IF1, and final IF3 attenuators)

Description: **SC5406B_CalcAutoSigGenAttenuation** returns the set of attenuation settings for all the attenuators that will configure the SC5406B for best dynamic range operation based on user input parameters such as frequency, perfSelection, etc when the internal signal generator is turned on. The values are calculated to maintain a good balance between the signal-to-noise dynamic range and the linearity dynamic range. The perfSelect input has 0=Optimized for linearity, 1=Best balance between linearity and noise, and 2=Optimize for SNR. Each attenuator must have memory allocated before calling this function. *SC5406B_ConvertRawCalData* must be called or valid structure calibration data must be entered before calling this function.

Function: **sc5406B_CalcGain**

Definition: **int sc5406B_CalcGain(**

```
int     sc5406B_CalcGain(
                        unsigned int frequency,
                        bool ifInvertEnable,
                        bool if3Fil1Enable,
                        attenuator_t *atten,
                        float temperature,
                        calibrationData_t *calData,
                        float *conversionGain);
```

Input:	unsigned int frequency	(input RF frequency in Hz)
	bool ifInvertEnable	(enable IF spectral inversion)
	attenuator_t *atten	(attenuation settings)
	float temperature	(temperature value of the device in degrees Celsius)
	calibrationData_t *calData	(calibration data for the device)
Output:	float *conversionGain	(calculated calibrate conversion gain for current settings)

Description: **sc5406B_CalcGain** calculates the calibrated gain based on the current user settings.

Function:	**sc5406B_CalcIfResponseCorrection**
Definition:	**int sc5406B_CalcIfResponseCorrection (**

```
int     sc5406B_CalcIfResponseCorrection (
                    float *offsetFrequencies,
                    unsigned int nPoints,
                    bool ifFil1PathEnable,
                    calibrationData_t *calData,
                    ifResponseCorrect_t *correctedIfResponse)
```

Input:	float *offsetFrequencies	(floating point number 1-D array)
	unsigned int nPoints	(number of points in the 1-D array)
	bool ifFil1PathEnable	(IF filter 1 path enable)
	calibrationData_t *calibrationData	(calibration data for the device)
Output:	float *correctedIfResponse	

Description: **SC5406B_CalculateIfResponseCorrection** determines the IF correct response for the set of IF offset frequencies. These offset frequencies may be the frequency components of an FFT of the acquired data being offset from its center frequency. To obtain the offset frequencies, one can simply subtract the frequencies from the IF center frequency. For example, if a digitizer sampling at 100 MHz is used to digitize the 70 MHz IF signal with bandwidth of 3 MHz, the center of the digitized signal is 30 MHz +/- 1.5 MHz. After performing digital spectral inversion and performing an FFT, take the subset of frequency components from 28.5MHz to 31.5 MHz and subtract 30 MHz to obtain the offset frequencies of -1.5 MHz to 1.5 MHz. Use this set of offset frequencies to compute the gain and phase corrections to be applied to the original signal spectrum at 28.5 MHz to 31.5 MHz. This algorithm may not be sufficient for computation of broadband signals due to the lack of computation speed and correction accuracy. The calibration stored does not account for in-band phase and amplitude variations due to temperature and these variations may cause sufficient errors, especially in broadband digital signals. The user should apply in situ equalization to correct for the in-band amplitude and phase errors.

Function: **SC5406B_ConvertRawTempData**

Definition:
```
int     sc5406B_ConvertRawTempData(
                unsigned int rawTempData,
                float *temperature)
```

Input:	unsigned int rawTempData	(16-bit rawTempData stored in a 32-bit unsigned int)
Output:	float *temperature	(temperature value of the device in degrees Celsius)

Description: **SC5406B_ConvertRawTempData** converts the rawTempData into a floating point number.

Function: **sc5406B_spline**

Definition:
```
int     sc5406B_spline( double *xArray,
            double *yArray,
            int  nPoints,
            double  firstBoundary ,
            double  secondBoundary ,
            double *yInterpolant)
```

Input:	double *xArray	(the set of independent values)
	double *yArray	(the set of x-dependent function values; size is the same as xArray)
	int nPoints	(the number of points in xArray)
	double firstBoundary	(the second derivative of the first point in the set)
	double secondBoundary	(the second derivative of the last point in the set)
Output:	double *yInterpolant	(the return set of interpolants)

Description: Returns the Spline interpolants of the input parameters.

Function: **sc5406B_splineInterp**

Definition:
```
int     sc5406B_splineInterp(
                double *xArray,
                double *yArray,
                double *yInterpolant,
                double nPoints,
                double x,
                double *interpolatedYValue)
```

Input:	double *xArray	(the set of independent values)
	double *yArray	(the set of x-dependent function values; size is the same as xArray)
	double *yInterpolant	(the returned interpolant from spline())
	int nPoints	(the numbers of points in xArray)
	double x	(the value at which interpolation is performed)
Output:	double *interpolatedYValue	(the corresponding interpolated value at x)

Description: Returns the Spline interpolated value.

Programming the RS232 Interface

Function Definitions and Usage of the RS232 API

The driver functions to access the device through the RS232 port are written upon NI-VISA, so NI-VISA must be installed to use them. There is no separate installer (.inf file) requirement as NI-VISA contains the RS232 protocol. The driver functions are provided as a DLL which can be called from C/C++, BASIC, LabVIEW, etc. The LabVIEW functions provided are simply wrappers of this DLL.

The functions are near identical to the USB set with the exception that sc5406B_SearchDevices is not provided, and the sc5406B_OpenDevice returns the device handle differently; see the rs232 header file for more information. Also, refer to the USB function descriptions for details on function usage. The device handle is defined as an *unsigned integer*, and is passed into the function as a pointer in the RS232 implementation, which differs from the USB version where the device handle is a return type of *deviceHandle*. Furthermore, the baud rate must be passed into the function at this point. The device supports 2 baud rates: 57600 and 115200. The baud rate for the device must be set at power up or on hardware reset of the device through pin 18 of the auxiliary front panel connector. This pin is defaulted to logic high, which set the baud rate at 57600. Pulling this pin to logic low will set the rate at 115200.

Function:	**sc5406B_OpenDevice**	
Definition:	**int *sc5406B_OpenDevice(char *visaResource, unsigned int baudrate, unsigned int *deviceHandle)**	
Return:	int	(status)
Output:	char *visaResource	(resource name such as "COM1")
	unsigned int baudrate	(sets the host to the baudrate of the device)
Output:	unsigned int* deviceHandle	(deviceHandle)
Description:	**sc5306a_OpenDevice** opens the device and turns on the front panel "active" LED if successful. This function returns a handle to the device for other function calls.	

Addressing the RS232 Registers Directly

When the user uses the supplied API, data sent and returned is appropriately handled and the user gets the proper end result. However, if the user chooses to read and write to the RS232 registers directly, the following information, as well as the register descriptions in the USB section, are helpful and needed.

The device with the RS232 option has a standard interface buffered by an RS232 transceiver, so that it may interface directly with many host devices such as a desktop computer. The interface is provide through the communication I/O connector and its pinouts are giving in Table 1. The device communication control is provided in Table 13.

Table 13. RS232 communication settings

Baud rate	Rate of transmission. Pin 12 of the Digital IO connector selects the rate. By default if the pin is pulled high or open, the rate is set 56700 at power up or upon HW reset. When the pin is pulled low (jumper to pin 11) or grounding it, the rate is set to 115200.
Data bits	The number of bits in the data is fixed at 8.
Parity	Parity is 0 (zero)
Stop bits	1 stop bit
Flow control	0 or none

Writing to the device via RS232

It is important that all necessary bytes associated with any one register is fully sent, in other words, if a register requires a total of 4 bytes (address plus data) then all 4 bytes must be sent even though the last byte may be a null. The device upon receiving the first register addressing byte will wait for all the data bytes associated with it before acting on the register instruction. Failure to complete the register transmission will cause the device to behave erratically or hang. Information for the configuration or write-to registers is given in Table 2.

When the device receives all the information for a register and finishes performing its instruction, it will **return 1 byte back** to the host. Querying this return byte ensures that the prior configuration command has been successfully executed and the device is ready for the next register command. It is important to clear the incoming RX buffer on the host by querying it or force flushing it to avoid in-coming data corruption of querying registers. The return byte value is 1 on success and 0 on an unsuccessful configuration.

Reading from the device via RS232

To query information from the device, the query registers are addressed and data is returned. The returned RS232 data length for querying registers is always 2 bytes, however valid returned data depends on the queried register; Table 3 contains the query register information. As with the configuration registers, it is important that the data byte(s) associated with the query registers are sent even if they are nulls. Data is returned MSB first. The returned valid data length is also detailed below in Table 14. Note that temperature is returned as a digital code so please refer to the Reading Temperature Data section for information to convert it to floating number in degree Celsius

Table 14 Valid returned data

REGISTER	BYTE 1	BYTE 0
GET_DEVICE_STATUS (0x18)	valid	valid
GET_TEMPERATURE (0x19)	valid	valid
READ_CAL_EEPROM (0x20)	non-valid	valid
READ_USER_EEPROM (0x22)	non-valid	valid

Programming the SC5406B Serial Peripheral Interface

The SPI Communication Connector

The SC5406B-USB/SPI uses a 9-pin micro-D subminiature connector for SPI communication with the device through a 4-wire serial peripheral interface. The pinout of this male connector, viewed from the RF connector side as shown below, is listed in Table 15. In addition to the 4-wire SPI lines, is the SerialReady line that indicates whether the device is ready to accept data or not. Additional lines for device reset and remote status indicators are available on a separate auxiliary header and its description maybe found the SC5406B Operating and Programming manual under the *Auxiliary Connections*

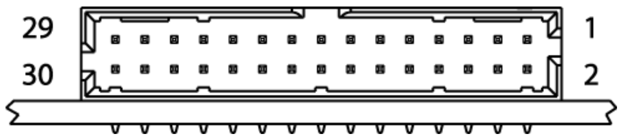


Table 15 SPI pin definitions

Pin Number	SPI Function	Description
25	$\overline{CS}$	Chip Select (active low, output from master)
26	CLK	Serial Clock (output from master)
27	MISO	Master Input - Slave Output (output from slave)
28	GND	Signal Ground
29	MOSI	Master Output Slave Input (output from master)
30	SRDY	Indicates on high when SPI is ready

The SC5406B SPI Architecture

The SC5406B SPI interface is implemented using 8-bit length physical buffers for both the input and output, hence they need to be read and cleared before consecutive byte data can be transferred to and from them. Therefore, a time delay is required between consecutive bytes of a command written to or read from the SC5406B by the host. The chip-select pin ($\overline{CS}$) must be asserted low before data is clocked in or out of the product. $\overline{CS}$ must be asserted for the entire duration of the command.

Commands to the device vary between two to five bytes of data. Once a full command has been received, the SC5406B will proceed to process the command and de-assert low the SerialReady bit. The status of this bit can be read by the host by invoking the SerialReady register (0x1F). The SerialReady bit can also be monitored on pin 1 of the SPI interface connector. While SerialReady is de-asserted low, the SC5406B will ignore any incoming commands, and they are lost. Only the command received after

SerialReady is re-asserted high is then processed. It is important that the user monitors the SerialReady bit and performs transfers only when it is asserted high to avoid miscommunication with the product. Figure 5 shows the command transfer for obtaining the SerialReady bit, which is returned in bit [0] of the returned data byte 0. The device will return the same number of bytes back to the host via the MISO line as the number of bytes it receives via the MOSI line. Data returned typically do not carry any valid information unless specifically requested for valid data in a preceding query command; see the section on *Reading Requested Data via the SPI Bus*.

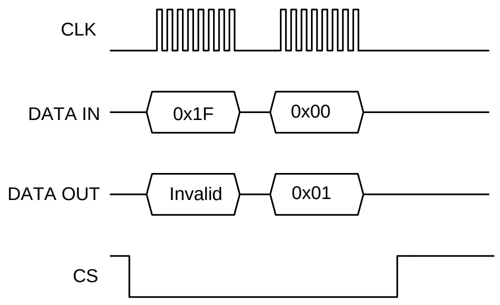
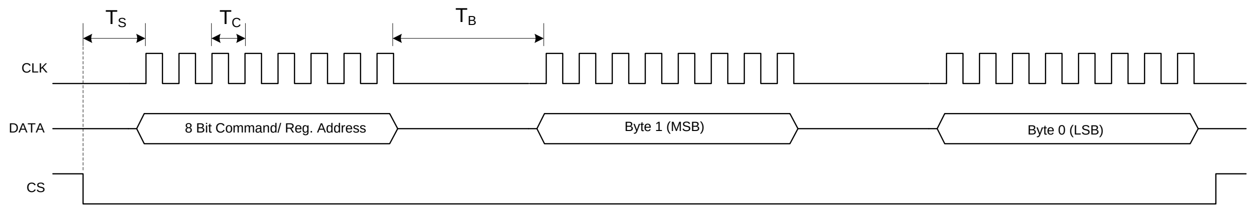


Figure 5 Querying the device for SerialReady status

SPI Clock Rates and Modes

Figure 6 shows a single 3-byte SPI command transfer initiated by the host, as the SC5406B is always in slave mode. The largest data length is 32 bits following the 8 bit command register, so parceling the 32 bits into bytes, the largest number of data bytes transferred is 4. The most significant byte (MSB) of the data is sent immediately after the register (address) byte. The $\overline{CS}$ pin must be asserted low for a minimum period of 1 μs before data is clocked into the SC5406B. The clock rate may be as high as 1.2 MHz. However, if the externally generated SPI commands do not have sufficient signal integrity due to cabling problems (impedance, crosstalk, etc.), the rate should be lowered. It is recommended that the clock rate not exceed 1.2 MHz to ensure proper serial operation. As mentioned above, the SPI architecture limits the byte rate because after every byte transfer, the input and output SPI buffers need to be cleared and loaded respectively by the SC5406B SPI engine. The time required by the SC5406B to perform this task is indicated in Figure 6 by T_B, which is the time interval between the end of one byte transfer and the beginning of another within a command. The recommended time delay for T_B is 5μs or greater.



T_S : Time between CS assertion and first clock cycle >= 5 uS
T_C : Clock period = 1 uS typical (Clock rate depends on signal integrity from host)
T_B : Duration between byte transfer >= 5 uS

Figure 6. Single SPI command transfer consisting of 3 bytes

After each command is received successfully, it is processed by the SC5406B. The time required to process a command is dependent on the command itself. Measured times for command completions are typically between $40\ \mu s$ to $350\ \mu s$ after reception. It is required that the user poll the status of the SerialReady bit before sending another command. The minimum wait time between successive polls of the SerialReady register is $10\ \mu s$. However, for large frequency step sizes where the frequency takes several milliseconds to settle to it new value, it is important to allow for frequency settling before sending in a new frequency configuration command.

There are two selectable modes of SPI operation available on the device. Leaving pin 23 of the *communication I/O connector* open or pulled high (3.3V), mode 1 is enabled at power-up or upon device reset. Jumping the pin to ground will enable mode 0 at power-up or upon reset. Once the mode is set, which typically take a second after power-up, logic on pin 23 will no longer affect the device. In the default mode (mode 1) serial data in and out of the device are clocked on the falling edge of the SPI clock while the CS line is asserted active low. In mode 0, both data in and out are clocked on the rising edge of the SPI clock. Both modes require that the most significant bit (msb) is written first. The recommended clock rate for mode 0 is between 150 kHz and 1.2 MHz, and for mode 1 is between 100 Hz and 1.2 MHz.

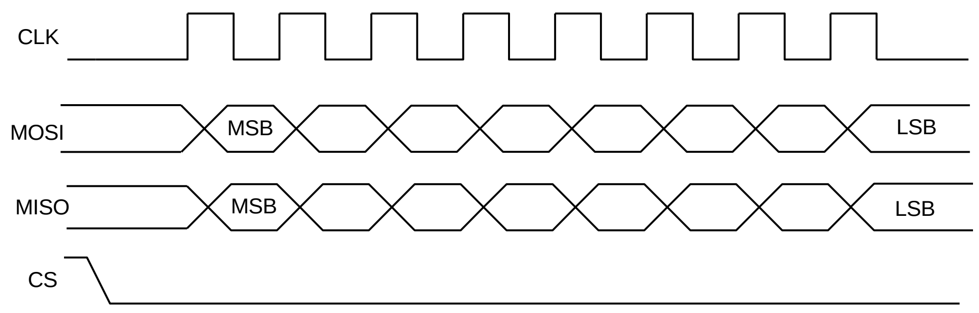


Figure 7 SPI mode 1

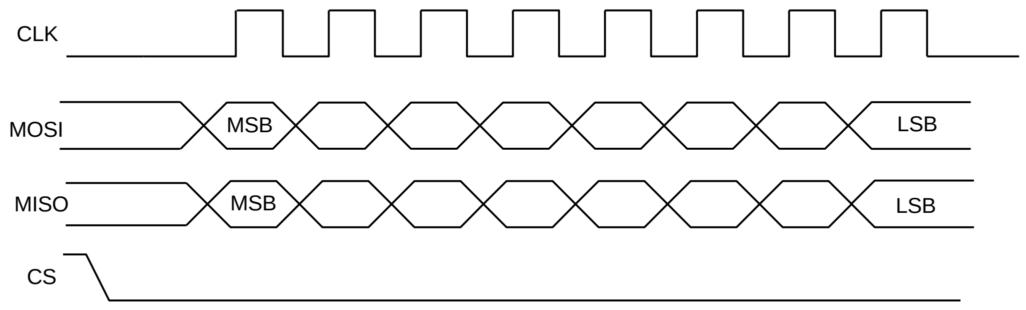


Figure 8 SPI mode 0

Writing Configuration Data via the SPI Bus

SPI commands for the SC5406B vary between 2 bytes to 5 bytes. The most significant byte (MSB) is the command register address as noted in the register map of Table 16. The subsequent bytes contain configuration data. As data from the host is being transferred to the SC5406B via the MOSI line, data present on its SPI output buffer is simultaneously transferred back via the MISO line. The data present on the SPI output buffer is data that had been requested by a preceding **Query** command. See the section *Reading Requested Data via the SPI Bus* for more information on retrieving data from the device. Figure 9 shows the contents of a series of single 3-byte SPI commands written to the SC5406B. Consecutive transfers should only be made when SerialReady is asserted high or after a pause period of $500\mu s$ or more.

Table 16 Configuration registers

Register (Address)	Data Bytes	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Default
INITIALIZE (0x01)	[7:0]	Open	Open	Open	Open	Open	Open	Open	Mode	0x00
SET_SYSTEM_ACTIVE (0x02)	[7:0]	Open	Open	Open	Open	Open	Open	Open	Enable SYS LED	0x00
POWER_SHUT_DOWN (0x05)	[7:0]	Open	Open	Open	Open	Open	Open	Open	Enable	0x00
RF_FREQUENCY (0x10)	[7:0]	Frequency Word [7:0]								0x00
	[15:8]	Frequency Word [15:8]								0x00
	[23:16]	Frequency Word [23:16]								0x00
	[31:24]	Frequency Word [31:24]								0x00
ATTENUATOR_SETTING (0x11)	[7:0]	Attenuator Value								0x00
	[15:8]	Attenuator								0x00
RF_MODE_SETTING (0x13)	[7:0]	Open	Open	Open	Open	Open	Fast Tune Enable	Fine Tune		0x00
IF_BAND_SELECT (0x15)	[7:0]	Open	Open	Open	Open	Open	Open	Open	Band	0x00
SIG-GEN_ENABLE (0x1B)	[7:0]	Open	Open	Open	Open	Open	Open	Open	Enable	0x00
REFERENCE_SETTING (0x16)	[7:0]	Open	Open	Open	Open	Reserv	100 MHz Out Sel	Ref Out Enable	Lock Enable	0x00
REFERENCE_DAC (0x17)	[7:0]	DAC word [7:0]								0x00
	[15:8]	DAC word [15:8]								0x00
IF_INVERT_SETTING (0x1D)	[7:0]	Open	Open	Open	Open	Open	Open	Open	Enable	
WRITE_USER_EEPROM (0x23)	[7:0]	EEPROM DATA [7:0]								
	[15:8]	EEPROM Address [7:0]								
	[23:16]	EEPROM Address [15:8]								
PHASE_SETTING (0x32)	[7:0]	Units Value[7:4]				Tenths Value				0x00
	[15:8]	Open	Open	Units Value [13:8]						0x00

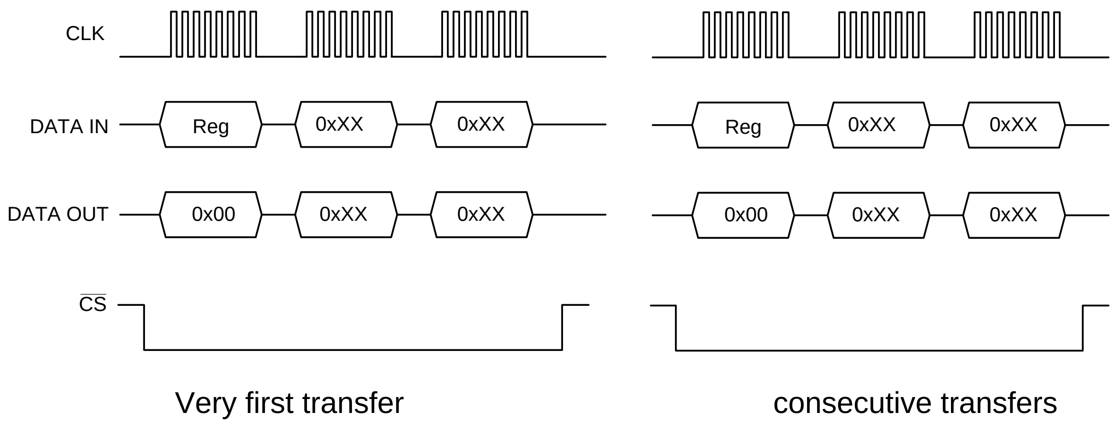


Figure 9 Transfers of 3 byte commands

Reading Requested Data via the SPI Bus

Data is simultaneously written and read back during an SPI transfer cycle; however the returned data may be invalid. To read back valid data a query command to request for data must be issued first, followed by reading the SPI output buffer, a total of 2 SPI transfer cycles. The query registers are listed in Table 17, and namely the FETCH_TEMPERATURE, FETCH_DEVICE_STATUS, FETCH_CAL_EEPROM, and FETCH_USER_EEPROM registers.

Table 17: Query Registers

Register (Address)	Data Byte	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Default
FETCH_DEVICE_STATUS (0x18)	[7:0]	Open	Open	Open	Open	Open	Open	Open	Open	0x00
FETCH_TEMPERATURE (0x19)	[7:0]	Open	Open	Open	Open	Open	Open	Open	Open	0x00
SPI_OUTPUT_BUFFER (0x1A)	[7:0]	Data Byte 0								0x00
	[15:8]	Data Byte 1								0x00
SERIAL_READY (0x1F)	[7:0]	Open	Open	Open	Open	Open	Open	Open	Open	0x00
FETCH_CAL_EEPROM (0x20)	[7:0]	EEPROM Address [7:0]								0x00
	[15:8]	EEPROM Address [15:8]								0x00
FETCH_USER_EEPROM (0x22)	[7:0]	EEPROM Address [7:0]								0x00
	[15:8]	EEPROM Address [15:8]								0x00

After issuing a request command, the device gathers the information and places the results in the SPI_OUTPUT_BUFFER register (0x1A), which can be read back by querying it. The SPI_OUTPUT_BUFFER must contain the register value (0x1A) in the first byte, followed by 2 empty bytes to return the requested data. Of the 3 bytes returned, only the last 2 bytes contain valid data. An example to request for temperature from the device is shown in the sequence of steps of Figure 10.

Querying for temperature data in the SPI_OUTPUT_BUFFER should be sent after polling the SERIAL_READY register to ensure that the prior request command has been fully executed. In figure 9, polling the SERIAL_READY register is not shown explicitly. If the delay between consecutive commands is longer than the preceding command processing time, then querying of the SERIAL_READY register may not be required.

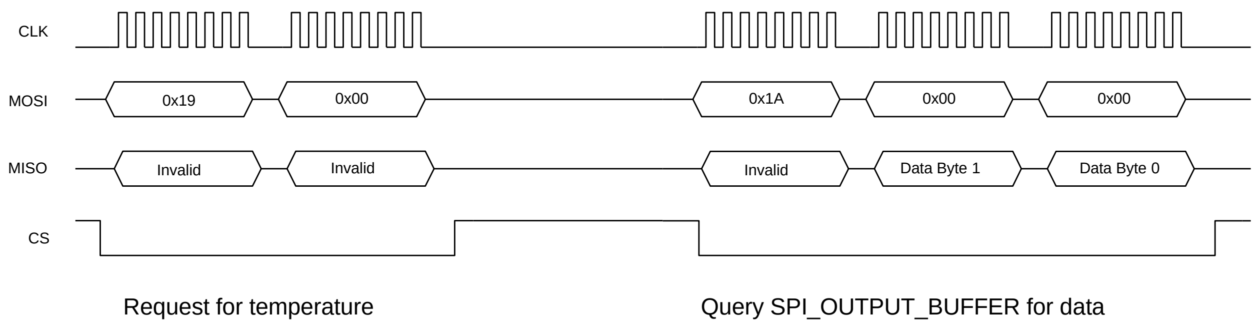


Figure 10 Reading the device temperature

In the above example, valid data is present in the last 2 bytes; byte 1 and byte 0. Table 18 shows the valid data bytes associated with the querying register.

Table 18 Valid returned data bytes

Register (Address)	**Reg Code**	Byte 1	Byte 0
GET TEMPERATURE	0x19	Valid	Valid
GET DEVICE STATUS	0x18	Valid	Valid
READ USER EEPROM	0x22		Valid
READ CAL EEPROM	0x20		Valid

CALIBRATION & MAINTENANCE

The SC5406B is factory calibrated and ships with a certificate of calibration. SignalCore strongly recommends that the SC5406B be returned for factory calibration every 12 months or whenever a problem is suspected. The specific calibration interval is left to the end user and is dependent upon the accuracy required for a particular application.

SC5406B calibration data is stored in the RF module (metal housing). Therefore, changing or replacing interface adapters will not affect unit calibration. However, SignalCore maintains a calibration data archive of all units shipped. Archiving this data is important should a customer need to reload calibration data into their device for any reason. SignalCore also uses the archived data for comparative analysis when units are returned for calibration.

Should any customer need to reload calibration data for their SC5406B, SignalCore offers free support through support@signalcore.com. SignalCore will provide a copy of the archived calibration data along with instructions on how to upload the file to the SC5406B.

The SC5406B requires no scheduled preventative maintenance other than maintaining clean, reliable connections to the device as mentioned in the "*Getting Started*" section of this manual. There are no serviceable parts or hardware adjustments that can be made by the end user.

Revision Notes.

Rev. 1.0	Original document
Rev. 1.1	Address Removed
Rev. 1.2	Corrected torque range

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