SC1905 Release Notes
User Guide

UG6853; Rev 0; 01/19

Abstract

This document provides information to evaluate the operation and performance of the SC1905 with different power amplifiers.

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1. <u>Introduction</u>

1.1. Overview

The SC1905 RF power amplifier linearizer (RFPAL) is designed to fully address the linearization requirements for 5G cellular infrastructure (i.e., LTE, TD-LTE, WCDMA) and other systems. The SC1905 is pin-compatible with the SC1894, supporting signal bandwidth up to 100MHz over a 698MHz to 3800MHz frequency range.

The SC1905 includes the following three levels of features:

- Linearizer
  - o Wideband performance for fully and non-fully occupied signals.
  - o Optimized for Citizens Broadband Radio Service (CBRS) Band (3550MHz to 3700MHz) Applications.
  - o Support for the following external clock system clock rates (MHz): 10, 13, 15.36, 19.2, 20, 26, and 30.72.
  - o Power indicator sliders based on RFIN AGC (PDET) and RFFB AGC values. A new scratch variable was added to always reflect the current value of the RFFB AGC index being used by the firmware.
- Features for debug purposes only (no performance guaranteed)
  - o RFIN and RFFB power measurement unit (PMU)
    - ▪ Independent RFIN and RFFB power measurement. See section 6.1 for details.
  - o Spectrum monitoring and spectral emission mask (SEM). See section 6.2 for details.
  - o Complementary cumulative distribution function (CCDF). See section 6.3 for details.
- The RFPAL Advanced GUI is used for evaluation to allow access to the EEPROM customer configuration parameters in the ACCP tab. These parameters are described in the SC1905 SPI programming guide [3].

⚠ *Read the RFPAL Advanced GUI Installation Guide [1].*

⚠ *It is required to uninstall all previous GUI versions and all previously installed firmware before installing the RFPAL Advanced GUI version 3.0.9.0.*

- SC1905 Frequency Bands:
  - o 09: 3300MHz to 3800MHz
  - o 08: 2700MHz to 3500MHz
  - o 07: 1800MHz to 2700MHz
  - o 06: 698MHz to 2700MHz (Stitched range. To limit spurious, it is recommended to limit the minimum and maximum frequency scanning range to the frequency range needed for the application.)
  - o 05: 1040MHz to 2080MHz
  - o 04: 698MHz to 1040MHz

- Evaluation Kits (contact a Maxim Integrated Sales representative for availability):
  - o 3300MHz to 3800MHz (P/N SC1905-EVK3400)
  - o 2300MHz to 2700MHz (P/N SC1905-EVK2400)
  - o 1800MHz to 2200MHz (P/N SC1905-EVK1900)

1.2. Scope

This document provides a comprehensive user guide for the SC1905 in order to evaluate the operation and performance with a given power amplifier. The documents referenced in section 1.4 are companion documents for use when implementing the SC1905 in a design.

1.3. Limitations

- RFIN and RFFB power levels reported by the GUI need to be calibrated since the offset varies with the EV kit frequency band.
- The SC1905 supports instantaneous signal bandwidths from 5MHz to 100MHz.
- The SC1905 is guaranteed to operate across power supply and temperature variations as specified in the data sheet.

1.4. Reference Documents

	Document
[1]	RFPAL Advanced GUI Installation Guide
[2]	SC1905 Hardware Design Guide
[3]	SC1905 SPI Programming Guide
[4]	SC1905 Data Sheet
[5]	Designing Linearizable RF PA using RFPAL

2. <u>Quick Start Guide</u>

To get started with the evaluation, the following steps are recommended:

- Install the GUI as described in RFPAL Advanced GUI Installation Guide [1].
- Check the SC1905 evaluation kit hardware configuration in section 3.
- Set up the SC1905 evaluation kit with the PA line-up as described in section 4.
- First, focus on testing a static waveform at the PA maximum output power targeted in Optimized mode. Make sure to reset the SC1905 after changing the PA or signal conditions.
- For performance optimization, refer to section 3.4.
- For tuning your power amplifier, refer to the application note "Designing_Linearizable_RF_PA_using_RFPAL application" [5].
- For dynamic performance, make sure to first calibrate in smooth mode. Refer to section 5.6.2.1.
- Refer to section 5 for detailed operation of the SC1905.
- Refer to the debug features in section 6.
    - o RFIN and RFFB Power Measurement. See section 6.1 for details.
    - o Spectrum Monitoring and Spectral Emission Mask (SEM). See section 6.2 for details.
    - o Complementary Cumulative Distribution Function (CCDF). See section 6.3 for details.
- See the performance data example in the Power Amplifier Results on the SC1905 web page.

3. SC1905 Evaluation Kit Setup

3.1. SC1905 Evaluation Board with Integrated Delay Line
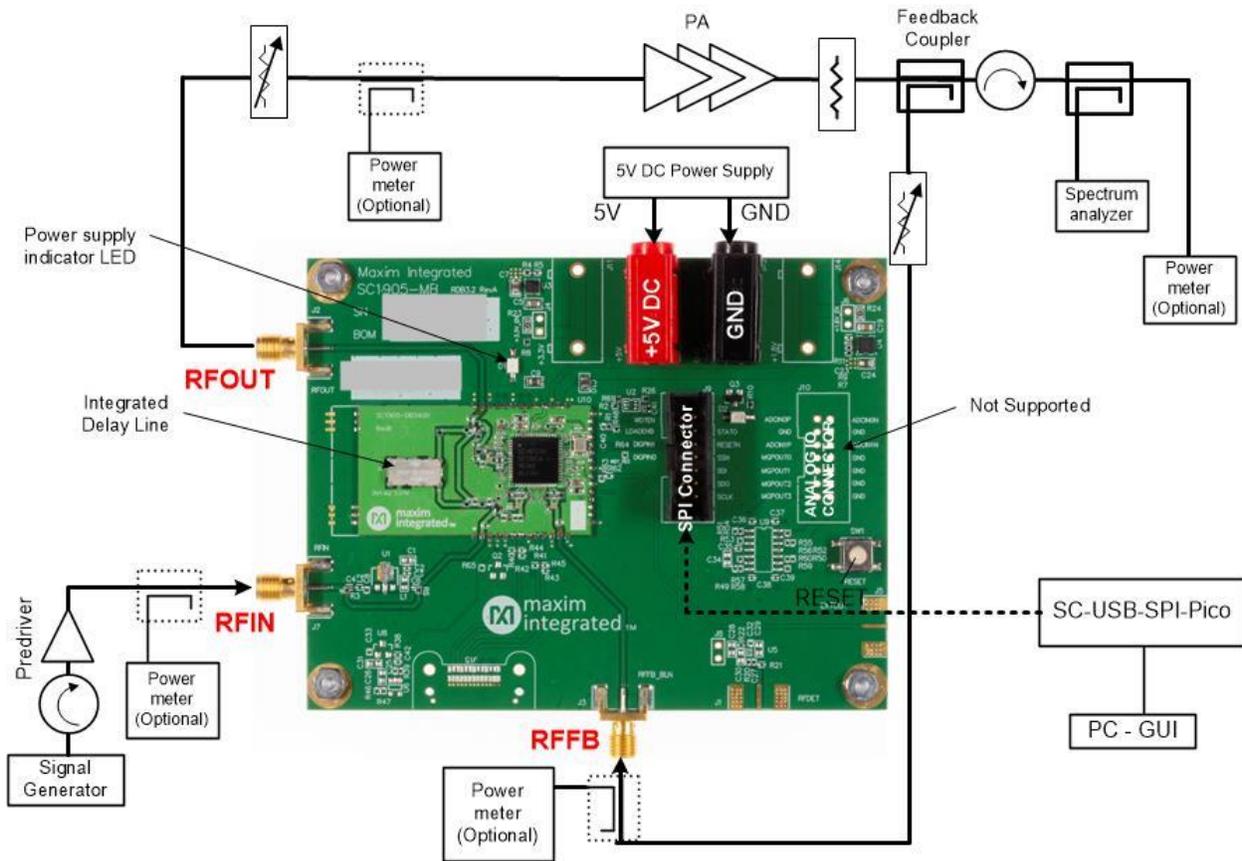
Figure 1. SC1905 evaluation board connection diagram.

1. The SC1905 Evaluation Board must be powered from a +5V, DC power supply capable of providing 0.6A (although the actual average power consumption of SC1905 is lower). Connect the power supply to the banana jacks on the SC1905 Evaluation Board labeled +5V (red) and GND (black).
2. RFOUT is connected to the power amplifier input. The attenuator between the RFOUT and the PA is useful for setting the RFIN level of the Linearizer (assuming that the PA is adjusted to a fixed output power) and should be set using the RFIN AGC slider on the GUI. While not absolutely required, it is helpful that an adjustable attenuator is used for setting the power level of the RF power amplifier.
3. RFFB is connected to the power amplifier feedback coupler. While not absolutely required, it is helpful during the optimization of the linearization performance, to adjust the attenuator to set the RFFB level into the evaluation board by using the RFFB AGC slider.

⚠ *IMPORTANT — RFIN and RFFB level should follow the recommendations from section 5.4.*

4. Connect the USB cable from NI-8451 or SC-SPI-USB-Pico to the PC. Maxim recommends using a USB cable less than 4ft-long.
5. Reset SC1905 using either the GUI or the board reset button.

Multiple PCB configurations were required in order to cover all the frequency bands as specified in the data sheet. The different board configurations were required to accommodate the different coupling ratios for RFIN and RFOUT couplers as described in **Table 1**. It is important as well in the gain lineup to take into account the RFIN to RFOUT loss described in that same table.
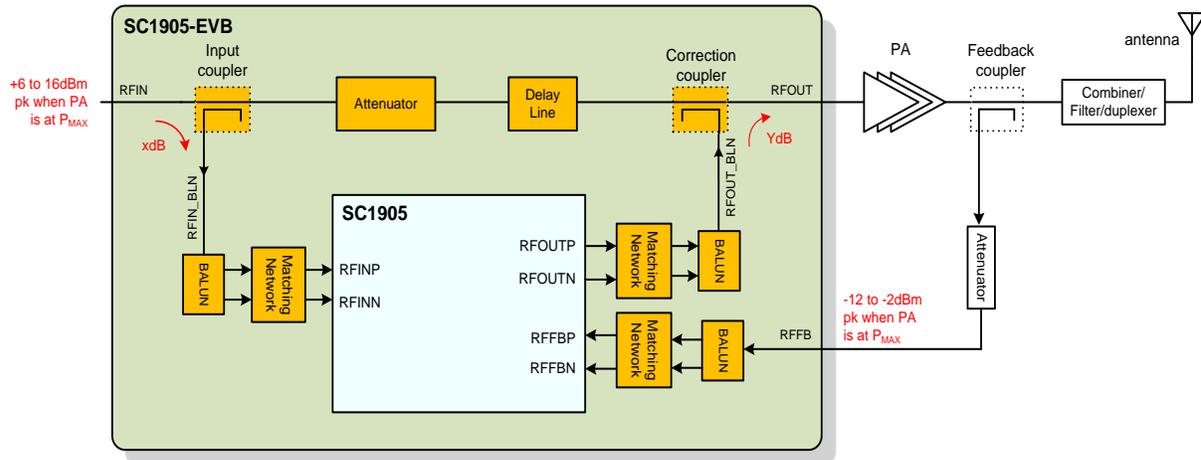
Figure 2. SC1905 system block diagram.

Table 1. RFIN and RFOUT Couplers for SC1905 Evaluation Boards

EV Kit #	Frequency Range (MHz)	RFIN Coupler	RFOUT Coupler	RFIN-RFOUT Loss (dB)
SC1905-EVK3400	3300-3800	5	7	7.5
SC1905-EVK2400	2300-2700	10	6	6.5

3.2. Programmable Through-Path Delay Line and Attenuator

The SC1905 EV kit printed circuit board integrates a ceramic delay line. In original configuration from Maxim, the delay value is set to 2ns (**Figure 3**). By modifying the location of the 0Ω jumpers, the delay can be set to 0ns bypassing the delay **(Figure 4).**

Provisions are also available for a through-path pi-attenuator.
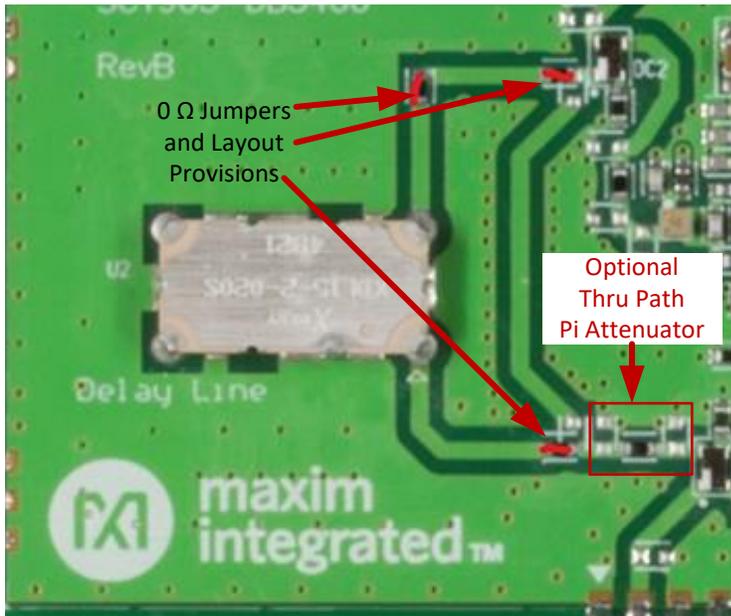
Figure 3. Default configuration to use delay line.
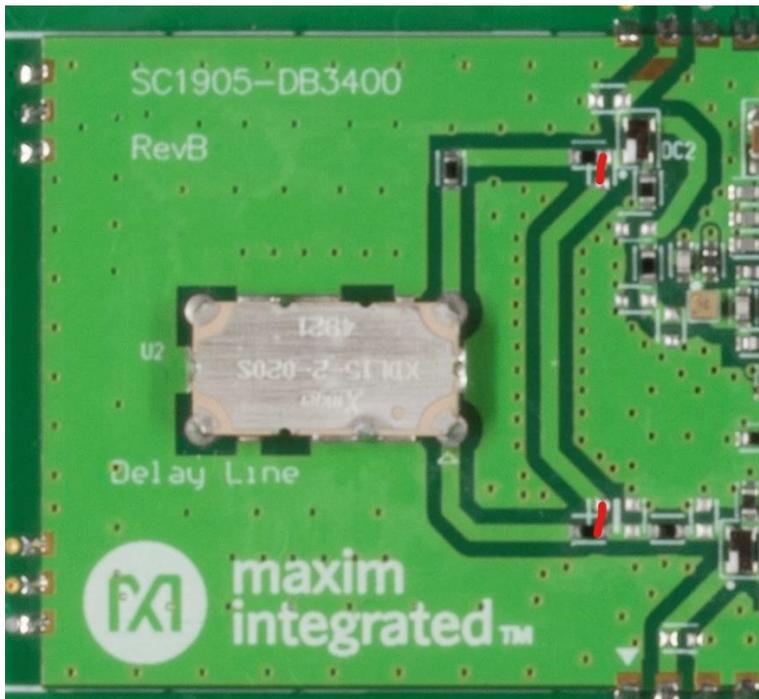
Figure 4. Location of 0Ω jumpers for 0ns delay.

3.3. Power Supply Connections and Regulators

In default configuration, Evaluation Boards require only 5V power supply connections (**Figure 5**). Onboard regulators are used to generate supply voltages (1.8V and 3.3V) for RFPAL IC.

In case it is required to bias RFPAL directly using external 3.3V and 1.8V supplies, provisions for connectors are available on the EV kit board as shown in Figure 5. Regulator outputs must be disconnected by removing 3.3V and 1.8V jumpers shown.
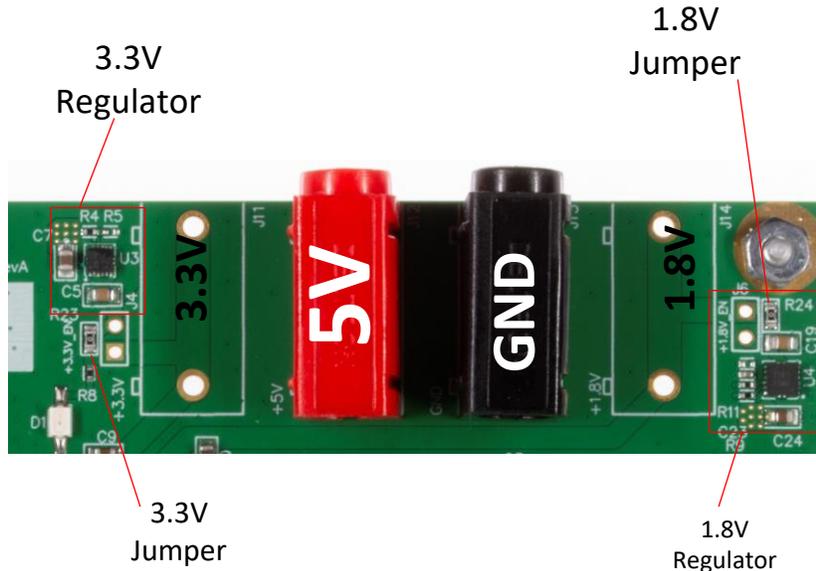
Figure 5. SC1905 - EV kit power supply connections.

3.4. What to look for if performance is lower than expected?

- Make sure that the Status Indicator indicates "TRACK." If not, then SC1905 has not fully converged to the optimal solution.
- Check the linearity of the signal source provided to the linearizer. A predriver between the signal generator and RFIN might be required to ensure that the signal source has enough linearity. It is recommended that the input linearity be at least 5dB to 10dB better than the desired linearity at the PA output.
- Check that RFIN and RFFB are at the recommended levels at the PA maximum output power (see section 4.1).
- Make sure the spectrum analyzer internal attenuation is not too high, increasing the noise floor and limiting performance. Reduce the spectrum analyzer's attenuation as much as possible while not overdriving the analyzer.
- Make sure the PA is not running into compression (see section 6.3).
- Try different delay line values, especially in case of signal bandwidth greater than 20MHz (see section 4.2). Make sure the firmware is configured to the correct frequency range and the input signal is within the frequency scanning boundaries (see section 5.3.3).
- For non-fully-occupied signals, it is recommended to configure some parameters as defined in the SPI programming guide [3].

3.5. Signal Generator Considerations for Power Level Change Performance Tests

To prevent the signal generator from transmitting undesirable peaks during power level changes, it is required to take the following precautions.

- With some signal generators, it is important to turn ALC OFF and to configure "*Power Search*" properly.
    - Select "*Manual*" option if available.
    - With some signal generators, "*Power Search*" doesn't have a "*Manual*" option. In this case, select "*Span.*" Then select "*Configure Span Power Search*" and select "User" for "Span Type" and configure "Start Frequency" and "Stop Frequency" to the center frequency of the signal test.

4. <u>SC1905 Hardware Setup</u>

4.1. RFIN and RFFB Levels

For optimal performance, it is required to set the correct RFIN and RFFB levels into SC1905 as described in the SC1905 data sheet [4]. As shown in Table 2, the different SC1905 EV kits have different offsets over frequency and it is important to calibrate the RFIN and RFFB offsets in the GUI.

If the system is set up as described in the following tables, the linearization provided by SC1905 should be sufficient over the entire output-power operating range of a typical power amplifier. The amount of correction required by the amplifier generally decreases as the PA-output power is backed off (constant SEM specifications).

For example, for SC1905-EVK1900 with 10dB RFIN coupler and 8dB PAR, it is recommended to set RFIN and RFFB power levels when the PA is at maximum output power:
- RFIN = +6dBm RMS, which is +14dBm peak into the coupler
- RFIN_BLN = -4dBm RMS, which is +4dBm peak into the Balun
- RFFB = -12dBm RMS, which is -4dBm peak.

4.2. RFIN and RFFB Evaluation Board Offsets

The RFIN and RFFB power measurement values reported by the GUI reflect the power level into SC1905. To reflect the power level into the SC1905 EV kit SMA connectors or any other reference points, calibration is required as explained in section 6.1.1 to adjust the RFIN and RFFB offsets. These offsets depend on the board design due to the RFIN coupler ratio and board loss as shown in Table 2.

Table 2. SC1905 EV Kit RFIN and RFFB Offsets over Frequencies

EV Kit	Frequency (MHz)	RFIN Offset[1] (dB)	RFFB Offset[2] (dB)
EVK3400[3]	3550	7.7	-3.5
EVK2400	2550	11.9	0

1. RFIN Offset = RFIN Measured at SMA Connector on SC1905 EV kit RFIN PMU value (Default in GUI = 0dB).
2. RFFB Offset = RFFB Measured at SMA Connector on SC1905 EV kit RFFB PMU value (Default in GUI = 0dB).
3. For SC1905-EVK3400, more fluctuation expected for reported PMU value due to board-to-board variation and PMU accuracy only up to 2.7GHz.

⚠ *IMPORTANT: RFIN and RFFB offsets are provided as examples and are expected to vary over ICs and EV kits. See GUI Figure 6 for an example.*

4.3. Through-Path Delay and Loss

The evaluation kit board utilizes an Anaren® XDL15-2-020S 2ns delay line. The evaluation kit board can be configured with 0Ω jumpers to either 2ns or ~0ns by by-passing it. It is also possible to replace the Anaren XDL15-2-020S 2ns delay line with Anaren XDL15-3-030S 3ns delay line as the evaluation boards were designed to accommodate both.

Table 3. Delay Line Insertion Loss

Parameter	Typical	Units	Frequency (MHz)
Delay	2	ns	698-3800
Insertion Loss	1.6	dB	700
Insertion Loss	1.8	dB	900
Insertion Loss	3.2	dB	2140
Insertion Loss	3.7	dB	2800
Insertion Loss	4.8	dB	3600
Insertion Loss	5	dB	3800

A through-path delay line between the input and output couplers (see Figure 3 for coupler locations) that approximates the internal delay of SC1905 can be required for optimal performance, especially for bandwidths wider than 20MHz.

For most wideband PA applications, the optimal delay is approximately 2ns to 3ns; this is the length of the delay circuit integrated with the evaluation kit. Some designs may require more or less delay in the through path to optimize performance. Maxim suggests making system measurements with the following delay-line options:
1. 2ns (integrated)
2. 3ns

For most PA's, the optimum delay value is 2ns to 3ns for best performance. For 100MHz performance, it is critical to minimize the memory effect, and, in that case, the 2ns delay line offers the best performances. For 20MHz signal bandwidth, the amplifiers can tolerate more memory effect, and, in that case, the 3ns delay line might offer better performance. The optimum delay line should be determined during product development.

NOTE
- The absolute phase of the delay line is not critical.
- The delay-line delay accuracy is not critical.

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4.4. Average Coefficient Indicator

The SC1905 provides an average coefficient indicator. The average coefficient indicator gives an indication if the SC1905 is operating within the optimal range for linearizing the amplifier under test. The average coefficient indicator, if checked, should be done once TRACK is reached at maximum output power. At the same time, the final linearity (ACLR or IMD level) of the system under test should be measured. This is intended to be used as an indicator during manufacturing as part of a factory alignment and verification. It is not intended to be used to monitor the system in field operation.

The SC1905 correction-signal processor is capable of operating over a wide-dynamic range. For this reason, the valid operating range can span a wide range of values. The optimal location for the indicator also heavily depends on the PA's IMx roll-off performance. As a general rule, the average indicator should be lower if the PA's IMs roll off very fast (i.e., IM3 >> IM5, etc.) or higher if the IMs are more 'flat' (i.e., IM3 ~ IM5, etc.). It is not recommended to "over optimize" using this parameter; any value within the range and possibly even beyond is a valid condition if the resulting corrected performance meets expectation.

If the Avg Coeff Val > 100 when operating at the typical power amplifier maximum output power and the system linearity is not as expected, then this is an indication that the correction power at RFOUT is not at a sufficient level to correct the amplifier. The path loss from RFOUT_BLN to RFOUT should be verified and a lower coupling factor used for the RFOUT coupler, or in case an attenuator is used in this path, it should be reduced.

If Avg Coeff Val < 10 at the typical power amplifier maximum output power, the ratio of correction power to signal power might be too high. A typical measure would be to increase the coupler value or insert an attenuator in the RFOUT path.

4.5. External Clock Configuration

The SC1905 provides support for the following standard system clock rates (MHz): 10, 13, 15.36, 19.2, 20, 26, and 30.72. When the external clock rate is selected, then the GUI automatically configures the required EEPROM parameters. Refer to the SPI programming guide [3] for details on selecting these clock rates from the host.

To test external clock, it is required to modify SC1905 EV kits.

4.6. Evaluation Kit Board Typical Power Consumption at 25°C

Table 4 shows the SC1905 evaluation kit board typical 5V power consumption at room temperature (25°C).

Table 4. Typical 5V Average Power and Current Consumption for SC1905 EV Kit (25°C)

Conditions [1]	5V Current (mA)	Total Power (mW)
No Firmware Running	27	135
Average Current/PWR During INIT/CAL Modes	245	1225
FSA/TRACK Duty-Cycled Feedback OFF	286	1430
Power Monitoring Unit Measurements (Frozen Mode)	376	1880

1. Measurements made at the +5V supply of the SC1905 EV kit.

5. SC1905 Linerization Operation

This section describes how to change certain parameters within the SC1905 as well as how to access status information over the SC1905 SPI. The supplied RFPAL GUI enables the user to access the SC1905 SPI using the SPI to USB converter.

5.1. SC1905 GUI

Figure 6. SC1905 main GUI window.
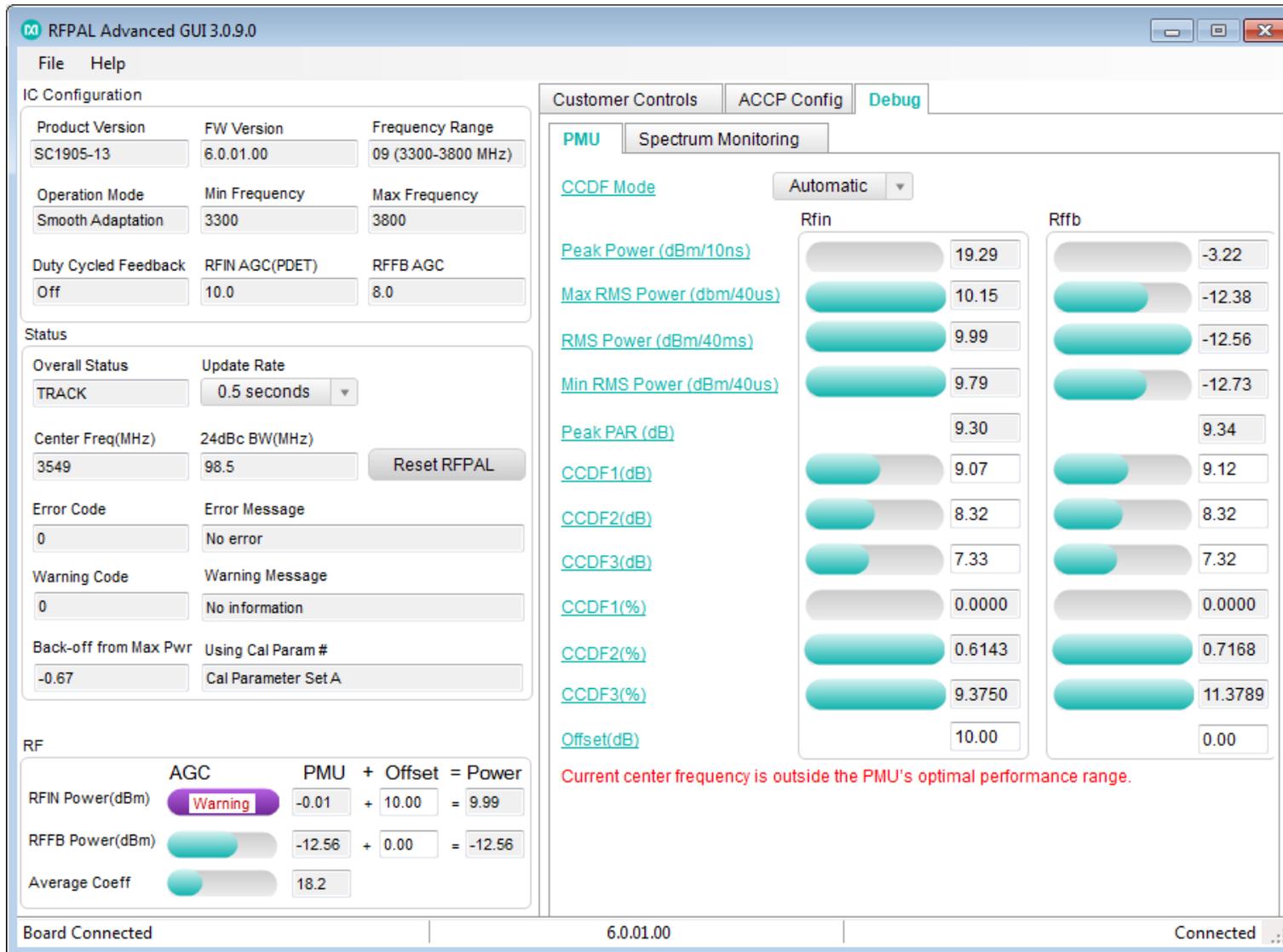
Figure 7. SC1905 PMU window.
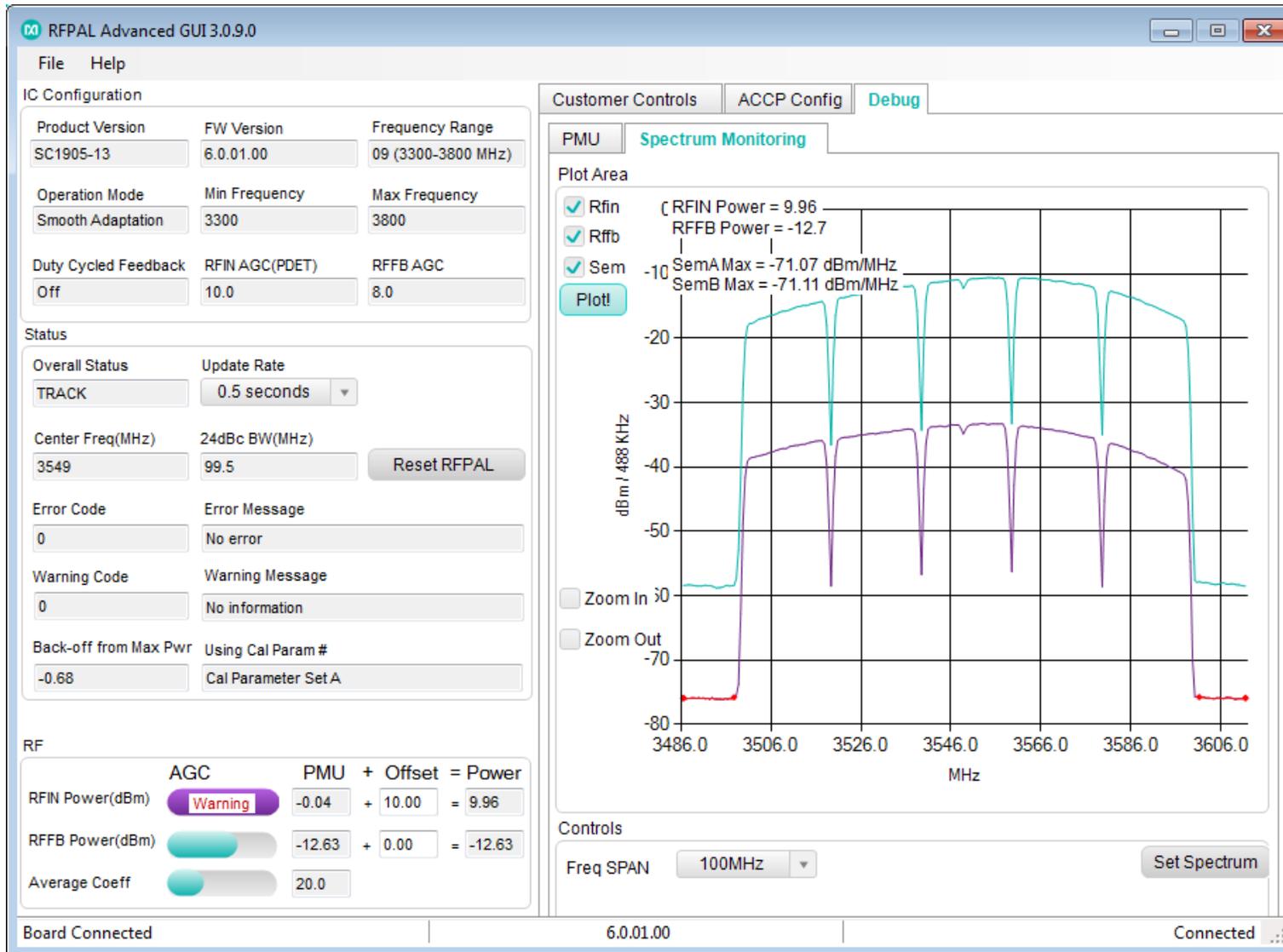
Figure 8. SC1905 spectrum monitoring tab.

Figure 9. SC1905 advanced GUI.

5.2.   IC Configuration

The IC Information indicates the hardware status as well as the setting of user parameters available in the EEPROM.

The firmware version loaded on the SC1905 can be read using the RFPAL Advanced GUI. See section 5.8 to change the firmware.

5.3.   Frequency Range (Min, Max, Center) and Bandwidth

5.3.1.   Frequency Range

The SC1905 supports operation from 698MHz to 3800MHz divided in multiple ranges. The SC1905 only scans for the input frequency within the band that is selected. The range is an EEPROM parameter and can be read from the GUI over the SPI interface. The following ranges are supported:

Table 5. SC1905 Frequency Ranges

Frequency Range	Guaranteed Frequency Ranges GUI Frequency Pulldown Options[1]		Available Frequency Ranges for Testing	
Range	Min Freq	Max Freq	Min Freq	Max
04	698	1040	520	1040
05	1040	2080	1040	2080
06[2]	698	2700	520	3049
07	1800	2700	1616	3049
08	2700	3500	2666	4500
09	3300	3800	3191	4500

1. Operation outside the Guaranteed Frequency Ranges is not guaranteed.
2. For stitched range 06, it is recommended to limit the frequency range needed for the application due to spurious considerations.

5.3.2.   Changing Frequency Range

The frequency range of the SC1905 can be changed using the SPI. This change is written to the internal EEPROM, so that it only needs to be done once to reconfigure the SC1905 to operate in a new band. There is no limit to the number of times the SC1905 can be configured to a new frequency range.

You should be sure that your scanning range matches the design frequency of your board or evaluation kit.

5.3.3.   Min Frequency and Max Frequency

The Frequency Scanning Bounds define the frequency range over which the SC1905 scans for the RF signal on RFIN and RFFB. Min frequency (MHz) and max frequency (MHz) are the EEPROM parameters that define the scanning bounds. The current settings for these values can be read over the SPI. The GUI displays these values in the Status box.

5.3.4. Changing Min Frequency and Max Frequency

The min frequency is the lowest frequency that the SC1905 scans when searching for the signal center frequency and max frequency is the highest frequency that the SC1905 scans when searching for the signal center frequency. It is good practice to set the min frequency and the max frequency to the actual values required for the operating range of the application. Setting an unnecessary wide range can lead to intermittent spurs in the band of interest.

Setting the min frequency and max frequency writes the values to the internal EEPROM and it is only required to set them once. There is no limit to the number of times these parameters can be configured.

The default frequency scanning bounds for each range are the guaranteed frequency ranges as defined in **Table 5**. This table also shows the available frequency ranges that can be used to extend these ranges for test purpose.

5.3.5. Center Frequency and Bandwidth

Once the SC1905 exits the CAL state, the detected signal center frequency (±0.5MHz) and -24dBc signal bandwidth (±0.75MHz for BW < 5MHz, ±1.5MHz for BW ≥ 5MHz) may be obtained from the GUI. The SC1905 considers signals within this displayed bandwidth as "in band" and does not include this signal power as distortion to be corrected.
If the distortion products of your amplifier are above -24dBc, the SC1905 may consider them as signal and not operate properly.

The SC1905 does not attempt to correct signals that are less than 1MHz of modulated signal bandwidth.
The maximum signal bandwidth is 100MHz.

If the detected signal bandwidth does not reflect system or test equipment settings, it may indicate that the SC1905 is not operating under the correct conditions.

5.4. RFIN and RFFB AGC Sliders

The RFIN AGC (PDET) parameter is an attenuator in an AGC loop within the SC1905 analog circuitry. This RFIN AGC loop ensures that the peak voltage into the correction block stays within the desired range across RFIN level and temperature. In Optimized Correction mode, the RFIN AGC (PDET) index is determined during the PDET state between CAL and FSA. The RFIN AGC (PDET) index is an integer value between 0 and 15.

At room temperature, when the PA operates at maximum output power, the RFIN AGC (PDET) index must adhere to the following recommendations:

⚠ *For all bands (except 3400MHz to 3800MHz), recommend **1 < RFIN AGC (PDET) < 8***

⚠ *For 3400MHz to 3800MHz, recommend using **7 < RFIN AGC (PDET) < 14***

> *If RFIN AGC (PDET) is higher, then RFIN is too high and needs to be lowered.*
>
> *If RFIN AGC (PDET) is lower, then RFIN is too low and needs to be increased.*

Over temperature, the PA gain and SC1905 internal gain varies. To compensate for the PA gain variations, the PA AGC loop external to SC1905 adjusts the RFIN level to maintain a constant PA output power. If the RFIN level increases, the optimal PDET index needs to increase as well. Similarly, as temperature changes affect the SC1905 internal gain, the PDET index adjusts to maintain optimal signal levels within the SC1905. These PDET index adjustments create a short ACLR degradation.

For some applications, these temporary degradations in ACLR correction might not be acceptable and it is possible to disable the PDET index compensation over temperature variations by setting both the "PDET Temperature Compensation Flag" and PA Gain Compensation Flag to '1.' This holds the calibrated PDET value constant over all conditions. The tradeoff is that the correction performance may degrade slightly at extreme temperatures. This potential degradation is a function of the PA's gain and P1dB overtemperature within the temperature range required (see [3] for configuration details).

The RFFB AGC is an AGC loop within the SC1905 used to hold the RFFB signal to the optimum level. The higher the RFFB power level, the lower the RFFB AGC value. The RFFB AGC value should be between 4 and 12 at room temperature, when the PA operates at maximum power.

⚠ *For all bands, at maximum PA output power, **4 < RFFB AGC < 12***

> *If RFFB AGC is higher, then the RFFB is too low and needs to be increased.*
>
> *If RFFB AGC is lower, then the RFFB is too high and needs to be lowered.*

However, the RFIN/RFFB power level limits stipulated in the SC1905 data sheet must be met.

5.5. Firmware Status

The SC1905 supports various status commands from the GUI to aid during development and monitor the SC1905 status during operation. It is recommended that the GUI be used to monitor the SC1905 status during development.

The GUI displays the SC1905 status. The rate at which the GUI is updated is shown in Status - Update Rate. It is configurable and is set to be 0.5 seconds by default. It is possible to disable the GUI refresh and to only update the GUI with the "Force Update" button.

5.5.1. Overall Status

The state of the correction processor can be read using the SPI and is displayed on the GUI. These are important indicators to determine if the SC1905 is operating as intended. The GUI displays these states.

5.5.2. Firmware States

INIT

- Initialize microprocessor
- Initialize all internal data memories
- Load configuration parameters from EEPROM

CAL
- Calibrate internal VCO/PLL and internal gain levels
- Adaptation engine is scanning to find the carrier center frequency and bandwidth. If the average RFIN and RFFB levels are within the specified dynamic range (see section 4.1) then the SC1905 completes CAL and begins optimizing gain settings (PDET).
- Perform initial adaptation

PDET
- Optimize gain settings

FSA
- Full speed adaptation to converge quickly to initial pre-distortion solution.
- SC1905 rapidly adapts the coefficients with a large step size to converge to an ACLR close to the final one as fast as possible. RFFB is used to measure and minimize the system's out-of-band distortion.
- Large changes in the ACLR may occur as the optimum values are found.
- PMU measurement values are available.

TRACK
- Firmware has converged to the best possible predistortion solution
- Slow-rate adaptation to account for small changes over power, temperature and voltage.
- Monitor feedback signal for average power changes and adjust adaptation parameters appropriately.
- Monitor feedback signal for center frequency, bandwidth or carrier configuration changes and adjust predistortion parameters appropriately.
- PMU measurement values are available.

5.5.3. Error/Warning Codes

The SC1905 provides warning or error codes if these registers are polled over the SPI. Warnings do not interrupt the operation of the IC although a warning typically indicates that optimal performance is not being obtained. Errors indicate that the SC1905 resets itself to clear an error condition.

Different error and warning codes are described in **Table 6** and **Table 7**.

Table 6. Error Codes

Error Code	Meaning
0	No Error
3	"EEPROM corrupted" Improper use of the part resulted in EEPROM corruption. Downloading the firmware again using the RFPAL GUI might fix this error. If not, contact the Maxim Technical support team.
5	"Center Frequency outside the Defined Frequency Range" Center Frequency is outside the min and max frequency range. Modify the min and max frequency range to fix this error.
13	"Wrong CLK Setting" Clock rate doesn't correspond to the external clock configuration EEPROM parameters. Refer to SPI Programming Guide [3] for more details.
Others	"Internal Chip Error" Contact the Maxim Technical support team if you get any other error that doesn't get fixed after reset or downloading the firmware again using the RFPAL GUI.

Table 7. Warning Codes

Warning Code	Meaning
0	No Warning
44/48	"Center Frequency Too Low" This warning should not happen for customers using the GUI but could happen for a customer using a host to control SC1905. This indicates that the device is operating outside the recommended frequency ranges defined in Table 5.
62	"IC Temperature Outside Allowed Range" Check ATE Calibration Offset Zone Written flag (0xFDB3) and set to "0." Refer to SPI Programming Guide [3] for details.
Others	"Internal Warning" Contact the Maxim Technical support team for further information.

When the firmware issues a warning, the GUI does not clear that warning until the "Clear Warning" button is pressed, even if the warning is no longer applicable. So, after a warning is reported, it is recommended to clear it.

5.5.4. GUI Log Files

The GUI allows the Error and Warning codes to be logged; each time the GUI is started an "Error/Warning" log file is created.

The log file is created under:
C:\Users\<user.name>\AppData\Roaming\Scintera\ScinteraGUI

The format is: etrace20181218_140314 indicating date and time of the log file start.
The first eight characters are date in yyyymmdd format (December 18 2018 in this case) and the last six digits are time of day in 24-hour hhmmss format (2PM 03minutes and 14s in this case).

All errors and warning are captured in this log file. The New Log File button allows starting a new log file without having to close the GUI.

5.5.5. GUI Collect Dump

This opens a file explorer window to designate the path to where the Dump Files are created and saved.

By default, for Windows® 7, the Dump file is created under the Desktop.

The Dump File .scidmp contains important variables and state information used for factory troubleshooting/debugging. This is only available using the GUI.

5.5.6. Reset

The SC1905 supports a hardware reset pin as outlined in the hardware design guide. The HW reset is implemented on the evaluation kit as a push button as show in Figure 1. There is a GUI command button which is equivalent to the HW reset. When using the GUI, it is not recommended to use the pushbutton reset on the PCB.

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5.6. Operation Modes

The firmware supports two user-selectable operating modes: Optimized Correction Mode and Smooth Adaptation Mode. While it is strongly recommended to use smooth adaptation, the user should determine which mode to use based upon the system performance and evaluation criteria.

The SPI interface is used to read the calibration parameters to determine what operating mode the SC1905 is in. The GUI does this periodically and displays the operating mode in the Status box.

5.6.1. Optimized Correction Mode

This is the default mode of operation and mostly used during initial evaluation of a system. It can be useful to determine the best possible performance achievable under a given set of conditions, but the dynamic performance is very poor. Only Smooth Adaptation Mode should be used for systems deployed in the field. Optimized Correction Mode is mostly used just for experimental purposes or performing the factory calibration in order to enable Smooth Adaptation Mode. This mode sets the adaptation parameters to achieve the best ACLR cancellation at all power levels once reconvergence is achieved. Readaptation is triggered whenever the average power level or signal bandwidth is changed over a 50ms period. The readaptation appears noisy and exhibits rapid changes in ACLR until the device completes reconvergences.

5.6.2. Smooth Adaptation Mode

Smooth Adaptation Mode fixes certain adaptation parameters to speed up the reconvergence resulting in less ACLR degradation under dynamic signal conditions. Operation in this mode requires an initial factory calibration of the SC1905 with the Power Amplifier system. Smooth adaptation mode may result in slightly degraded performance in backoff when compared with Optimized Correction Mode. At maximum power, there is no difference in correction performance between Smooth Adaptation Mode and Optimized Correction Mode.
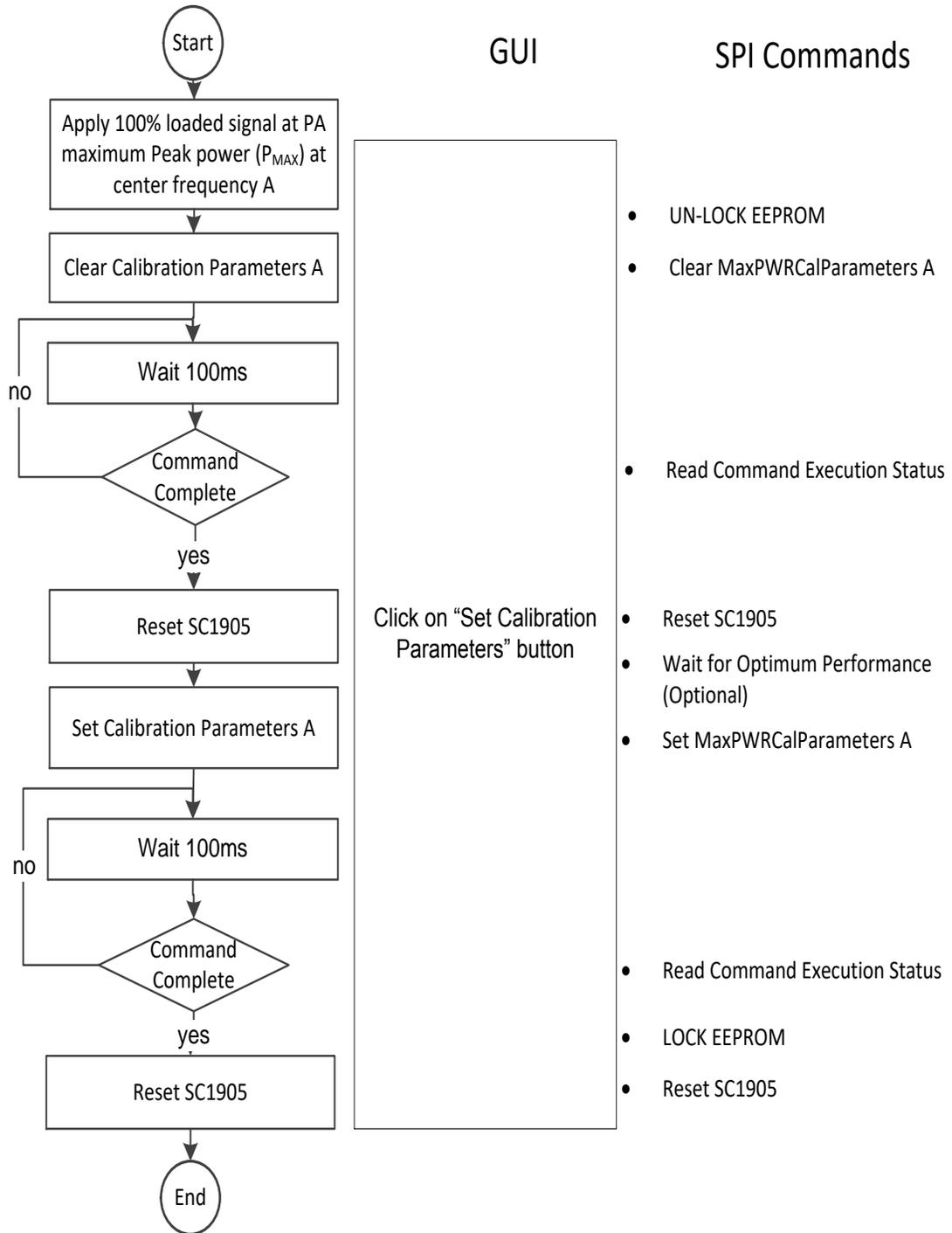See section 5.6.2.1 for detailed calibration procedure.

Figure 10. Smooth Adaptation Calibration procedure at center frequency A.

⚠ *IMPORTANT: Smooth Adaptation Calibration must be done with the system at maximum peak PA output power with minimum PAR (for Maximum RMS power) and maximum expected signal bandwidth.*

5.6.2.1. Calibration – Selecting Smooth Adaptation Mode

Smooth adaptation calibration is required during manufacturing. It is possible to calibrate at either one or two center frequencies. With the system at least at constant, maximum peak output power in operation (or even 0.5dB higher) and the maximum signal bandwidth, the SC1905 adapts and the calibration parameters are stored in the EEPROM. A signal with 100% resource block (RB) utilization should be used; the PAR being around 7dB. For TDD systems; it is recommended to use 100% RB utilization during the TX ON period.

The GUI enables the user to perform this calibration with a single push of the "Set Calibration Parameters" button. When pressing the button "Set Calibration Parameters", the GUI automatically executes all the SPI commands described in **Figure 10**.
To enable this Smooth Adaptation Mode from a host, the host firmware needs to follow the same steps. See the SPI Programming Guide [3]

When pressing the button "Set Calibration Parameters", the GUI first Un-Lock the EEPROM and then sends a "Clear MaxPWRCalParameters A" message communication command to SC1905. Then the GUI reads the execution status of the command to confirm that the firmware has executed this command and cleared all the Maximum Power Calibration Parameters. After getting confirmation that the command has been completed, then the GUI resets the SC1905. After Reset, the GUI waits one second and issues a "Set MaxPWRCalParameters A" message communication command to SC1905. Then the firmware automatically stores all the Maximum Power Calibration Parameters, coefficients and checksum to the customer configuration parameter zone in the EEPROM.
Once the firmware has completed this command, it sends back a message to confirm that the command has been completed. As a last step, the GUI resets the SC1905 to boot up in Smooth adaptation mode.

Once this procedure is done, the SC1905 at power up or reset always operates in Smooth Adaptation Mode unless the calibration parameters are cleared. The calibration is specific to the system so if the PA or other components in the system change, the SC1905 should be re-calibrated. If the maximum operating power is changed, the procedure should also be re-done.

When this mode is enabled, the GUI displays the difference between the calibrated power and the current power: Backoff from Calibrated Max Power.

With two frequency calibrations, the smooth adaptation calibration parameters corresponding to the closer calibration frequency is chosen at a given frequency. The threshold for deciding which frequency to use is the midpoint of the two calibration frequencies. For example, with calibration at 3800MHz and 3700MHz and a center frequency of 3760MHz, the parameters from the calibration at 3800MHz is selected. See the SPI Programming Guide [3] for details.

5.6.2.2. Clearing Calibration Parameters

Clearing the calibration parameters puts the SC1905 into the default Optimized Correction Mode. It is important to clear all the calibration parameters. The GUI enables the user to clear these parameters with a single push of the "Clear Calibration Parameters" button. The host needs to first unlock the EEPROM and then send a simple "Clear MaxPWRCalParameters A" message to SC1905 to clear all the Maximum Power Calibration Parameters.

5.7. Adaptation and Correction Options

5.7.1. Duty-Cycled Feedback

This is an EEPROM parameter. Duty cycling of the feedback receiver and adaptation circuitry offers the benefit of reduced average power consumption. The feedback receiver and adaptation are duty cycled as soon as adaptation starts after calibration completes. This can significantly slow down convergence; alternatively, the firmware can be configured to only duty cycle once it reaches TRACK state. Refer to [4] for the details. By default, Duty-Cycled Feedback is disabled.

When Duty Cycle Feedback is "Off":
- o   This is the default mode.
- o   SC1905 continuously adapts coefficients and monitors RFFB.
- o   In this mode, the coefficients also continuously adapt with 100% duty cycle.

When Duty Cycle Feedback is "On":
- o   Once it is "On" the device comes up in this mode on power-up or reset.
- o   Duty-Cycle period = ON_TIME + OFF_TIME = 100 + 1000 = 1100ms
- o   During ON_TIME (100ms), SC1905 adapts coefficients and monitors power-level change on RFFB
- o   During OFF_TIME (1s), the coefficients do not adapt, and correction still applies. SC1905 does not monitor RFFB power-level change, center-frequency change or signal-bandwidth change.

5.7.2. Adaptation States

The adaptation engine can be stopped to freeze the current coefficients. This is typically used for debug and lab evaluation purposes only. The last calculated coefficients are applied to the correction signal processor and are not updated.

- • Running: Default state. Adaptation mode running as described above.
- • Frozen: Freeze coefficient adaptation. All other circuits are left in the state they were in when the freeze command is applied.

5.7.3. Enabling and Disabling Correction

Once in TRACK, it is possible to turn off the predistortion signal. This is set to "FW Control" by default and can be used to toggle between corrected and uncorrected performance of the PA. It is typically used during evaluation and development. It is not recommended to disable SC1905 at low-output powers since the firmware handles this automatically.

Disabled: The predistortion signal is disabled and coefficients are not adapted. All other circuits are left in the state they were in when the disable command was applied.

FW Control: The predistortion signal is enabled.

During other states, this option is disabled since the RFOUT must be under firmware control.

5.7.4. Wideband Performance Optimization

Guard Band is an EEPROM parameter defined as the frequency band between the carrier edge (defined by the -24dBc signal bandwidth) and the IMD measurement region used for adaptation.

By default (value is "0"), the Guard Band is set to 20% of the signal bandwidth. This configuration is for IMD5 performance optimization of contiguous carriers with signal bandwidth greater than 40MHz.

For noncontiguous carriers or for close-in IMD optimization, it is recommended to try different options.
The Guard Band parameter can be configured to 1MHz, 1.5MHz, 2MHz or 2.5MHz.
From the host, the Guard Band can be configured as any positive multiple of 0.5MHz. See SC1905 SPI programming guide for detail [3].

5.8. Upgrading SC1905 Firmware

The internal EEPROM in the SC1905 supports field upgrades of the firmware. The firmware is upgradeable using the GUI.

5.8.1. GUI function Adding New Firmware to "Available Firmware" list

"Add Firmware" allows adding future firmware to the "Available Firmware" list. A New Firmware version is included in the CD provided with the EV kit board and can easily be added to the "Installed Firmware" list. New firmware versions are provided in encrypted format ".sci."

Click on "Add Firmware" and navigate to the file to be added.

Select the .sci file and click Open. The firmware is added to the available firmware drop down and downloaded to the SC1905 chip.

5.8.2. Change Firmware

To download firmware to SC1905, select one of the "Available Firmware" and click "Change Firmware."

5.9. Cost Function

The cost function is measured at the RFFB input and is a scalar value proportional to ACLR measurement. The magnitude of this scalar depends on the modulation type. Monitoring the relative change of this scalar provides an indication of a given PA's ACLR.

The values reported by the GUI are averaged over 30 measurements.

5.10. Advanced Customer Configuration Parameters

As shown in **Figure 9**, the Advanced Customer Configuration (ACCP) tab allows one to view and configure the different EEPROM configuration parameters. Refer to the SPI programming guide [3] for detailed descriptions of these different parameters.

6. <u>Debug Features</u>

The debug features include the following:
- Power measurement unit. See section 6.1 for details.
- Spectral monitoring. See section 6.2 for details.
- Complementary cumulative distribution function (CCDF). See section 6.3 for details.

6.1. Power Measurement Unit (PMU) Features

The SC1905 integrates two sets of analog power detectors, analog-to-digital converters and sampling integration. As soon as the SC1905 has detected the signal-center frequency and signal bandwidth, it uses the SPI interface every 300ms to provide precise RFIN and RFFB power measurements, as shown in Table 8.

Table 8. RFIN and RFFB Power Measurements

RFIN and RFFB Power Measurement	Units	Description
RFIN and RFFB Peak Power	dBm/10ns	Highest 10ns average values for both RFIN and RFFB over the 40ms average window.
RFIN and RFFB RMS Power	dBm/40ms	Over a 40ms measurement window.
RFIN and RFFB Max RMS Power	dBm/40μs	Highest 40μs average values for both RFIN and RFFB over the 40ms average window. This value allows reporting power either during Preamble or during portions of the waveform where the most user resource blocks are occupied without needing synchronization signals, knowledge of frame boundaries, or support from the baseband.
RFIN and RFFB Min RMS Power	dBm/40μs	Lowest 40μs average values for both RFIN and RFFB over the 40ms average window.
Peak PAR	dB	Peak Power (dBm/10ns) minus RMS Power (dBm/40ms).
RFIN and RFFB CCDF	%	The percentage of samples with a power level higher than the three different threshold levels defined by the corresponding CCDF fields (dB) These thresholds are defined as the Peak Par (dB) minus 0.25dB, 1dB and 2db in automatic mode or can be configured manually by the customer in manual mode. See section 6.3 for details.

To provide enough integration samples to precisely measure signals with high-peak to average values, the default measurement time for the power detector is 40ms.

⚠ *IMPORTANT: When the SC1905 detects the signal center frequency and signal bandwidth, the RFIN values are measured even if the RFFB is off (PA disabled or failed) for more than 40ms.*

> *The SC1905 does not adapt the predistortion coefficients during the measurement time.*

If the frame length of the waveform is not a multiple of 40ms, or a value that is evenly divisible by 40ms, the power measurement is done over an incomplete frame length.

6.1.1. PMU Calibration

The reference points for the RFIN and RFFB PMU are the inputs of the chip. For more precise power measurements, the PMU requires a single-point calibration in manufacturing. The PMU calibration typically consists of setting the PA at maximum output power. Use an external calibrated power meter to read the PA power, and then perform the following steps:

1. The SC1905 converges and reaches TRACK.
2. Read the PMU value over the SPI for RFFB and use the value as the reference point.
3. Repeat step 1 and step 2 but for RFIN to calibrate the RFIN value.
4. These reference values are then stored in the EEPROM or host.
5. Apply the EEPROM offsets to the PMU values read from the SC1905.
6. If some offsets are stored externally, the host can add the offset values to the PMU values read from the SC1905.

See the SPI programming guide for examples and usage. This calibration can be done at the same time as the calibration for smooth adaptation mode if desired.

The GUI enables the customer to display the absolute power at outside reference points (typically, the absolute PA output power) by providing a window to enter the value read from the external power meter. This value is then used to calculate the offset, which is applied to the power as measured by the SC1905 and displayed as Ref power.

If the calibration is not done, then the offset in the GUI is preset for the approximate coupler loss and matching circuit loss for both RFIN and RFFB. The approximate power at the board connectors is displayed in Ref.

The GUI calculates the offset when the expected power is entered and "Calibrate RFFB PMU" or "Calibrate RFIN PMU" is pushed. Expected power is the value read from external reference such as calibrated power meter or spectrum analyzer. Alternatively, the offset can be manually entered in the offset window.

$$P\,[Ref]\ = P\,[Chip] + Offset$$

⚠ *IMPORTANT: RFIN and RFFB power indicators must be calibrated.*

6.1.2. TDD Considerations – Operation with < 100% Duty Cycle

The SC1905 PMU operates continuously over the measurement window; it does not discard samples, which may have been taken when the PA is off. This affects the reading for waveforms with less than 100% duty cycle as seen in TDD applications. For example, the PMU value read for a 50% PA on time (duty cycle) is 3dB lower than the value with 100% duty cycle. Calculate the PA on time power from the PMU value using the following recommendations:

1. For systems with a fixed duty cycle, calibrate the PMU with the procedure in section 6.1.1 using a waveform with the proper Rx/Tx duty cycle. This is the preferred method.
2. For systems with variable Rx/Tx duty cycle, use the host controller to scale the measurement value by the duty cycle (D_{CYCLE}) and calibrate the PMU values with a 100% duty cycle. Then convert the read PMU values into dBm values as follows:

$$P_{RFIN} = \frac{RFIN\_PMU * 3.01}{1024} + OFFSET_{RFIN} - 10 * log10(D_{CYCLE})$$

$$P_{RFFB} = \frac{RFFB\_PMU * 3.01}{1024} + OFFSET_{RFFB} - 10 * \log10(D_{CYCLE})$$

The duty cycle (D_{CYCLE}) factor does not need to be applied to RFIN and RFFB Peak Power (dBm/10ns), RFIN and RFFB Max RMS Power (dBm/40µs), RFIN and RFFB Min RMS Power (dBm/40µs), and Peak PAR (dB).

6.2. Spectrum Monitoring (SEM and PSD)

The spectrum emission mask (SEM) is measured for the RFFB signal at the same time as the RFFB PMU values described in section 6.1 It is averaged over the same 40ms integration window and updated every 300ms.
The power spectrum density (PSD) plots are only generated when pressing the "Plot!" button in the GUI.

6.2.1. Power Spectrum Density (PSD) Plot

To plot the PSD, select the RFIN, the RFFB, or both and configure the frequency span.

⚠ *IMPORTANT: After selecting the frequency span (MHz), it is required to press "Set Spectrum" for the change to take effect.*

Every time the "Plot!" button is pressed, the selected power-spectrum density plots are captured and displayed.
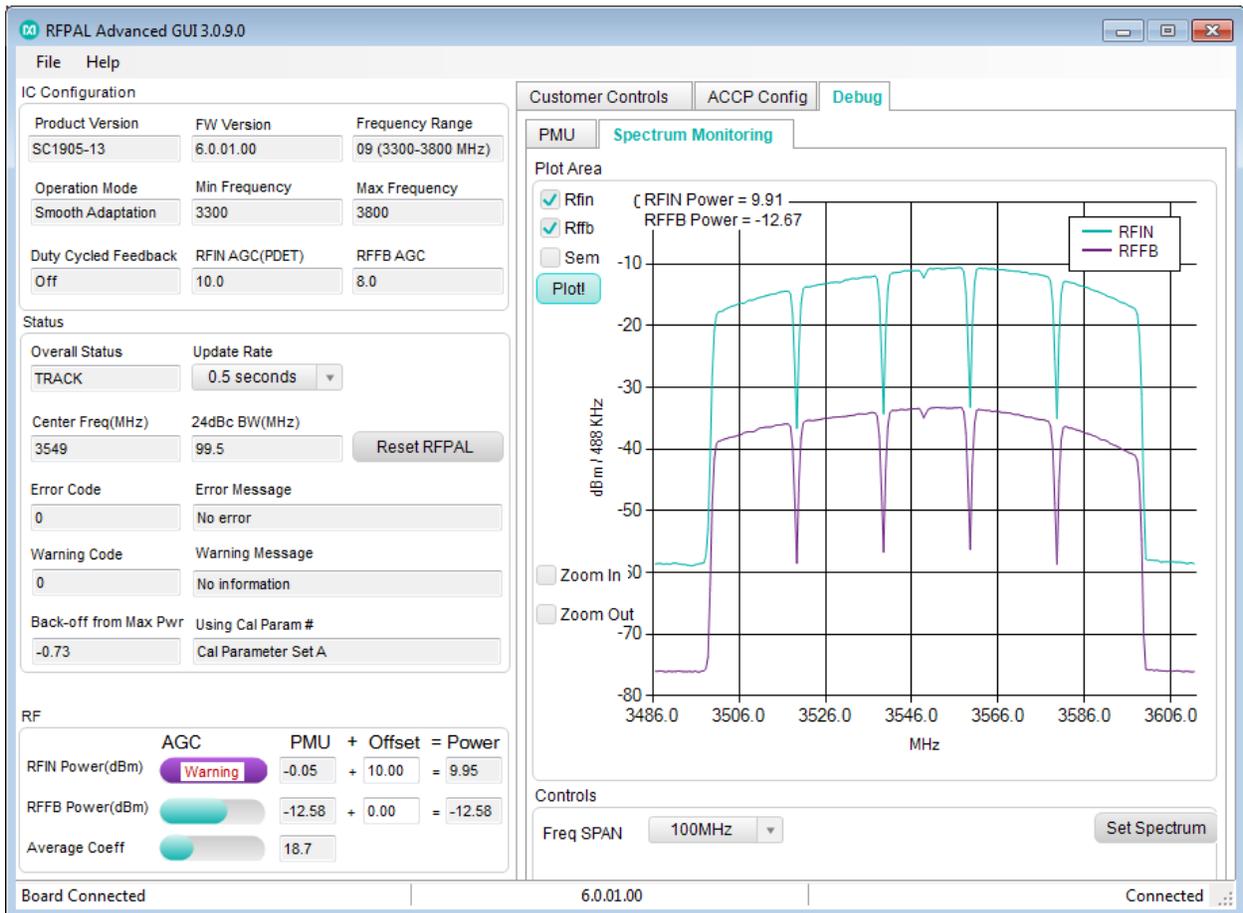

Figure 11. Power spectrum density plot.

6.2.2. Spectrum Emission Mask (SEM)

⚠ *IMPORTANT: The SEM graph in red is only valid if:*

    a. RFFB is selected since SEM is always based on RFFB.

    b. Center Frequency is not changed.

    c. Frequency Span set = 100MHz.

The reported SEM value is always valid and based on a 100MHz sampling rate with detected center frequency independent of the frequency span and center frequency selection.

When selecting RFFB and then SEM, a window opens with the following parameters:

- AccMaxSemRangeA: maximum Spectrum Emission Mask of Lower and Upper SEM bands defined by LowerSemFreqA and UpperSemFreqA over SemMeasBw. Average Lower and Upper SEM values are measured with 1MHz windows averaged over SemMeasBw/2MHz average window. This maximum SEMA value of the Lower and Upper SEM bands A is updated every 300ms.

- AccMaxSemRangeB: maximum spectrum emission mask of lower and upper SEM bands defined by LowerSemFreqB and UpperSemFreqB over SemMeasBw updated every 300ms. Average lower and upper SEM values are measured with 1MHz windows averaged over SemMeasBw/2MHz average window. The maximum value of the lower and upper SEM bands is updated every 300ms. This maximum SEMB value of the lower and upper SEM bands B is updated every 300ms.

- AccSemMaxSemPsdMeas: highest 40µs PSD value in dBm/MHz over 40ms window. Updated every 300ms.

- LowerSemFreqA: 2 × LowerOffsetA in MHz from the lower edge of the signal

- UpperSemFreqA: 2 × UpperOffsetA in MHz from the upper edge of the signal

- LowerSemFreqB: 2 × LowerOffsetB in MHz from the lower edge of the signal

- UpperSemFreqB: 2 × UpperOffsetB in MHz from the upper edge of the signal

- SemMeasBw: 2 × SEM Measurement Bandwidth in MHz

⚠ *IMPORTANT: It is recommended to set LowerSemFreqA = UpperSemFreqA and LowerSemFreqB = UpperSemFreqB.*

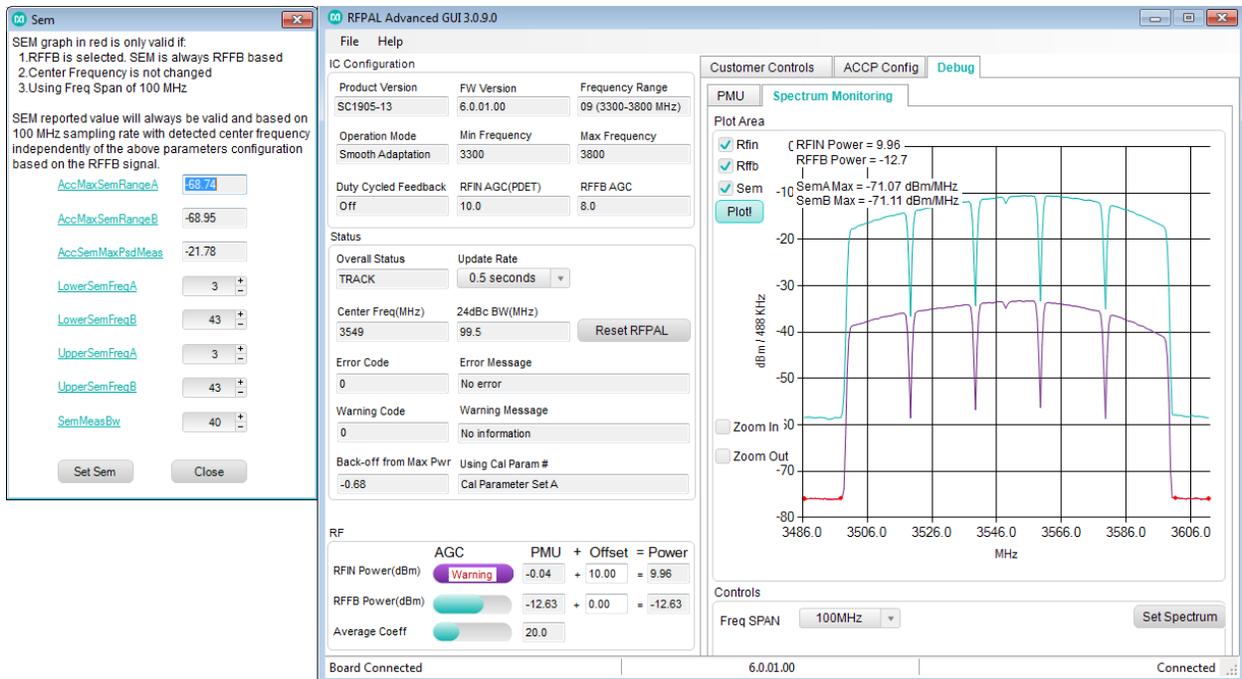Figure 12 shows an example of the SEM settings with 5x20Mhz 8dB PAR waveform.

Figure 12. SEM setting.

6.3. Complementary Cumulative Distribution Function (CCDF)

The SC1905 reports the percentage of points that are over a user-specified threshold. The thresholds are defined as CCDF1 (dB), CCDF2 (dB), and CCDF3 (dB). Three sets of data-pairs are collected for RFIN and RFFB based on the thresholds: CCDF1 (%), CCDF2 (%), and CCDF3 (%). These represent three different points on the CCDF curve. These CCDF (%) are the percentage of samples with power level going above the three different threshold levels defined by CCDF1 (dB), CCDF2 (dB), and CCDF3 (dB).

In automatic mode, these thresholds are respectively defined as CCDF1 (dB) = Peak PAR (dB) - 0.25dB, CCDF2 (dB) = Peak PAR (dB) - 1dB and CCDF3 (dB) = Peak PAR (dB) - 2dB.

In Manual mode, it is required to configure these thresholds as needed after each Reset as these parameters are not saved into the EEPROM.

⚠ *IMPORTANT: On the GUI PMU tab, the Peak PAR (dB) values of RFIN and RFFB should be within 1dB of each other to make sure that the PA is not running too much into compression.*

7. Revision History

REVISION NUMBER	REVISION DATE	DESCRIPTION	PAGES CHANGED
0	01/19	Initial release	—