AN1437: SiWx917 RF Regulatory Testing

This application note provides guidelines on performing RF regulatory tests and calibrations with products based on SiWx917 Single-chip Wireless Solutions.

KEY POINTS

- RF Regulatory Testing Guidelines
- SiWx917 Power Control and Gain Tables
- APIs and example applications for RF Testing
- Programming the SiWx917 Gain Tables

1. Introduction

The output power of the SiWx917 must be controlled in such a way that the device meets the requirements of the applicable local regulatory standards (FCC, CE, MIC, etc.) and passes the various tests defined by the regulatory authorities.

1.1 Regulatory Overview

Regulatory requirements are in place to ensure that devices are safe, reliable, and do not interfere with other electronic devices. The applicable regulations vary depending on the country or region. Some regulations (such as EMC and Safety) are common to all electronic devices while others are applied to specific applications. For wireless devices, the RF performance and emission is also regulated and conformity to the specified limits must be verified by comprehensive test suites.

Table 1.1 summarizes the major RF regulatory bodies around the world and the associated RF standards applicable to typical SiWx917 based 2.4 GHz applications. Refer to the documentation issued by the associated authorization body for the detailed test cases and limitations. For additional guidelines on RF regulatory procedures, refer to AN1048: Regulatory RF Module Certifications.

Table 1.1. Major Regulatory Authorities and Associated Primary RF Standards

Authority	Standard	Link
FCC (USA)	FCC 47 CFR PART 15 SUBPART C	https://www.fcc.gov/
ISED/IC (Canada)	RSS-247 Issue 2 RSS-Gen Issue 5	https://ised-isde.canada.ca/site/ised/en
ETSI/CE/RED (Europe)	EN 300 328 EN 301 489	https://www.etsi.org/standards
MIC/TELEC (Japan)	ARIB STD-T66 ARIB STD-T108 (for Wi-Fi channel 14)	http://www.soumu.go.jp/english/
KCC (Korea)	KS X 3123	https://eng.kcc.go.kr/user/ehpMain.do

1.2 SiWx917 Power Control and Gain Tables

The SiWx917 output power is controlled through **power indices**, which can be configured separately for Wi-Fi and BLE transmissions. In addition, the maximum compliant power indices are stored, and in normal end-to-end operating modes, the TX output power is backed off by the SiWx917 firmware if the configured TX power is higher than the maximum compliant power level. The TX power is also automatically set to the maximum allowed level if Power Index = 127 is configured.

The maximum compliant Power Indices (i.e., TX power back off values) are specified in the **gain tables** for each regulatory region, channel, and Wi-Fi standard / BLE PHY. If the device is certified for multiple antennas, then a separate gain table must be defined for each antenna and the appropriate gain table must be loaded based on the actual antenna being used. While the SiWx917 firmware provides default gain tables, the antenna being used could affect the regulatory compliance; therefore, it is recommended to evaluate the passing criteria of all the applicable RF regulatory limits and adjust the gain table if necessary. The final product must use the same gain table(s) as what was derived during the certification/conformity testing. Inappropriate use of the gain tables may result in violation of regulatory limits, in which case Silicon Laboratories is not liable.

Note: For BLE, gain tables are supported only when the high-performance (HP) RF chain is used. The gain tables have currently no effect when the low-power (LP) BLE RF chain is selected.

The SiWx917 firmware maintains two types of gain tables: **worldwide** gain tables and **region-based** gain tables. Worldwide tables specify the maximum power indices compliant with protocol related limits (like EVM) while region-based tables store the maximum power indices compliant with regional RF regulatory requirements. The worldwide tables are pre-populated in the SiWx917 flash during production and must not be overwritten. The region-based tables also have a default value set; however, they can be overwritten by the application in runtime.

In normal end-to-end WLAN and BLE HP operating modes, the actual power index used for transmissions is the minimum value of the configured power index, the worldwide gain table value, and (unless the operating region is set to Worldwide) the region-based gain table value. For testing the TX performance and evaluating the optimum gain table values, a special **Transmit Test** mode (a.k.a. PER mode) is also available. In Transmit Test mode, the TX power index is NOT limited by the gain tables and the actual TX power index will be the same as the configured power index. See Section 2.1 API Functions for guidelines on how to enable Transmit Test mode.

2. APIs and Examples

2.1 API Functions

Use the WiSeConnect API functions listed in Table 2.1 Wi-Fi RF Test APIs on page 3 and Table 2.2 BLE RF Test APIs on page 3 to implement custom, connectionless test applications in SoC or NCP modes.

To enable Wi-Fi Transmission Test mode, initialize the SiWx917 in SL_SI91X_TRANSMIT_TEST_MODE operation mode. For BLE, there is no dedicated Transmission Test operation mode. Instead, unrestricted BLE transmission can be initiated with the rsi_ble_per_transmit function.

Table 2.1. Wi-Fi RF Test APIs

API Function	Description
sl_si91x_transmit_test_start	Enable infinite Wi-Fi transmission in either burst packets, continuously modulated stream, or continuous unmodulated wave (tone) mode at a specified channel, power level, and data rate. The SiWx917 must be initialized in Transmit Test mode before calling this API.
sl_si91x_transmit_test_stop	Disable infinite Wi-Fi transmission
sl_wifi_get_statistics	Poll Wi-Fi operational statistics
sl_wifi_start_statistic_report	Enable asynchronous TX/RX statistics report for every 1 second
sl_wifi_stop_statistic_report	Disable asynchronous TX/RX statistics report
sl_wifi_update_gain_table	Update Wi-Fi Gain Table

Table 2.2. BLE RF Test APIs

API Function	Description
rsi_ble_per_transmit	Enable/disable infinite “PER Mode” BLE transmission with specified parameters in burst packet, continuously modulated stream, or continuous unmodulated wave (tone) mode.
rsi_ble_per_receive	Enable/disable continuous “PER Mode” BLE reception with specified parameters
rsi_bt_per_stats	Poll the BLE TX/RX PER statistics
rsi_bt_cmd_update_gain_table_offset_or_max_pwr	Update the BLE Max Power or Offset Gain Table

2.2 Example Applications

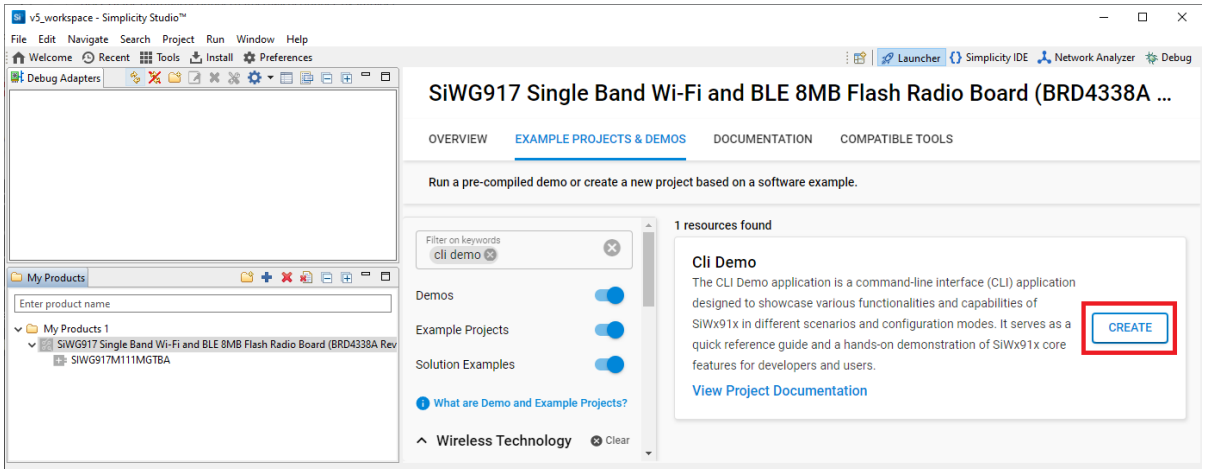
The WiSeConnect SDK comes with multiple example applications demonstrating various features in the SDK. The CLI Demo example application provides a serial command line interface for the API functions that are most commonly used during RF testing and therefore, it is recommended for evaluating and testing the SiWx917 RF performance. Additional guidelines on how to use the CLI Demo application for RF testing are provided in Section 2.2.1 CLI Demo.

Table 2.3. Example Applications for RF Regulatory Testing

Example Application	Description
CLI Demo	Provides command line interface (CLI) for various WiseConnect API functions. Enables runtime configuration of test parameters (power, data rate, channel, etc.)
WLAN RF Test	Configure the SiWx91x to transmit Wi-Fi packets with pre-defined parameters.
User Gain Table	Update the SiWx917 Wi-Fi Gain Table and transmit Wi-Fi with pre-defined parameters.
BLE PER	Configure the SiWx91x to Transmit/Receive BLE packets with pre-defined parameters. Can be used for PER testing.

2.2.1 CLI Demo

To create a new CLI Demo application, open the Launcher View in Simplicity Studio, select a compatible SiWx917 based product, switch to the Example Projects & Demos tab and select the CLI Demo application:



Once the project is created, follow the guidelines provided in the project readme.md file to get started.

Use the CLI commands below to initiate infinite transmission of Wi-Fi TX test signals:

```
wifi_init -i transmit_test
wifi_set_antenna -i client -a 0
wifi_transmit_test_start <power_index> <rate> <length> <mode> <channel>
```

The parameters for the `wifi_transmit_test_start` command are:

Parameter	Description
`power_index`	Transmit power in dbm, set to 127 to use the max power index from Gain Table
`rate`	Data rate id • 802.11b/gn/n: As specified in sl_wifi_data_rate_t (e.g., 1 → 802.11b / 1 Mbps, 263 → MCS7 • 802.11ax: MCS index (0-7) To enable 802.11ax mode, the enable_11ax flag must be enabled in the sl_si91x_request_tx_test_info_t transmit test configuration structure
`length`	Length of the transmitted packet in bytes (valid range is [24 … 1500] in burst packets mode and [24 … 260] in modulated stream and unmodulated wave mode)
`mode`	0 → Burst Packets Mode, 1 → Modulated Stream Mode, 2 → Unmodualted Tone (CW) Mode with tone at zero offset, 3 → CW Mode with tone at -2.5 MHz offset, 4 → CW Mode with tone at + 5 MHz offset
`channel`	WLAN channel (1-14)

Note: Before starting CW mode, start Continuous mode with the power and channel values which are intended to be used in CW mode.

Use the `wifi_transmit_test_stop` command to stop the transmission and the `sl_wifi_update_gain_table` command to load a predefined custom Wi-Fi gain table to the SiWx917.

3. Gain Table Calibration

Note: Note: The gain and frequency offset must be calibrated prior to beginning the gain table calibration. Guidelines on how to perform the gain and frequency offset calibrations are provided in a separate application note.

To perform the gain table calibration for a single antenna:

1. Initiate transmission in Transmit Test / PER Mode at power levels ranging from 0 dBm to +23 dBm and record the max power index where the device is passing the regulatory tests (like band-edge emissions).

   Perform the sweep for all:
   - Regulatory regions (FCC, ETSI, TELEC, etc.) needed.
   - Wi-Fi protocols (802.11b/g/n/ax) and BLE PHYs (1M/2M/500 kbps/125 kbps) the application is going to use.
   - Channels
2. Fill the gain table with the evaluated max power indices and load it to the SiWx917 after every boot-up.

If the application can use different antennas, then the gain table calibration must be performed for each antenna and the application should load the appropriate gain table based on the antenna being used.

3.1 Gain Table Format

The gain tables are defined as 1D arrays, which have the power indices for the different regions, channels, and protocols listed one after the other.

For SoC and NCP applications, the gain tables are defined simply as the payloads of uint8_t arrays which are then uploaded to the SiWx917 using the WiSeConnect APIs listed in Section 2.1 API Functions.

Each region is referred by a Region Code in the Gain Tables. See Table 3.1 Wi-Fi Region Codes on page 6 for the available region codes:

Table 3.1. Wi-Fi Region Codes

Regulatory Region	Region Code
FCC	0
ETSI	1
MIC/TELEC	2
Worldwide*	3
KCC	4
Note: The contents of the worldwide tables must not be changed by the application.	

If the application needs to support a region that is not listed in Table 3.1 Wi-Fi Region Codes on page 6, then one of the existing regions can be used to store the gain table for the new region, assuming the scan channels in the new region are identical to the scan channels in the original region. For example, if a new region needs to be added which specifies the same scan channels as ETSI, then region 1 can be used to store the gain table and as selected operating region. If none of the existing regions match the scan channels of the new region, then a support request should be raised for adding the new region in the firmware.

3.1.1 Wi-Fi Gain Table

The format of the Wi-Fi Gain Table is as below:

```
{<NUMBER OF REGIONS>,
<REGION CODE 1>, <NO. OF CHANNELS IN THIS REGION>,
   <CHANNEL NUMBER 1>,
         <2×MAX POWER FOR 11b RATE>, <2×MAX POWER FOR 11g RATE>,<2×MAX POWER FOR 11n RATE>,
         <2×MAX POWER FOR 11ax RATE>,
   <CHANNEL NUMBER 2>,
         <2×MAX POWER FOR 11b RATE>, <2×MAX POWER FOR 11g RATE>, <2×MAX POWER FOR 11n RATE>,
         <2×MAX POWER FOR 11ax RATE>,
...
   <CHANNEL NUMBER n>,
         <2×MAX POWER FOR 11b RATE>, <2×MAX POWER FOR 11g RATE>, <2×MAX POWER FOR 11n RATE>,
         <2×MAX POWER FOR 11ax RATE>,
<REGION CODE 2>, <NO.OF CHANNELS IN THIS REGION>,
   <CHANNEL NUMBER 1>,
         <2×MAX POWER FOR 11b RATE>, <2×MAX POWER FOR 11g RATE>, <2×MAX POWER FOR 11n RATE>,
         <2×MAX POWER FOR 11ax RATE>,

...
}
```

Note:

- The maximum size for the Wi-Fi Gain Table is 128 bytes
- In each entry, list 2× the max power value desired (i.e., 0.5 dB steps)
- If the max. TX power is the same for all the channels, then use 17 (0x11) as the number of channels and specify a single channel entry with 255 as channel number.
- If the max TX power is NOT the same for all channels, then indicate the number of channels and specify the TX power values for all the channels one by one.
- For MIC, there is also a third gain table format: When 0x2n is used as the number of channels, then specify n channel entries, of which the first one (with channel number = 12) will set the limits for channels 1-12 while the remaining entries can be used to specify the limits for channels 13-14. Furthermore, if only two entries are listed, for channel numbers 12 and 14, then the former will set the limits for channels 1-12 and the latter will set the limits for channels 13-14.

Example Wi-Fi Gain Table Payload:

```
{4, //Number of regions
0, //FCC
11, //Number of channels
// Ch   11b   11g   11n   11ax
    1,   34,   26,   24,   22,
    2,   36,   30,   30,   28,
    3,   40,   34,   34,   32,
    4,   40,   36,   36,   34,
    5,   40,   38,   38,   38,
    6,   40,   38,   38,   38,
    7,   40,   38,   38,   38,
    8,   40,   38,   38,   38,
    9,   40,   36,   36,   32,
   10,   36,   34,   34,   28,
   11,   36,   28,   26,   24,
1, //ETSI
0x11, //Single entry for all channels
// Ch   11b   11g   11n   11ax
  255,   36,   36,   36,   36,
2, //MIC
0x23, //Single entry for Ch 1-12 + 3 extra channel
// Ch   11b   11g   11n   11ax
   12,   36,   36,   36,   36,
   13,   34,   34,   34,   34,
   14,   34,   34,   34,   34,
4, //KCC
0x11, //Single entry for all channels
// Ch   11b   11g   11n   11ax
  255,   36,   36,   36,   36
}
```

The above Wi-Fi Gain Table applies the following max TX power limitations:

- FCC:
  - 802.11b: +17…+20 dBm depending on channel
  - 802.11g/n/ax: +11…+19 dBm depending on channel
- ETSI:
  - +18 dBm (for 802.11b/g/n/ax and all channels)
- MIC:
  - Channel 1-12: +18 dBm (for 802.11b/g/n/ax)
  - Channel 13-14: +17 dBm (for 802.11b/g/n/ax)
- KCC:
  - +18 dBm (for 802.11b/g/n/ax and all channels)

3.1.2 BLE Gain Table

For BLE, there are two gain tables: the Max Power Gain Table and the Offset Gain Table. The former specifies an absolute maximum TX power limit for each region while the latter is used to apply additional offset limitations on a per region and per channel basis.

The format of the BLE Gain Tables is as below:

- **BLE Max Power Gain Table:**

```
{<REGION CODE 1>, <MAX POWER>,
 <REGION CODE 2>, <MAX POWER>,
 …
 <REGION CODE n>, <MAX POWER>
}
```

Note:

- The maximum size for the BLE Max Power Gain Table is 10 bytes
- In each entry, list the max power value desired in dBm (i.e., 1 dB steps)

- **BLE Offset Gain Table:**

```
{<NUMBER OF REGIONS>,
<REGION CODE 1>, <NO. OF CHANNELS IN THIS REGION>,
   <CHANNEL NUMBER 1>,
            <POWER OFFSET FOR 1M>, <POWER OFFSET FOR 2M>, <POWER OFFSET FOR 125Kbps>,
            <POWER OFFSET FOR 500Kbps>,
   <CHANNEL NUMBER 2>
            <POWER OFFSET FOR 1M>, <POWER OFFSET FOR 2M>, <POWER OFFSET FOR 125Kbps>,
            <POWER OFFSET FOR 500Kbps>,
...
   <CHANNEL NUMBER n>
            <POWER OFFSET FOR 1M>, <POWER OFFSET FOR 2M>, <POWER OFFSET FOR 125Kbps>,
            <POWER OFFSET FOR 500Kbps>,
<REGION CODE 2>, <NO.OF CHANNELS IN THIS REGION>,
   <CHANNEL NUMBER 1>,
            <POWER OFFSET FOR 1M>, <POWER OFFSET FOR 2M>, <POWER OFFSET FOR 125Kbps>,
            <POWER OFFSET FOR 500Kbps>,

…
}
```

Note:

- The maximum size for the BLE Offset Gain Table is 128 bytes
- In each entry, list the desired value desired in dB (i.e., 1 dB steps)
- The offset value specified for channel number 255 represents all channels except those that are explicitly specified.

Example BLE Gain Table Payloads:

Max Power Table:

```
{
0, 18, //FCC
1, 10, //ETSI
2, 10, //MIC
3, 18, //WORLDWIDE
4, 10  //KCC
}
```

Offset Table:

```
                    {5, //Number of regions
                            0, //FCC
                            4, //Number of channels
                            // Ch   1M   2M   125kbps   500kbps
                              255,   0,   0,     5,        0,
                                0,   0,   0,     5,        0,
                               38,   0,   2,     5,        0,
                               39,   0,  16,     5,        0,
                            1, //ETSI
                            4, //Number of channels
                            // Ch   1M   2M   125kbps   500kbps
                              255,   0,   0,     0,        0,
                                0,   0,   0,     0,        0,
                               19,   0,   0,     0,        0,
                               39,   0,   0,     0,        0,
                            2, //MIC
                            4, //Number of channels
                            // Ch   1M   2M   125kbps   500kbps
                              255,   0,   0,     0,        0,
                                0,   2,   2,     2,        2,
                               19,   0,   0,     0,        0,
                               39,   0,   0,     0,        0,
                            3, //WORLDWIDE
                            4, //Number of channels
                            // Ch   1M   2M   125kbps   500kbps
                              255,   0,   0,     0,        0,
                                0,   0,   0,     0,        0,
                               19,   0,   0,     0,        0,
                               39,   0,   0,     0,        0,
                            4, //KCC
                            4, //Number of channels
                            // Ch   1M   2M   125kbps   500kbps
                              255,   0,   0,     0,        0,
                                0,   2,   2,     2,        2,
                               20,   0,   0,     0,        0,
                               39,   0,   0,     0,        0
                            }
```

The above BLE Max Power and Offset Gain Tables apply the following max TX power limitations:

- FCC
  - 1M PHY:
    - +18 dBm on all channels
  - 2M PHY:
    - Ch 38: +16 dBm
    - Ch 39: +2 dBm
    - All other channels: +18 dBm
  - 500 kbps PHY:
    - +18 dBm on all channels
  - 125 kbps PHY:
    - +13 dBm on all channels
- ETSI
  - +10 dBm on all channels
- MIC:
  - Ch 0: +8 dBm (for all PHYs)
  - All other channels: +10 dBm (for all PHYs)
- KCC:
  - Ch 0: +8 dBm (for all PHYs)
  - All other channels: +10 dBm (for all PHYs)

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