AN1440: SiWx917 Gain Offset Calibration

This application note covers the TX output power offset calibration procedure for SiWx917 Single Chip Wireless Solutions.

KEY POINTS

- Gain offset calibration
- Wi-Fi TX power measurement
- WiSeConnect APIs and examples for TX power testing and calibration

1. Introduction

Gain offset is the difference between the actual power delivered to the load (antenna) and the configured TX power. It is affected by all parts of the RF chain, including the SiWx917 PA, the RF matching network and the antenna feed line. During production, a baseline calibration data is written in the SiWx917 eFuse memory, which assumes a typical ~2 dB front-end loss and results around ±1 dB TX power accuracy.

For more accurate power control, an additional calibration is needed which compensates the actual losses (or gains) in the RF front-end circuitry and (if performed individually on each manufactured device) minimizes the part-to-part variation. The total loss/gain in the RF front-end circuitry depends on the components used and the PCB layout & stack-up and as such, is specific to the application board. As a result, this application specific gain offset (referred simply by gain offset from now on) must be calibrated on the custom application board by the end-product manufacturer.

Note: The frequency offset and RF regulatory transmit power table (a.k.a. Gain Table) must be also calibrated. Guidelines on how to perform these calibrations are provided in *AN1436: SiWx917 QMS Crystal Calibration Application Note* and *AN1437: SiWx917 RF Regulatory Testing*.

The gain offset calibration is performed by adjusting the associated compensation values so that the gain offset error is minimized. To measure the gain offset error, transmit a modulated test signal with a specific Power Index and measure the actual TX power with a spectrum analyzer or Wi-Fi signal analyzer. The gain offset error can be calculated as the following:

```
Gain offset error [dB] = Power level reported by test equipment [dBm] + Cable loss [dB] – Power Index [dBm]
```

Note:

- For best overall accuracy, it is recommended to use 802.11g – 6 Mbps modulation and Power Index = 16 [dBm] for the test signal.
- Because the gain offset can be slightly different at different frequencies, the calibration must be performed separately at low, mid. and high frequencies (Wi-Fi channel 1, 6 and 11).
- The gain offset calibration needs to be performed at room temperature.

After evaluating the gain offset error, update the compensation parameters, and verify that the gain offset is minimized. In some cases, the calibration may need to be repeated to fine-tune the results.

The gain offset calibration values are stored in the flash memory and can be updated either directly via the programming/debugging interface or by the application through the WiSeConect APIs listed in 2.1 WiSeConnect APIs. Guidelines on how to write the calibration data during the end-product manufacturing are provided in a separate user's guide

Because the gain offset can be adjusted in 0.5 dB steps, 0–0.5 dB residual gain offset error is expected. Furthermore, in order to avoid exceeding RF regulatory limits, it is recommended to tune the actual TX power slightly below the configured TX power (i.e., negative gain offset error).

As the gain offset variation depends on multiple process and part-to-part variations, it is recommended to analyze a sufficiently large sample size. For best TX power accuracy, the gain offset calibration should be performed for each product individually. Depending on the observed total gain offset variation and the TX power accuracy requirements, a common gain offset compensation could be also used, however in this case, the gain offset calibration values also should be evaluated on a sufficiently large sample size.

2. WiSeConnect APIs and Example Applications

2.1 WiSeConnect APIs

Use the WiSeConnect API functions listed in the table below to generate the test signals and update/read the Gain Offset calibration values.

Table 2.1. Recommended API Functions for Gain Offset Calibration

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_si91x_calibration_read`	Read the frequency and gain offset calibration data.
`sl_si91x_calibration_write`	Update the frequency and gain offset calibration data.

Note: The SiWx917 should be initialized in Wi-Fi Transmit Test operation mode (`SL_SI91X_TRANSMIT_TEST_MODE`) for the tests.

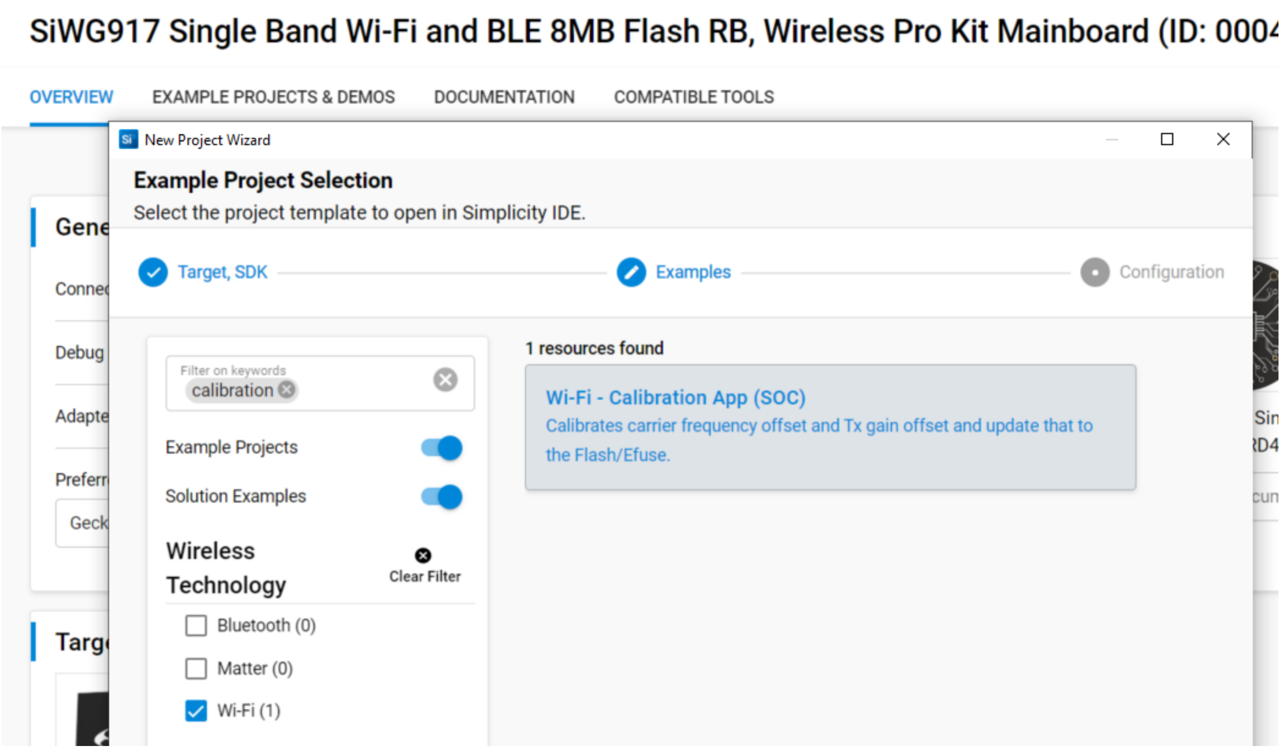
An example application, called Calibration App, is also provided by the WiSeConnect SDK which can be used to perform the Gain Offset calibration via a serial command line interface. Guidelines on how to use the Calibration App example are provided in 2.2 Wi-Fi Calibration App.

2.2 Wi-Fi Calibration App

2.2.1 Setup

The Wi-Fi Calibration App example project provides an easy-to-use serial command line interface for performing the SiWx917 Gain Offset calibration.

To create a Wi-Fi Calibration (SoC or NCP) application, open the new project wizard in Simplicity studio and choose the Wi-Fi Calibration App application.



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

The TX test signal properties can be configured by modifying `tx_test_info` structure definition in the *app.c* file:

Member	Description	Recommended value
power	Test signal Power Index	16
rate	Data rate id, as specified in sl_wifi_data_rate_t	SL_WIFI_DATA_RATE_6 (→ 802.11g / 6 Mbps)
mode	Transmit Mode	Either 0 → BURST_MODE (for burst packets mode) or 1 → CONTINUOUS_MODE (for continuously modulated stream mode)
length	Length of the transmitted packet in bytes	1000 in burst packets mode or 260 in continuously modulated stream mode
channel	WLAN channel	1/6/11

2.2.2 Usage

After startup, the application automatically starts Test Mode Wi-Fi transmission with the given configuration.

The gain offset (and frequency offset) calibration values can be updated with the `sl_calib_write` CLI command. The syntax of the command is as follows:

```
sl_calib_write=<target>,<flags>,<gain_offset_low>,<gain_offset_mid>,<gain_offset_high>[, <xo_ctune>]
```

The parameters for the `wifi_transmit_test_start` command are shown in the table below.

Parameter	Description
target	Target memory. Must be set to 1 (Flash)
flags	Bit 0: Reserved for future use Bit 1: Update XO Ctune calibration data to current value (tuned with the `sl_freq_offset` command) Bit 2: Update XO Ctune calibration data to value provided as argument `xo_ctune` Bit 3: N/A Bit 4: Update low frequency gain offset calibration data with argument `gain_offset_low` Bit 5: Update mid. frequency gain offset calibration data with argument `gain_offset_mid` Bit 6: Update high frequency gain offset calibration data with argument `gain_offset_high` BIT31-7: Reserved for future use
gain_offset_low	2× the gain offset error observed at Channel 1 (0.5 dB steps)
gain_offset_mid	2× the gain offset error observed at Channel 6 (0.5 dB steps)
gain_offset_high	2× the gain offset error observed at Channel 11 (0.5 dB steps)
xo_ctune	(Optional) XO Ctune calibration value [0…255]

For example, to increase the low frequency TX power by 1 dB, issue the `sl_calib_write=1,16,-2,0,0` command whereas to decrease the TX power at high frequencies by 0.5 dB, issue `sl_calib_write=1,64,0,0,1`.

Note: The SiWx917 must be reset to apply the updated gain offset calibration parameters.

3. Gain Offset Measurement

The gain offset can be measured in two ways: Either with continuously modulated stream test signal and a spectrum analyzer configured in channel power integration mode, or with burst packets and a Wi-Fi signal analyzer configured in TX analysis mode.

The recommended parameters for the test signal are as follows:

- Modulation: 802.11g – 6 Mbps
- Channels: 1 (low) / 6 (mid) / 11 (high)
- Power setting: Power Index = 16
- Mode: Burst packets or continuously modulated stream
- Packet/stream length: 1000 byte for burst packets/260 byte for continuous stream
- Region: Worldwide

Note: Unmodulated continuous wave transmission should not be used for this calibration as the output power of unmodulated tones may differ from the output power of modulated signals.

3.1 Measurement with Spectrum Analyzer

1. Configure the device to transmit a 16 dBm, continuous stream mode, 802.11g / 6 Mbps test signal at channel 1/6/11.

   If using the Wi-Fi Calibration App, then modify the tx_test_info definition as below for calibrating channel 1:

```
sl_si91x_request_tx_test_info_t tx_test_info = {
  .enable      = 1,
  .power       = 16,
  .rate        = SL_WIFI_DATA_RATE_6, // -> 802.11g - 6 Mbps
  .length      = 260,
  .mode        = 1,                   // CONTINUOUS_MODE
  .channel     = 6,                   // 1/6/11
...
};
```

2. Connect the RF port of the device to the spectrum analyzer. If the test setup includes any cables or adapters, then the results should be compensated with the RF attenuation of these.
3. Configure the spectrum analyzer to calculate the integrated channel power. See the table below for the recommended settings.

Table 3.1. Spectrum Analyzer Settings For TX Power Measurement

Setting	Value
Reference level	At least 8 dB higher than Wi-Fi TX power level (e.g. 24 dBm for 16 dBm TX power)
Center frequency	Operating frequency (2412 MHz for channel 0, 2437 MHz for channel 6, 2462 MHz for channel 11)
Detector	RMS
RBW	<1 MHz
Sweep time	Period to guarantee accurate measurement
Measurement	Channel Power
Integration Bandwidth	20 MHz

4. Observe the TX power and calculate the gain offset error. An example is shown on the figure below, where Power Index = 16 [dBm] was programmed, the adapter attenuation is ~0.3 dB and the power level at the spectrum analyzer is 14.8 dBm, which means the gain offset error is 14.8 dBm-16 dBm+0.3 dB≈ -0.9 dB .

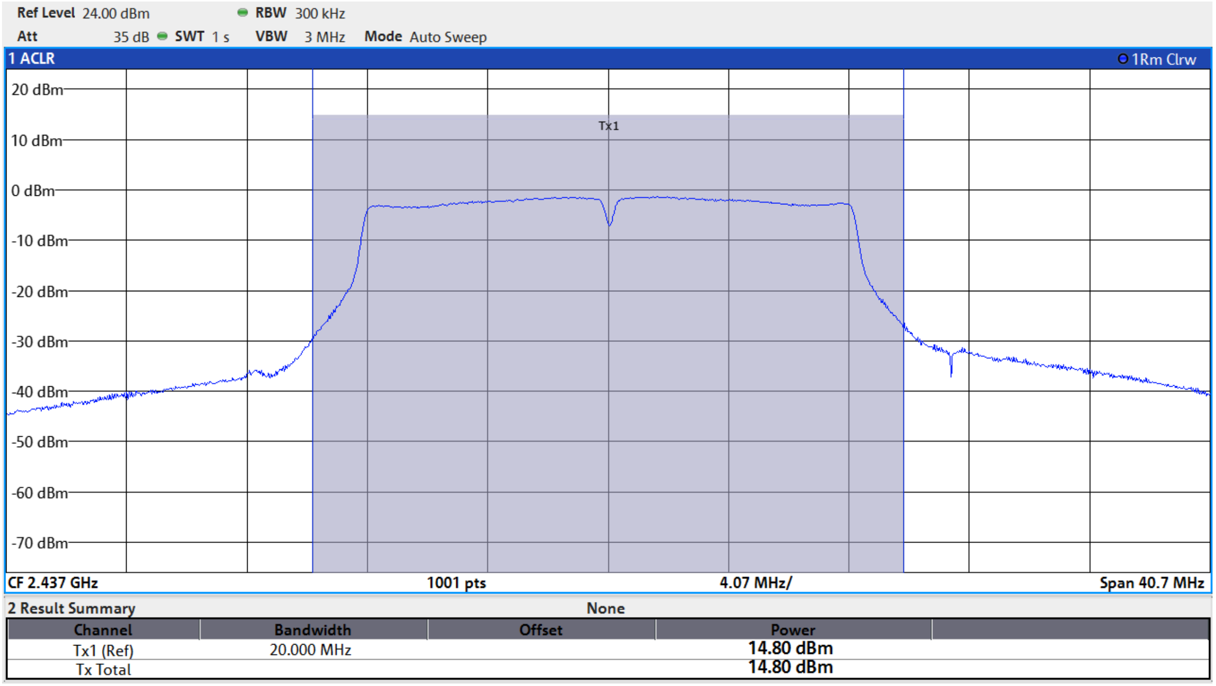


Figure 3.1. Power Measured with Spectrum Analyzer Before Gain Offset Calibration

5. Update the gain offset calibration value to eliminate the offset error. In the example provided, the mid frequency gain offset should be increased by ~1 dB. If using the Wi-Fi Calibration App, then issuing `sl_calib_write=1,32,0,-2,0` will increase the mid. frequency gain offset by 1.0 dB.

   Note: The SiWx917 must be reset to apply the updated gain offset calibration parameters.

6. Verify the gain offset with the updated calibration and, if necessary, repeat step 4 and 5 until the gain offset error is reduced to -0.5~0 dB.

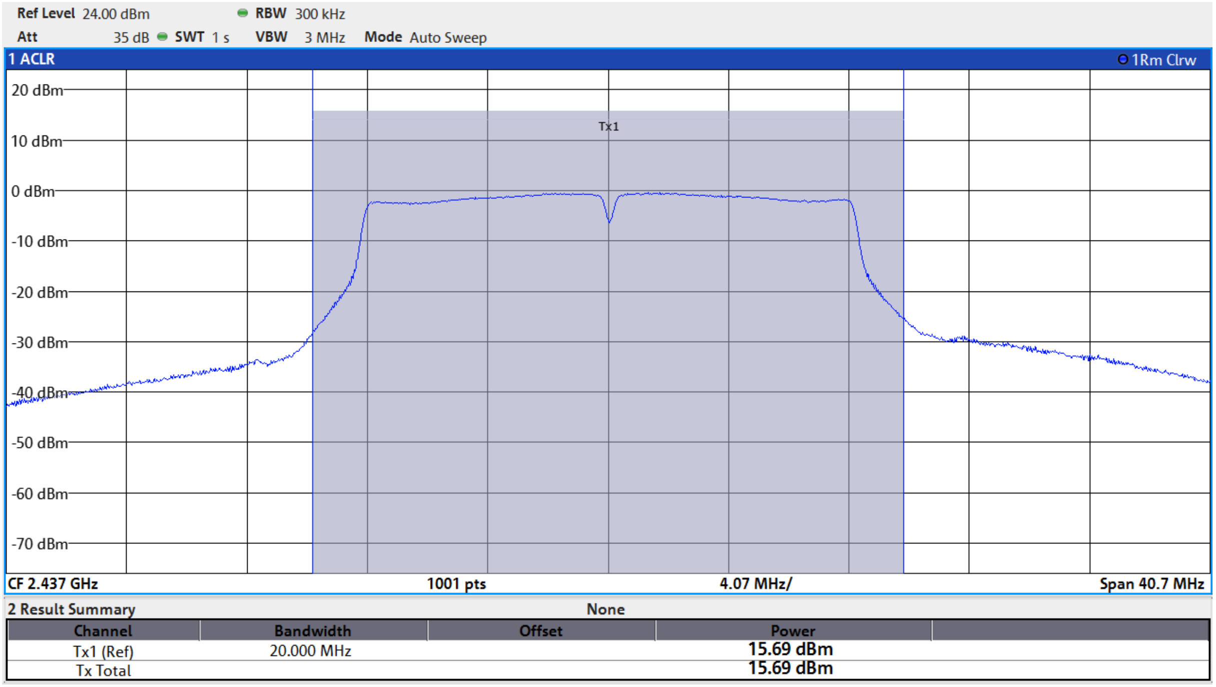


Figure 3.2. TX Power Measured with Spectrum Analyzer After Gain Offset Calibration

3.2 Measurement with Wi-Fi Signal Analyzer

1. Configure the device to transmit 16 dBm burst packets with 802.11g – 6 Mbps rate at channel 1/6/11 in transmit test mode.

   If using the Wi-Fi Calibration App, then update the tx_test_info definition as below for calibrating channel 1:

```
sl_si91x_request_tx_test_info_t tx_test_info = {
  .enable      = 1,
  .power       = 16,
  .rate        = SL_WIFI_DATA_RATE_6, // -> 802.11g - 6 Mbps
  .length      = 1000,
  .mode        = 0,                   // BURST_MODE
  .channel     = 6,                   // 1/6/11
...
};
```

2. Connect the RF port of the signal analyzer. If the test setup includes any cables or adapters, then the results should be compensated with the RF attenuation of these.
3. Configure the signal analyzer to Wi-Fi 802.11g TX analysis mode.
4. Observe the TX power and calculate the gain offset error. An example is shown in the figure below, where Power Index = 16 [dBm] was programmed, the adapter attenuation is ~0.3 dB and the power level at the signal analyzer is 14.84 dBm, which means the gain offset error is 14.84 dBm-16 dBm+0.3 dB≈ -0.9 dB.

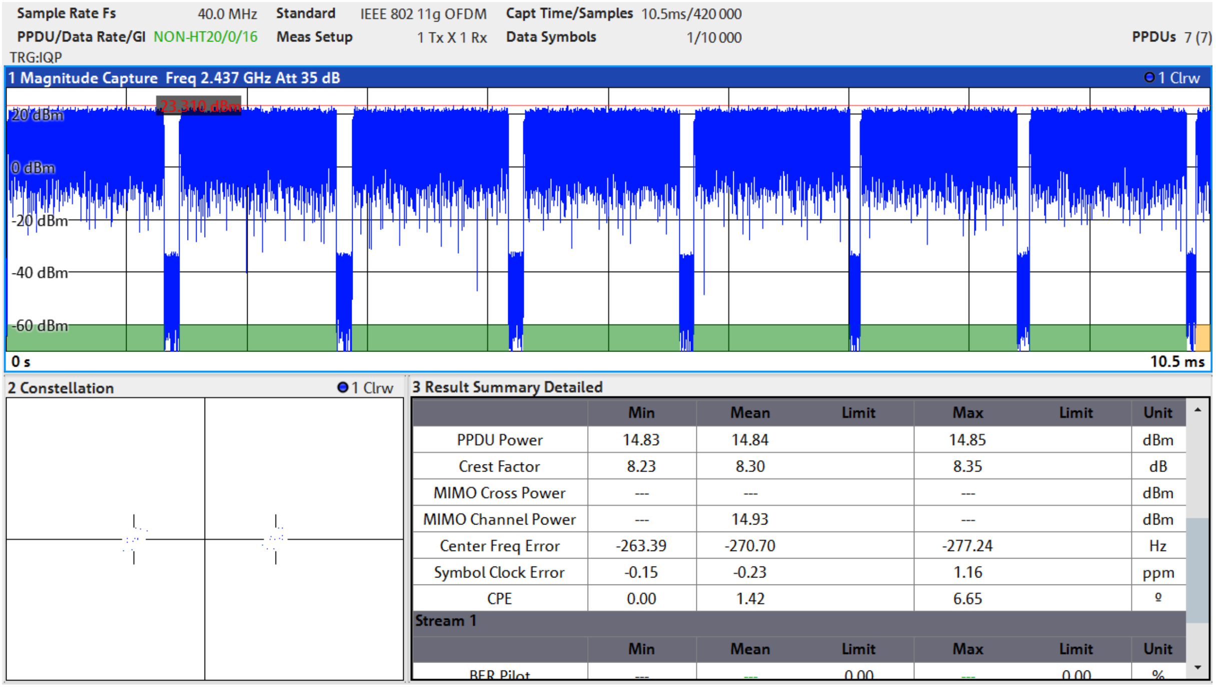


Figure 3.3. TX Power Measured with Wi-Fi Signal Analyzer Before Gain Offset Calibration

5. Update the gain offset calibration value to eliminate the offset error. In the example provided, the mid. frequency gain offset should be increased by ~1 dB.

   If using the Wi-Fi Calibration App, then issuing `sl_calib_write=1,32,0,-2,0` will increase the mid. frequency gain offset by 1.0 dB.

   Note: The SiWx917 must be reset to apply the updated gain offset calibration parameters.

6. Verify the gain offset with the updated calibration and, if necessary, repeat step 4 and 5 until the gain offset error is reduced to -0.5~0 dB.

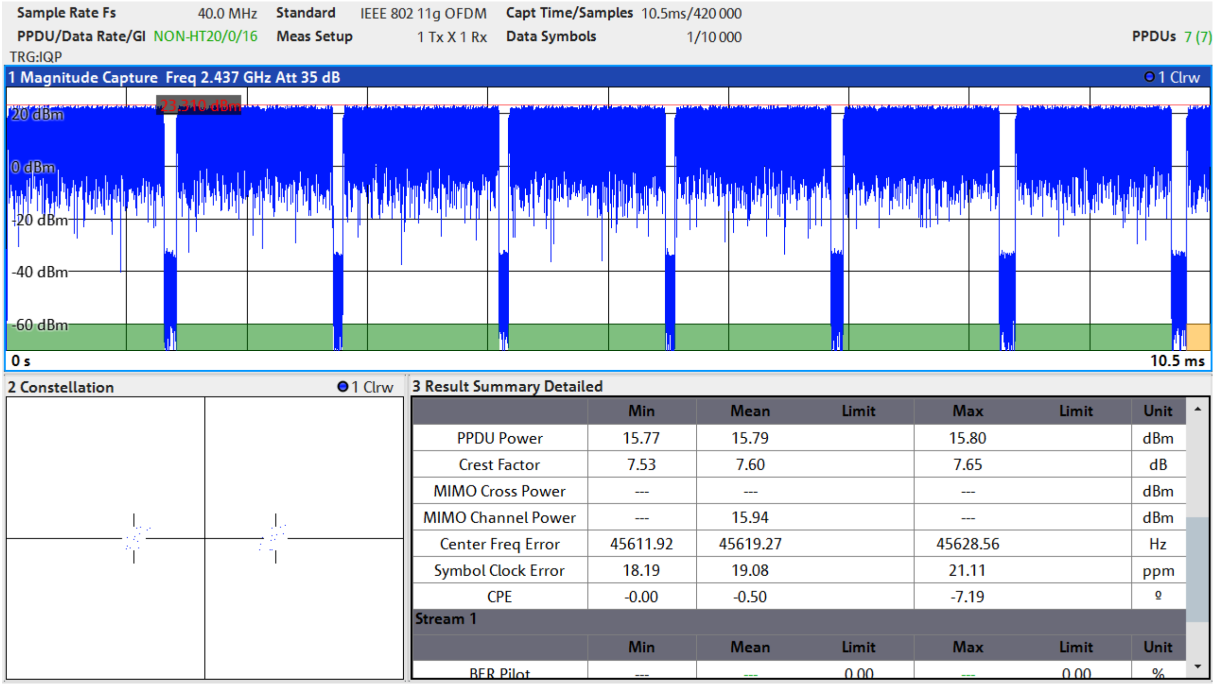


Figure 3.4. TX Power Measured with Wi-Fi Signal Analyzer After Gain Offset Calibration

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