AN1437: SiWx917Mx RF Regulatory Testing

This application note provides guidelines on performing RF regulatory tests and calibrations with products based on SiWx917M Single-chip Wireless Solutions.

KEY POINTS

- RF Regulatory Testing Guidelines
- SiWx917M Power Control and Gain Tables
- APIs and example applications for RF Testing
- Programming the SiWx917M Gain Tables

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1. Introduction

The output power of the SiWx917M 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 SiWx917Mx 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	http://www.soumu.go.jp/english/
KCC (Korea)	KS X 3123	https://eng.kcc.go.kr/user/ehpMain.do

1.2 SiWx917Mx Power Control and Gain Tables

The SiWx917M TX output power is controlled using a *power index*, setting the target power level, and a set of max power limit (back-off) values, ensuring protocol standard and RF regulatory compliance and enabling highest possible TX power.

Separate power back-off tables are maintained for protocol standards and RF regulatory compliance and in normal end-to-end operating modes, the actual WLAN and BLE TX power level will be the minimum value of the configured power index, the protocol-specific limit, and the regulatory limit. The TX power is automatically set to the maximum allowed level whenever Power Index = 127 is used.

The protocol specific power limitations are calibrated during the SiWx917M production to ensure compliance to the active protocol standard (like EVM and Spectral Mask for Wi-Fi) and should not be overwritten.

Note: There can be ±2 dB part-to-part variation in the protocol specific power limits, which is the maximum TX power levels compliant with 802.11 standards.

The maximum TX power levels compliant with RF regulatory limits must be defined in the **gain table** for each regulatory region, channel, and Wi-Fi / BLE standard used by the application. While the SiWx917M firmware provides a default gain table, the RF front-end and antenna implementation could affect the regulatory compliance; therefore, it is recommended to follow the reference design and to use a custom gain table that is evaluated based on the passing criteria of all the applicable RF regulatory limits.

In addition, 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.

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.

In addition, unless the output power is limited by the protocol specific limits, the TX power is also compensated by the gain offset. The gain offset is used to compensate the losses in the application RF front-end circuitry and must be calibrated for optimum TX power accuracy. Additional information on gain offset and guidelines on how to calibrate it are provided in AN1440: SiWx917 Gain Offset Calibration.

For testing the TX performance and evaluating the optimum gain table values, an unrestricted ***Worldwide*** region and a special ***Transmit Test* mode** (a.k.a. PER mode) is available. Selecting ***Worldwide*** region disables the RF regulatory related power limitations. In case the device is also initialized in Transmit Test mode, then all TX power limitations will be disabled and the actual power index used for transmissions will be the same as the configured target power index. For guidelines on how to select Transmit Test mode, refer to 2.1 API Functions.

A simplified overview of the SiWx917M Wi-Fi TX power control algorithm is shown in the figure below. A similar algorithm is used for limiting the BLE TX power as well.

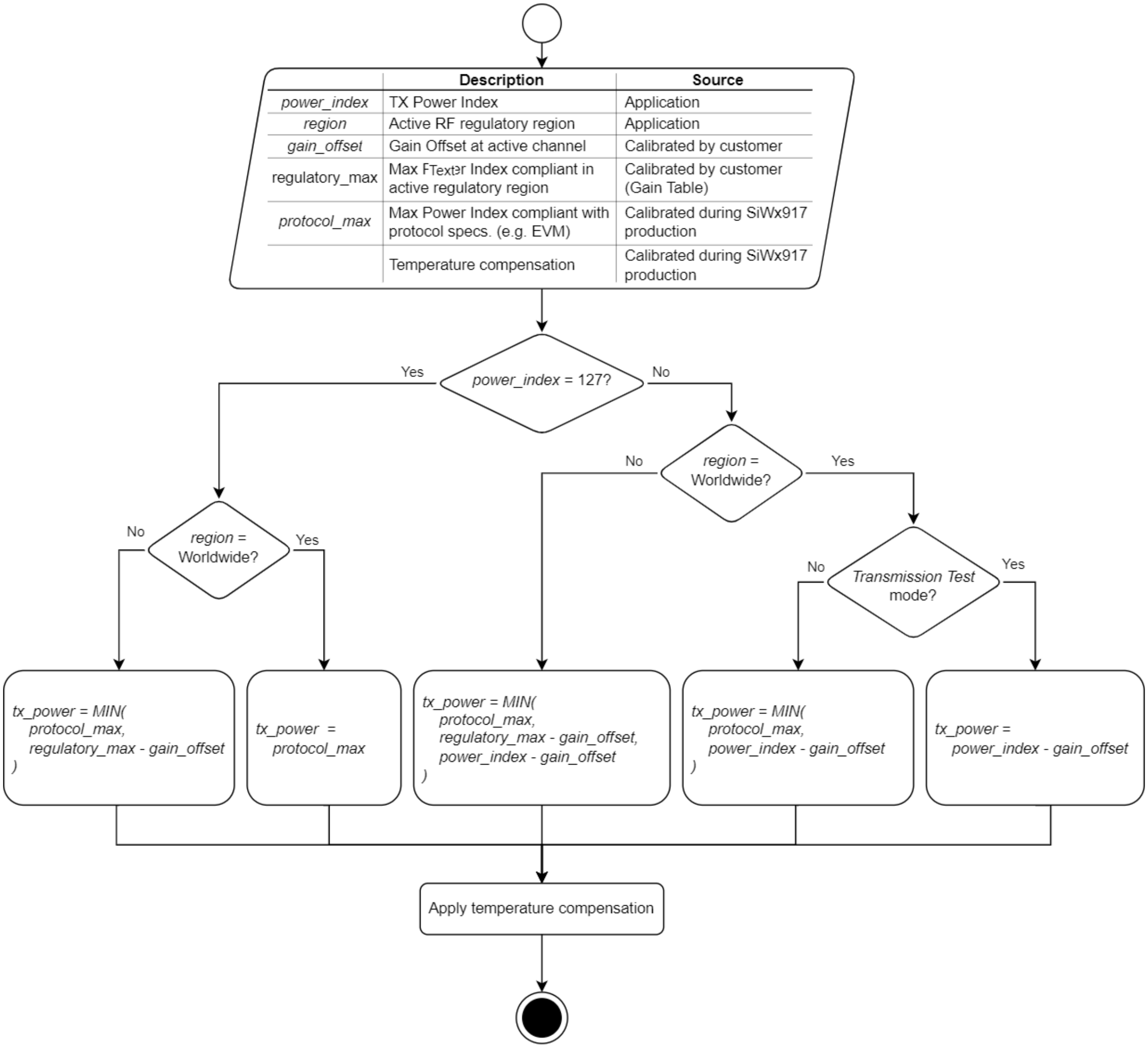


Figure 1.1. Wi-Fi TX Power Limiting Algorithm

2. WiSeConnect 3 SDK

2.1 API Functions

Use the WiSeConnect API functions listed in Table 2.1 Wi-Fi RF Test APIs on page 5 and Table 2.2 BLE RF Test APIs on page 5 to implement custom, connectionless test applications in SoC or NCP modes.

To enable Wi-Fi Transmission Test mode, initialize the SiWx917M 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 SiWx917M 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 aggregated for every 1 second (e.g., for RX PER testing)
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

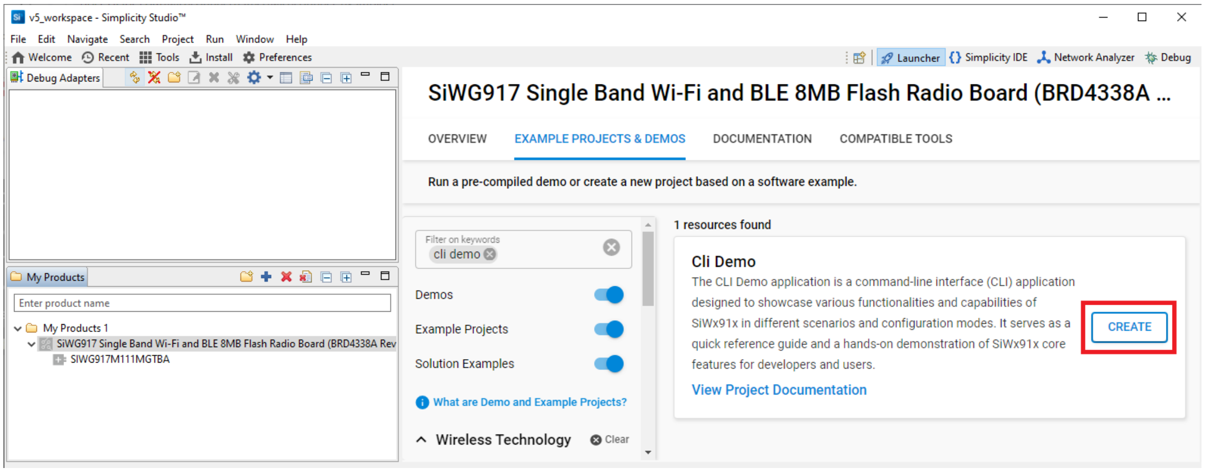
The WiSeConnect SDK comes with multiple example applications demonstrating various features in the SDK. The CLI Demo example application provides a serial command line interface for the API functions that are most commonly used during RF testing and therefore, it is recommended for evaluating and testing the SiWx917M 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 Wi-Fi WiseConnect API functions. Enables runtime configuration of test parameters (power, data rate, channel, etc.)
Wi-Fi BLE CLI Demo	Provides command line interface (CLI) for various Wi-Fi and BLE 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 SiWx917M 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 SiWx917M 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:

Wi-Fi Transmission Test

```
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/g/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 or the extended `wifi_ax_transmit_test_start` command should be used
`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 SiWx917M.

Wi-Fi RX Packet Error Rate Test

Use the CLI commands below to initialize the SiWx917M and print the packet TX/RX statistics aggregated by 1 second interval:

```
wifi_init -i transmit_test
```

```
wifi_set_antenna -i client -a 0
```

```
wifi_start_statistic_report -i <interface> -c <channel> -n <stats_count>
```

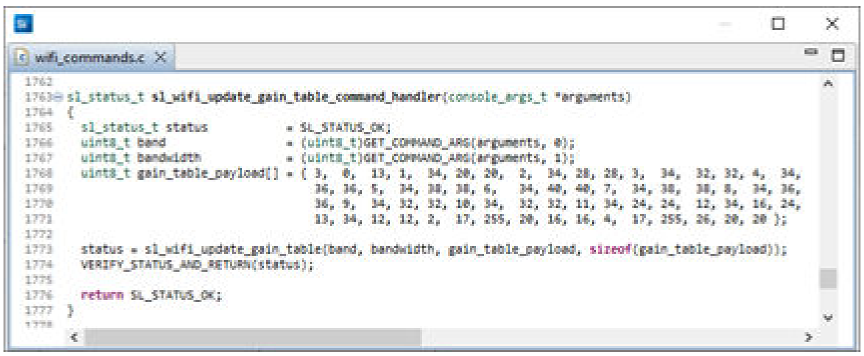
The parameters for the `wifi_start_statistic_report` command are as follows:

Parameter	Description
`interface`	Interface, e.g. `client`
`channel`	WLAN channel (1-14)
`stats_count`	Number of statistic reports, i.e. the duration of the statistics reporting in seconds

For additional details on how to perform RF transmit & receive AN1491: SiWx917 RF Transmit & Receive Measurements

Update the Wi-Fi Gain Table

To write the Wi-Fi gain table, issue the `wifi_update_gain_table 1 0` command.




```
sl_status_t sl_wifi_update_gain_table_command_handler(console_args_t *arguments)
{
  sl_status_t status           = SL_STATUS_OK;
  uint8_t band                 = (uint8_t)GET_COMMAND_ARG(arguments, 0);
  uint8_t bandwidth            = (uint8_t)GET_COMMAND_ARG(arguments, 1);
  uint8_t gain_table_payload[] = { 3,  0,  13, 1,  34, 20, 20,  2,  34, 28, 28, 3,  34,  32, 32, 4,  34,
                                   36, 36, 5,  34, 38, 38, 6,   34, 40, 40, 7,  34, 38,  38, 8,  34, 36,
                                   36, 9,  34, 32, 32, 10, 34,  32, 32, 11, 34, 24, 24,  12, 34, 16, 24,
                                   13, 34, 12, 12, 2,  17, 255, 20, 16, 16, 4,  17, 255, 26, 20, 20 };

  status = sl_wifi_update_gain_table(band, bandwidth, gain_table_payload, sizeof(gain_table_payload));
  VERIFY_STATUS_AND_RETURN(status);

  return SL_STATUS_OK;
}
```

Figure 2.1. CLI Demo Wi-Fi Gain Table Definition

3. Manufacturing Utility

The Manufacturing Utility is a set of commands built in the Simplicity Commander CLI supporting various production tasks, including performing the gain offset calibration.

Table 3.1. Manufacturing Utility Commands Used for Gain Offset Calibration

Command	Description
`commander manufacturing radio`	Enable/disable test mode infinite Wi-Fi transmission with specified settings.
`commander manufacturing gain`	Update the gain offset calibration data (incremental, i.e., adds specified value to the compensation value)
`commander manufacturing evmoffset`	Update the EVM offset calibration data. Also used for setting the flash memory as the gain offset calibration data source when the SiWx917 production calibration data is stored in the eFuse memory.

Example usage (SoC mode):

1. Start test mode infinite burst packet Wi-Fi transmission with power index=16 and 802.11g / 6 Mbps protocol: `commander manufacturing radio --start --power 16 --phy 6MBPS --channel 1 -d SiWG917M111MGTBA`
2. Increase low-band gain offset by 2 (decreases TX power by ~ 1 dB) and store: `commander manufacturing gain --ch1 2 --skipload -d SiWG917M111MGTBA`
3. Stop transmission: `commander manufacturing radio --stop --skipload -d SiWG917M111MGTBA`
4. Enable loading the gain offset calibration data from the flash memory instead of the eFuse memory by writing the EVM offset calibration data. (Writing all zeroes will not change the EVM offset calibration.) Only required to perform once and **only for SiWx917 parts having no internal flash memory.** `commander manufacturing evmoffset --off0 0 --off1 0 --off2 0 --off3 0 --off4 0 –store`

For the full set of command options, refer to the help information of the specific command (invoked with the --help option).

Additional guidelines on how to use the Manufacturing Utility are provided in UG574: SiWx917 SoC Manufacturing Utility User Guide and UG575: SiWx917 NCP Manufacturing Utility User's Guide.

4. 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 the application notes, AN1440: SiWx917 Gain Offset Calibration and AN1436: SiWx917 QMS Crystal Calibration.

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 SiWx917M 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.

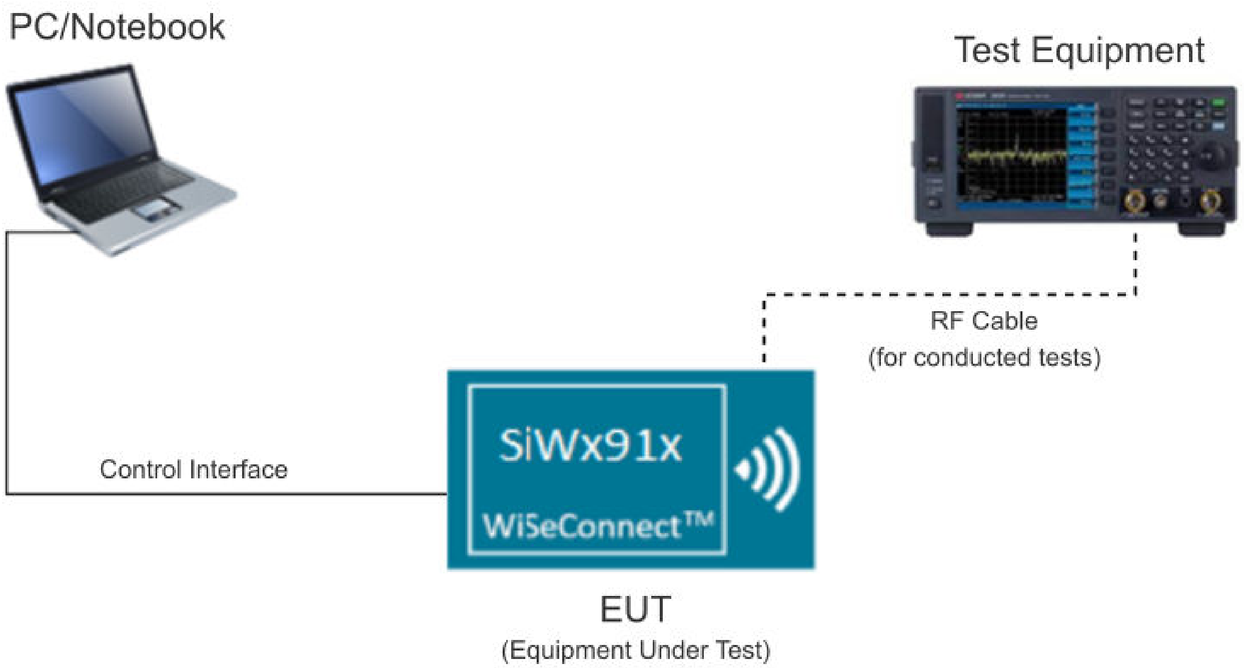


Figure 4.1. Test Setup

Note:

- The test setup and test procedure used for assessing regulatory compliance must adhere to the requirements specified in the associated regulatory standard
- To meet FCC emission limits, Band-Edge channels (1 and 11) Tx Power will be lowest. Other Channels will be relatively lower compared to middle channels.
- Channels 1 (2412 MHz) through 11 (2462 MHz) are supported for FCC. Channels 1 (2412 MHz) through 13 (2472 MHz) are supported for Europe and Japan. Channel 14 (2484 MHz) is supported for Japan.
- The radiated power in band edge is a strong function of the antenna properties. Front end reference design has an external bandpass filter to meet the regulatory emission standards, including FCC. Silicon Labs recommends using the same reference design.

4.1 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 SiWx917M 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 4.1 Wi-Fi Region Codes on page 11 for the available region codes:

Table 4.1. 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 4.1 Wi-Fi Region Codes on page 11, 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.

4.1.1 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 (e.g., for 17.5 dB Tx power, input 35). Consider the desired power value in steps of 0.5 dB.
- 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 ID.
- 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, where each entry sets the TX power limit for all channels that are higher than the channel ID specified in the previous entry (or from channel 1 for the first entry) and lower or equal to the specified channel ID. For example, if 4 channel entries are defined with channel IDs 2, 10, 13 and 14 , then the first entry will set the limits for Wi-Fi channel 1-2. the second for channel 3-10, the third for channel 13 and the fourth for channel 14.

Example Wi-Fi Gain Table Payload:

```
{4, //Number of regions
          0, //FCC
          11, //Number of channels
          // Ch   11b   11g   11n   11ax
              1,   33,   24,   21,   20,
              2,   34,   28,   28,   24,
              3,   40,   30,   32,   30,
              4,   40,   33,   36,   31,
              5,   40,   35,   36,   32,
              6,   40,   35,   36,   32,
              7,   40,   34,   36,   30,
              8,   38,   32,   36,   32,
              9,   38,   34,   34,   28,
             10,   34,   30,   30,   22,
             11,   34,   24,   22,   20,
          1, //ETSI
          0x11, //Single entry for all channels
          // Ch   11b   11g   11n   11ax
            255,   36,   36,   36,   24,
          2, //MIC
          0x24, //Single entry for Ch 1-12 + 3 extra channel
          // Ch   11b   11g   11n   11ax
              2,   34,   28,   32,   24,
             10,   34,   36,   36,   24,
             13,   34,   26,   24,   24,
             14,   36,    0,    0,    0,
          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: +16.5…+20 dBm depending on channel
  - 802.11g/n/ax: +10…+18 dBm depending on channel
- ETSI:
  - 802.11b/g/n: +18 dBm
  - 802.11ax: +12 dBm
- MIC:
  - Channel 1-2: +12...+17 dBm (depending on Wi-Fi standard)
  - Channel 3-10: +12...+18 dBm
  - Channel 11-13: +12...+17 dBm (depending on Wi-Fi standard)
  - Channel 14: Only 802.11b supported with +18 dBm max TX power
- KCC:
  - +18 dBm (for 802.11b/g/n/ax and all channels)

4.1.2 BLE Gain Table

The BLE regulatory TX power limitations are defined in separate gain tables for the different power modes (power chains). For the high power (HP) chain power, the limits are specified in the **Max Power Gain Table** and the **Offset Gain Table**. The former sets absolute maximum limits on a per regualtory region basis while the latter applies additional offset limitations on a per region, per modulation and per channel basis. For the low power (LP) chain, the limits are specified in two separate gain tables for the 0 dBm and +10 modes on a per region, per modulation and per channel basis.

The format of the BLE Gain Tables is as below:

- **BLE HP Chain 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 HP Chain 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
- Each listed power offset value represents the desired additional power back off, that should be applied (on top of the absolute limits listed in the Max Power Gain Table), expressed in dB (i.e., 1 dB steps).
- The offset value specified for channel number 255 represents all channels except those that are explicitly specified.

LP Chain 0 dBm and +8 dBm Gain Tables:

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

      …
      }
```

Note:

- The maximum size for the LP chain 0 dBm and +8 gain tables is 128 bytes.
- In each entry, list the desired power indices. The valid range is 1 to 31 for the 0 dBm table and 33 to 63 for the 8 dBm table.
- The offset value specified for channel number 255 represents all channels except those that are explicitly specified.

Example BLE Gain Table Payloads:

HP Chain Max Power Gain Table:

```
{
0, 18, //FCC
1, 8, //ETSI
2, 10, //MIC
3, 18, //WORLDWIDE
4, 10  //KCC
}
```

HP Chain Offset Gain Table:

```
             {5, //Number of regions
                              0, //FCC
                              5, //Number of channels
                              // Ch   1M   2M   125kbps   500kbps
                                255,   0,   0,    6,        0,
                                  0,   0,   0,    6,        0,
                                 37,   1,   3,    6,        0,
                                 38,   2,   4,    6,        1,
                                 39,   3,  18,    6,        2,
                              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
                              3, //Number of channels
                              // Ch   1M   2M   125kbps   500kbps
                                255,   0,   0,     0,       0,
                                  0,   0,   7,     0,       0,
                                  1,   0,   7,     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,   0,   0,     0,       0,
                                 20,   0,   0,     0,       0,
                                 39,   0,   0,     0,       0
                              }
```

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

- FCC
  - 1M PHY:
    - Ch 37: +17 dBm
    - Ch 38: +16 dBm
    - Ch 39: +15 dBm
    - All other channels: +18 dBm
  - 2M PHY:
    - Ch 37: +15 dBm
    - Ch 38: +14 dBm
    - Ch39: 0 dBm
    - All other channels: +18 dBm
  - 500 kbps PHY:
    - Ch 38: +17 dBm
    - Ch 39: +16 dBm
    - All other channels: +18 dBm
  - 125 kbps PHY:
    - +12 dBm on all channels
- ETSI
  - +8 dBm on all channels
- MIC:
  - Ch 0-1, 2M PHY: +3 dBm
  - All other channel and PHY combinations: +10 dBm

- KCC:
  - +10 dBm on all channels

LP Chain +8 dBm Gain Table:

```
{5, //Number of regions
        0, //FCC
        4, //Number of channels
        // Ch   1M   2M   125kbps   500kbps
          255,  63,  63,    63,       63,
            0,  63,  63,    63,       63,
           19,  63,  63,    63,       63,
           39,  63,  35,    63,       63,
        1, //ETSI
        4, //Number of channels
        // Ch   1M   2M   125kbps   500kbps
          255,  63,  63,    63,       63,
            0,  63,  63,    63,       63,
           19,  63,  63,    63,       63,
           39,  63,  63,    63,       63,
        2, //MIC
        4, //Number of channels
        // Ch   1M   2M   125kbps   500kbps
          255,  63,  63,    63,       63,
            0,  63,  63,    63,       63,
           19,  63,  63,    63,       63,
           39,  63,  63,    63,       63,
        3, //WORLDWIDE
        4, //Number of channels
        // Ch   1M   2M   125kbps   500kbps
          255,  63,  63,    63,       63,
            0,  63,  63,    63,       63,
           19,  63,  63,    63,       63,
           39,  63,  63,    63,       63,
        4, //KCC
        4, //Number of channels
        // Ch   1M   2M   125kbps   500kbps
          255,  63,  63,    63,       63,
            0,  63,  63,    63,       63,
           19,  63,  63,    63,       63,
           39,  63,  63,    63,       63,
        }
```

LP Chain 0 dBm Gain Table:

```
                  {5, //Number of regions
                           0, //FCC
                           4, //Number of channels
                           // Ch   1M   2M   125kbps   500kbps
                             255,  31,  31,    31,       31,
                               0,  31,  31,    31,       31,
                              19,  31,  31,    31,       31,
                              39,  31,   8,    31,       31,
                           1, //ETSI
                           4, //Number of channels
                           // Ch   1M   2M   125kbps   500kbps
                             255,  31,  31,    31,       31,
                               0,  31,  31,    31,       31,
                              19,  31,  31,    31,       31,
                              39,  31,  31,    31,       31,
                           2, //MIC
                           4, //Number of channels
                           // Ch   1M   2M   125kbps   500kbps
                             255,  31,  31,    31,       31,
                               0,  31,  31,    31,       31,
                              19,  31,  31,    31,       31,
                              39,  31,  31,    31,       31,
                           3, //WORLDWIDE
                           4, //Number of channels
                           // Ch   1M   2M   125kbps   500kbps
                             255,  31,  31,    31,       31,
                               0,  31,  31,    31,       31,
                              19,  31,  31,    31,       31,
                              39,  31,  31,    31,       31,
                           4, //KCC
                           4, //Number of channels
                           // Ch   1M   2M   125kbps   500kbps
                             255,  31,  31,    31,       31,
                               0,  31,  31,    31,       31,
                              19,  31,  31,    31,       31,
                              39,  31,  31,    31,       31,
                           }
```

The reference Gain Tables above enable using the BLE LP chain +8 dBm and 0 dBm mode max power settings, except for FCC region, channel 39 (2480 MHz) and 2 Mbps PHY, where the TX power is limited to -7~-5 dBm for FCC band-edge compliance.

5. Regulatory Pre-Compliance Test Results

The following pre-compliance conducted and radiated measurements were performed by Silicon Labs on BRD4338A and BRD4342A Radio Boards. The results are only indicative of the expected harmonic emission and band-edge performance; device manufacturers must certify their end-products themselves in an accredited test house and may need to apply additional power back-off, depending on the hardware implementation and margin requirements.

5.1 Harmonic Emissions

General Test Emissions

- R&S FSV Spectrum Analyzer, RBW = 1 MHz, VBW = 10 kHz, Detector: RMS
- WLAN: 802.11b PHY (DSSS 1 Mbps) – lowest data rate results in more concentrated power, hence the worst-case harmonics of all modulations
- Worst-case values across multiple Radio Boards
- 25 °C room temperature

Only the 2nd and 3rd harmonics are presented, as all higher order harmonics show great margins on the -41.2 dBm limit of FCC 15.247 in both the conducted and radiated tests.

5.1.1 Conducted Harmonics

Test Conditions:

- Measured at the micro-coaxial antenna port
- WLAN channels: 1 to 11
- BLE channels 0 to 39

Table 5.1. Conducted WLAN and BLE Worst-Case Harmonics [dBm]

Radio Board	Harmonic	WLAN	BLE		
		HP (19 dBm)	HP (19 dBm)	LP (8 dBm)	LP (0 dBm)
BRD4338A	H2	–54.3	–56.4	–61	-60.6
	H3	–61.3	–49.7	–51.2	–61.2
BRD4342A	H2	–60.7	–57.5	Port NC	–66.1
	H3	–64.2	–62.6		–60.2

The conducted harmonics are well below the –41.2 dBm limit with the help of the Band Pass Filter.

5.1.2 Radiated Harmonics

Test conditions:

- Measured in an anechoic antenna chamber
- WLAN channels: 1, 7, 13
- BLE channels 0, 18, 37
- Worst-case values across the three planes of the DUT, and two polarizations of the receiver antenna

Table 5.2. Radiated WLAN and BLE Worst-Case Harmonics in EIRP [dBm]

Radio Board	Harmonic	WLAN	BLE		
		HP (19 dBm)	HP (19 dBm)	LP (8 dBm)	LP (0 dBm)
BRD4338A	H2	–43	–47.3	–41.8	-57.6
	H3	–43.9	–45.6	–45	–42.9
BRD4342A (with RF shield)	H2	–48.2	–50.2	N/A[1]	–59.2
	H3	–48.8	–46.7		–51.3

Note:

1. Not available for Internal RF Switch configuration.

We have observed that the harmonic radiation originates from the bonding wire and the matching network area. The harmonic emission is also coupled to the B9 pin, which therefore must be left floating and not routed.

The table above shows the following:

- BRD4338A is compliant without an RF shield; however, it is recommended to include a shield footprint covering the RF area, which can be left unpopulated in the event of adequate radiated harmonic performance.
- BRD4342A is only compliant with an RF shield. The increased radiation is due to the following matching net-work properties compared to BRD4338A:
  - Different PA termination impedance at the harmonic frequencies
  - RX path connected to the TX path in a “direct tie” topology, introducing more area for potential radiation

Alternatively, about 3 dB extra harmonic margin can be yielded for both radio boards by backing off the TX power by 2 dB (e.g., decreasing the Power Index from 18 to 16).

5.2 FCC Band-Edge Performance

The FCC band-edge requirement sets a -41.2 dBm a limit on the power leaking into the adjacent out of band frequency bands of the following:

- f < 2390 MHz
- f > 2483.5 MHz

Test conditions:

- Measured at the micro-coaxial antenna port
- 25 °C room temperature
- Worst-case values across multiple Radio Boards
- Worst-case RU_Alloc and User_inx combinations
- WLAN channels: 1 to 11 and 802.11b-1 Mbps, 802.11g-6 Mbps, 802.11ax-MCS0
- BLE channels: 0, 1, 2, 3, 17, 18, 35, 36, 37 using the HP 19 dBm chain

The table below shows the output power level for all channels where the band-edge measurement passes with considerable margin. Note that for both Radio Boards, setting the power level to 127 and using region "FCC" automatically backs off the power at the lower and upper WLAN and BLE channels to comply with the band-edge standard.

Table 5.3. Conducted WLAN Output Power Restrictions for Band-Edge Compliance [dBm]

WLAN		Radio Board	Channel										
			1	2	3	4	5	6	7	8	9	10	11
b	1 Mbps	BRD4338A	17.5	17.6	19.8	19.9	21.7	21.3	21.2	20.9	20.8	17.1	17.2
g	6 Mbps		12.2	15	15.8	17.8	18.7	18.7	17.9	17.7	16.7	15.8	13.3
ax	MCS0		9.4	10.5	14.8	16	15.9	17.7	15.5	15.5	15.1	10.4	9.7
b	1 Mbps	BRD4342A	17.3	17.2	19.4	19.9	21.1	20.7	20.5	20.2	20.3	16.8	16.7
g	6 Mbps		12.7	14.9	16.2	17.1	17.5	18.1	18	16.4	16.4	15	12.4
ax	MCS0		9.1	12.1	14.6	15.8	16.6	17.3	14.7	14.4	14	10.5	9.3

Table 5.4. Conducted BLE Output Power Restrictions for Band-Edge Compliance [dBm]

BLE 19 dBm HP	Radio Board	Frequency [MHz]							
		2402	2404	2406	2440	2442	2476	2478	2480
1M	BRD4338A	21.1	21.2	21.2	21.6	21.6	19.2	19.2	14.6
2M		22.1	22.1	22.1	22.6	22.6	15.9	15.8	0.9
500k		21.2	21.2	21.3	21.6	21.6	19	19.2	14.4
125k		21.2	21.2	21.2	21.6	21.6	19	17.6	14.4
1M	BRD4342A	20.6	20.6	20.7	21.4	21.4	17.7	17.5	14.4
2M		21.6	21.6	21.6	22.3	22.3	15.1	16	0.95
500k		20.6	20.6	20.7	21.3	21.4	17.5	17.2	14.6
125k		20.5	20.5	20.6	21.3	17.5	17.5	17.9	14.5

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