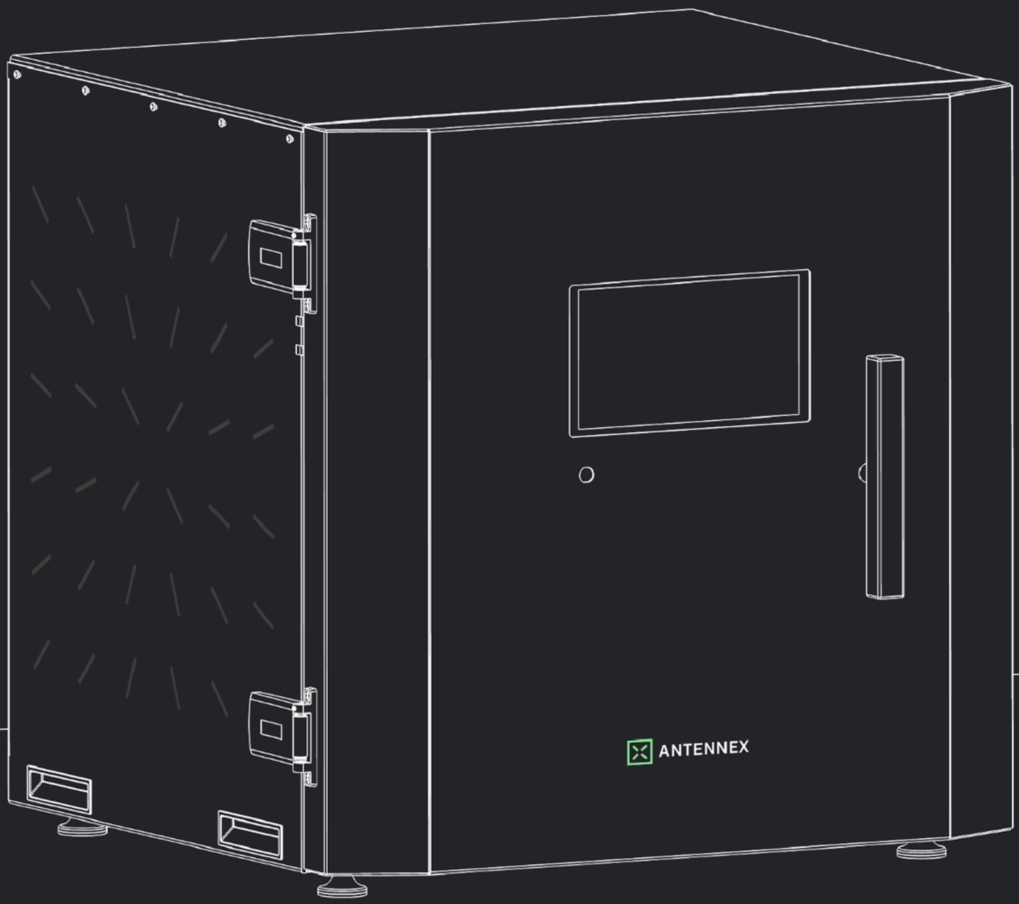
APPLICATION NOTE

Performing Spectrum Measurements using The Wireless Connector®



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Published in The Netherlands, March 31, 2025

Introduction

Measuring the spectrum of wireless devices is essential for optimizing performance, ensuring regulatory compliance and identifying unintended emissions. Two key metrics in this process are spectrum and Power Spectral Density (PSD), which provide insight into how a device transmits power across different frequencies. Additionally, they help determine other important performance metrics, such as harmonic distortion, spurious emissions, adjacent channel leakage ratio and signal compression.

Traditional methods using anechoic chambers rely on complex scanning mechanisms and lengthy measurement procedures to capture the full radiation characteristics of a device. These setups require precise positioning and rotation, leading to time-consuming and labor-intensive testing processes. In contrast, The Wireless Connector®, based on the principles of a reverberation chamber (RC), offers an efficient alternative. By leveraging the natural field-integration property of an RC, it enables fast, repeatable, and statistically robust spectrum measurements without the need for mechanical movements of any antenna.

This application note provides an overview of what is involved in performing spectrum measurements using The Wireless Connector®. It covers the fundamentals of spectrum and PSD, describes the measurement setup and calibration components, and provides guidance on obtaining accurate results using both the graphical user interface (GUI) and the remote control.

Understanding Spectrum and PSD in a Reverberation Chamber

In conducted measurements, spectrum analysis is a common method for evaluating how signal power is distributed across frequency. Two commonly used metrics are:

- Power spectrum: the absolute signal power measured across frequencies, expressed in dBm.
- PSD: the power per unit bandwidth across frequencies, commonly expressed in dBm/MHz.

In antenna measurements, the focus is typically on total radiated power (TRP). The TRP is evaluated by integrating the effective isotropic radiated power (EIRP) across the full sphere enclosing the antenna as defined in [1]:

$$\mathrm{TRP} = \frac{1}{4\pi}\int_0^{2\pi}\int_0^{\pi} \mathrm{EIRP}(\theta,\phi)\sin\theta \mathrm{d}\theta \mathrm{d}\phi \quad (1)$$

where θ and ϕ represent the spherical coordinate angles and $\mathrm{EIRP}(\theta,\phi)$ the angle-dependent EIRP.

With the increasing use of integrated active antennas, the distinction between conducted and radiated measurements fades. In the absence of a connector, measurements that were traditionally performed in a conducted setup must now be done over-the-air (OTA).

The implication of using the RC approach for OTA spectrum analysis is that the integral in (1) is performed implicitly. As such, a spectrum or PSD measurement performed in an RC can be interpreted as a *total radiated* spectrum or *total radiated* PSD. When the measurement focuses on a single frequency point, as in a zero span measurement [2], the resulting quantity corresponds to a single power value and is therefore essentially equivalent to TRP as defined in (1). The implicit integration across the full sphere is where the RC shows a large benefit: alignment is not required, and no signal power is hidden from the detector, regardless of the radiation direction or the potential time-varying nature of spurious emissions.
We use the terms spectrum and PSD in our system, omitting the *total radiated* part given the integration is implicit in the operation of the chamber. This also ensures consistency with established terminology and simplifies the interpretation for users familiar with conducted testing.

How to setup your hardware

A graphic of the full spectrum measurement setup is shown in Fig. 1, illustrating the connections between the reverberation chamber, spectrum analyzer (SA), and device under test (DUT).

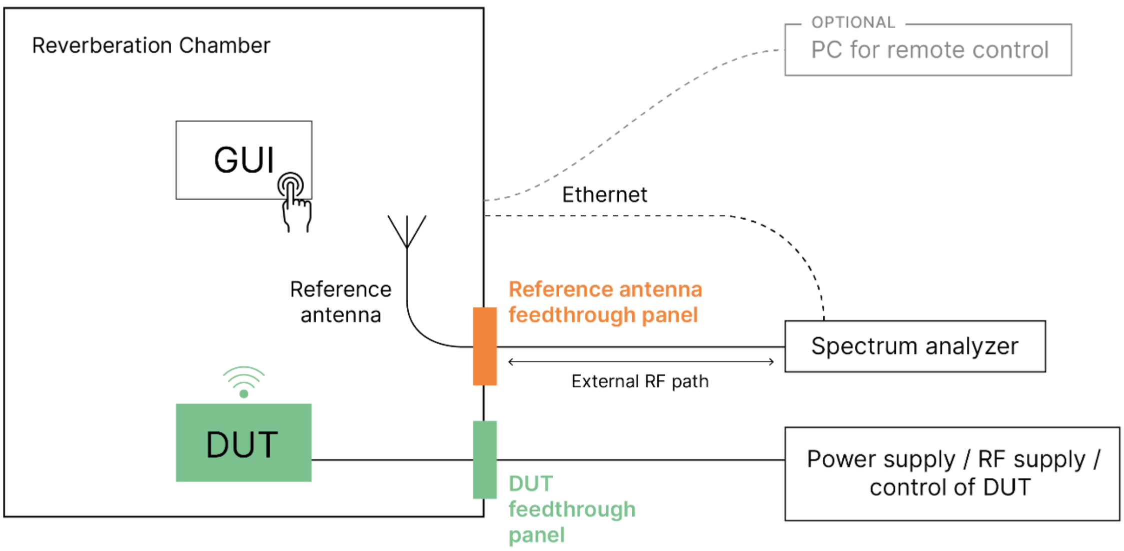

Fig. 1: Graphic overview of the spectrum measurement setup

Spectrum analyzer

In addition to The Wireless Connector®, external equipment is required to capture the measurement data. For spectrum and PSD measurements, a spectrum analyzer is used to capture the data. There is an RF connection between the SA and the reference antenna, which is located at the reference feedthrough panel on the side of the chamber. Depending on the frequency range of the reference antenna, the RF connection can be made using a coaxial cable or a waveguide.

The chamber controls the SA directly through its instrumentation library, eliminating the need for manual SCPI command scripting and simplifying the measurement process. This control is established via an ethernet cable between the chamber and the SA.

Device under test

The DUT should be placed inside the chamber, positioned within the designated DUT region shown in Fig. 2. Since the RC integrates the power radiated in all directions, precise alignment is not required within this region. However, for optimal measurement conditions, consider the following points for DUT positioning:

- Ensure that the antenna is directed upwards toward the pyramidical structure at the top of the chamber. This positioning helps prevent direct reflections from returning into the DUT, which could otherwise change its behavior and impact measurement accuracy.
- Prevent direct coupling between the DUT and the reference antenna. The blocking plate within the chamber helps achieve this by obstructing the unwanted direct path.
- Position the DUT such that its antenna is not placed too close to chamber elements or surfaces, which could alter the impedance and impact the DUT's performance.

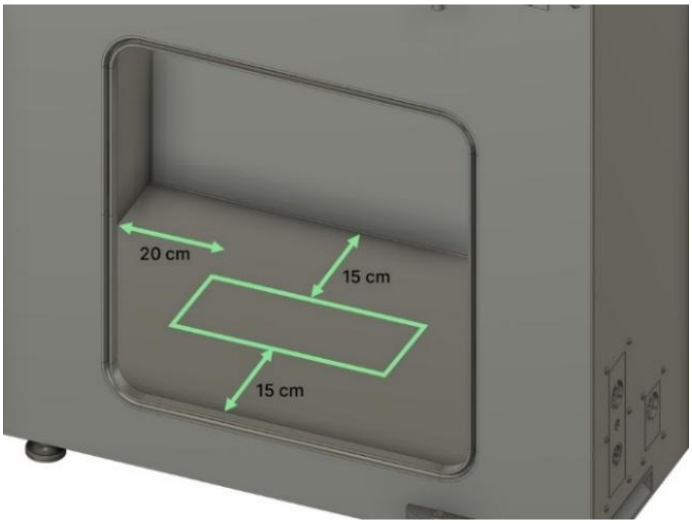

Fig. 2: Indicative DUT placement region. The DUT should not be placed too close to metal surfaces, and should be radiating upwards.

The connection to the DUT can be made through the DUT feedthrough panel located on the side of the chamber. Depending on the DUT's requirements, available feedthrough options include e.g. BNC, USB, Ethernet, coaxial connectors, or waveguides, allowing flexibility for different device configurations.

Remote Control (Optional)

A PC can be connected to the RC through an Ethernet connection. This allows for remote system operation using the API client and post-processing of the measurement results. While not mandatory, a connected PC can facilitate automation of the measurement process, additional control and data management.

The components of your calibration

Calibration is essential for obtaining absolute power levels from the measurements. The process consists of three key components, as illustrated in Fig. 3: chamber loss, antenna efficiency and the external calibration. These factors contribute to the overall signal attenuation, and their combined effect must be accounted for to obtain accurate absolute power levels, following:

$$P_{\mathrm{corr}} = P_{\mathrm{SA}} - G_{\mathrm{ref}} - \eta_{\mathrm{tot}} - G_{\mathrm{external}}, \quad (2)$$

where P_{corr} is the corrected power in dBm or PSD in dBm/Hz depending on P_{SA}, P_{SA} is the measured power in dBm or PSD in dBm/Hz returned by the SA, G_{ref} is the chamber gain in dB, η_{tot} is the total antenna efficiency in dB and G_{external} is the gain of the external hardware in dB. Since the losses of these three factors are simply summed in log scale, it's important to note that this equation does not account for any mismatch between the antenna and external hardware, or between the external hardware and the SA. To ensure the accuracy of the calibration, these mismatches should be minimized.

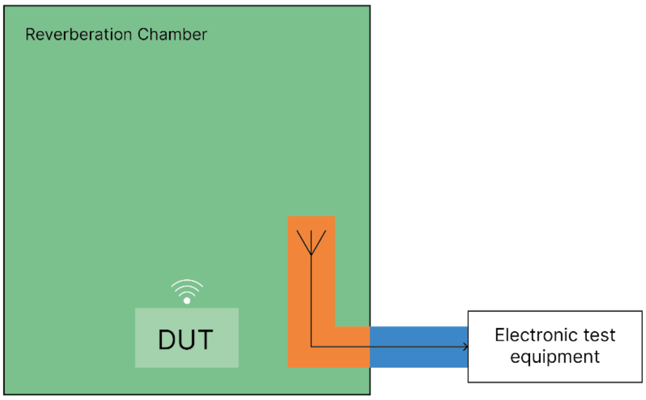

Fig. 3: Three parts of calibration: Chamber Losses (green), Antenna Efficiency (orange) and external calibration (blue)

Chamber Loss

The RC introduces inherent losses due to atmospheric attenuation and absorption by the chamber walls and stirrers. The introduction of a DUT increases this chamber loss, as the DUT alters the electromagnetic environment by adding absorption and changing the mode distribution.

To ensure accurate measurements, it is essential to characterize and compensate for the total chamber losses. This can be done in two ways [5]:

- Using the built-in calibration module together with an SA: This method performs a relative calibration, where only additional losses introduced by the DUT are measured. These relative losses are then combined with a preloaded reference calibration to determine the total chamber loss.
- Using a Vector Network Analyzer (VNA): In this method, the total chamber loss, including both the intrinsic chamber characteristics and the DUT induced loading, is measured directly. The VNA performs an absolute measurement of the chamber in the current setup configuration.

Calibration of the chamber loss can be done using a guided wizard on the GUI or through remote control, with example scripts available [4].

Antenna Efficiency

The reference antenna introduces its own losses, which must be accounted for in the calibration process. The antenna efficiency describes the ratio of received power to incident power, including all losses up to and including the connector in the reference feedthrough panel. The antenna's efficiency must be known to address this, and is typically provided by Antennex or derived from separate measurements. To ensure that the system accurately corrects for the reference antenna's inherent losses during measurement, the losses have to be incorporated in an antenna efficiency file. This efficiency file can be updated through the chamber's display [3] or via the remote connection [4].

External Calibration

Beyond chamber and antenna-related losses, external losses introduced by cables, waveguides, or other connection elements between The Wireless Connector® and external measurement equipment must be accounted for. These losses depend on the length, type, and frequency response of the transmission medium and can have a significant impact, especially at higher frequencies.
To accurately compensate for these losses, a separate measurement of the full external path must be performed using a VNA or similar equipment. The measured losses should then be incorporated into an external calibration file. This file can be uploaded via the chamber's built-in display [3] or through the remote control [4], such that the system can correctly process these losses during postprocessing.

How to configure your setup

A proper setup of the RC and SA is crucial for obtaining accurate and repeatable measurements. The RC should ensure a statistically isotropic field, while the SA has to capture the data. Configuration of these devices correctly is therefore essential to ensure the DUT is evaluated reliably across the desired frequency range.

Reverberation chamber settings

By default, the RC operates in stepped mode with predefined settings:

- Step size: 5° per step for both stirrers
- Stirrer positions: 10 positions for both the horizontal and the vertical stirrer

These settings provide a good balance between measurement accuracy and acquisition time. However, if necessary, they can be adjusted to suit specific requirements through the advanced RC settings in the GUI or remote control [3].

Stirrer Positions

The stirrers vary their position to create a uniform, statistically isotropic field in the chamber. They must move through a sufficiently large number of positions to ensure optimal field uniformity. Each movement introduces a new field distribution, and as more positions are sampled, the overall measurement uncertainty is reduced. However, increasing the number of stirrer positions also extends the total test time, making it important to find a balance between accuracy and time efficiency.

Fig. 4 illustrates the theoretical relationship between the number of stirrer positions and measurement uncertainty due to stirring. As the number of positions increases, the uncertainty decreases, indicating better statistical confidence in the measurements. The default setting of

100 (10 × 10) stirrer positions ensures sufficient uncertainty in the measurements while maintaining a reasonable testing duration. Further details on the specific uncertainty metric are provided in the next section, where the methodology for calculating this uncertainty is explained.

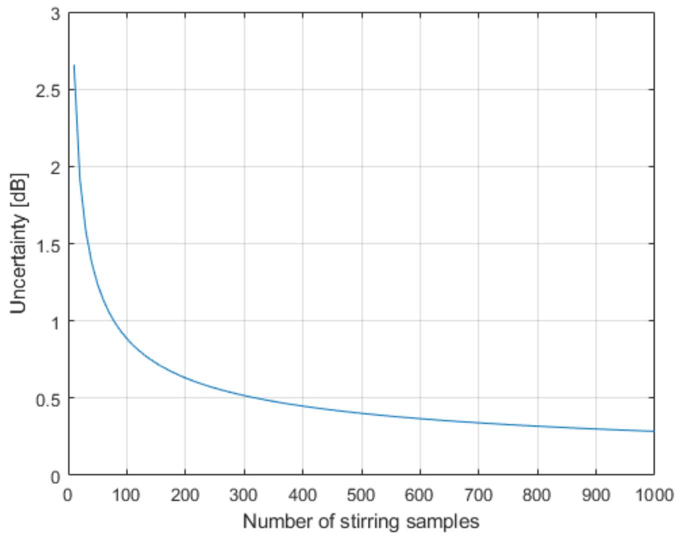

Fig. 4: Theoretical uncertainty vs number of stirrer positions

Step size or stirrer speed
The movement of the stirrers can be configured in two ways:

- Stepped stirring: The stirrers rotate in discrete increments, pausing at each position for a measurement. It is important to ensure that each step introduces sufficient variation in the field to prevent correlation between samples. The required minimal incremental step is given in Table 1 as function of frequency band. The default step size is 5°.
- Continuous stirring: In this mode the stirrers rotate at a fixed speed while measurements are being taken. This mode allows for faster data collection and better averaging over time, but it requires careful configuration of the settings. The sampling rate should be slow enough compared to the stirrer speed to ensure each sample is taken at a sufficiently different stirrer position.

Frequency band (GHz)	Minimal stirrer rotation (°)
5 – 8	20
8 – 14	10
14 – 20	3
20 – 30	1.5
>30	1

Table 1. Minimal stirrer rotation for uncorrelated measurements as function of frequency.

Spectrum analyzer settings

The only settings you need to specify for basic measurements are the start and stop frequencies. The rest of the settings are determined automatically by the ANTENNEX standard settings or the SA itself. However, certain parameters may need to be adjusted depending on the signal characteristics and measurement requirements. Advanced spectrum analyzer settings can be applied using a custom SA preset [3].

RBW

The resolution bandwidth (RBW) determines the frequency resolution of the SA. It defines the width of the frequency bins over which power is measured. A smaller RBW provides better frequency resolution but can result in longer measurement times.

The optimal RBW depends on the type of signal being measured. For example, for a continuous wave (CW) signal, you may want to focus on capturing the total power, including phase noise, which requires a narrower RBW. In contrast, for a noisy signal like Wideband Code Division Multiple Access, a broader RBW is often preferred to capture the PSD more efficiently. Balancing the RBW is crucial to achieve both accurate resolution and manageable measurement duration. The default setting is for the SA to automatically select the RBW.

Number of Points

The number of frequency points refers to how many data points are sampled across the frequency range of interest. A higher number of points provides finer frequency resolution, but it also increases the total measurement time.

It is important to find a balance between the required frequency resolution and the total measurement duration, when selecting the number of points. A common guideline in spectrum analysis is that at least two frequency points per RBW are required to avoid missing narrowband signals, which leads to a minimum number of points given by:

$$N_{\min} = \frac{\mathrm{f_{stop}} - \mathrm{f_{start}}}{\mathrm{RBW}} * 2 + 1. \qquad (3)$$

This is also used as the default number of points by the chamber, with a minimum of 101 points due to limitations of classical instrumentation used for these types of measurements.

Detector Mode and Averaging Type

The detector mode determines how the signal power is averaged or sampled during the measurement. The SA typically has different detector modes and averaging types to optimize for different signal types and measurement purposes. In this application note, the goal is to accurately measure the spectrum. The measured signals, proportional to the fields, are sometimes small (destructive interference) and sometimes large (constructive interference) depending on the position of the stirrer.

Both sample and average detector modes are valid choices for measuring a spectrum. In many cases, they are interchangeable, and the difference in result will be minimal. However, it is recommended to use the average mode in combination with an appropriate averaging type to take advantage of the internal averaging capabilities of the SA.

It is important to choose a proper averaging type, when the average detector mode is selected. Spectrum analyzers typically offer several options, such as average power, log average power, and voltage average. Since both small and large signals are equally important in this measurement, log average power should be avoided. Moreover, because the final figure of merit is a power quantity, it is strongly recommended to use average power (RMS).

Therefore, the default configuration sets the detection mode to average, and the averaging type to RMS.

How to perform a spectrum measurement

The previous sections covered the spectrum measurement setup, the necessary calibration components, and the configuration of the RC and SA settings for accurate measurements. These topics are now demonstrated in a practical example. An example with the Sivers EVK06002 as DUT is used to showcase the capability of the chamber and how to perform spectrum measurements using The Wireless connector®.

- The setup follows the configuration shown in Fig. 1. Since the DUT operates above the frequency range supported by the SA, a harmonic mixer is used in the external path to extend its range. The reference antenna is connected to the harmonic mixer, and the harmonic mixer is connected to the SA according to the manufacturer's specifications.
- The Sivers EVK06002 generates its own RF signal, so only power is supplied via a BNC connection, while communication is established over USB. In this example, the DUT operates in CW mode, without beam switching or dynamic changes in output parameters.
- Chamber loss calibration is performed using the SA and calibration module. External calibration is not required, as the USB-connected harmonic mixer shits the SA reference plane to its own output. Furthermore, the antenna efficiency file is uploaded.

Performing a spectrum measurement is straightforward, once the equipment is set up and the calibration is complete. You can perform a measurement either through the GUI, which offers an intuitive way to configure and execute a single test, or through remote control for automated testing or integration into a larger test framework. In this example, measurements are performed using the default RC and SA settings, unless specified otherwise in the results.

Fig. 5 presents a 10GHz spectrum measured with 6667 frequency points, 100 stirrer positions and an RBW of 3MHz, revealing additional spurious that appear at a greater frequency offset from the carrier. For this DUT, the spectrum appears relatively clean, but such a measurement would immediately highlight potential issues with the DUT, such as oscillations, harmonics or LO leakage.

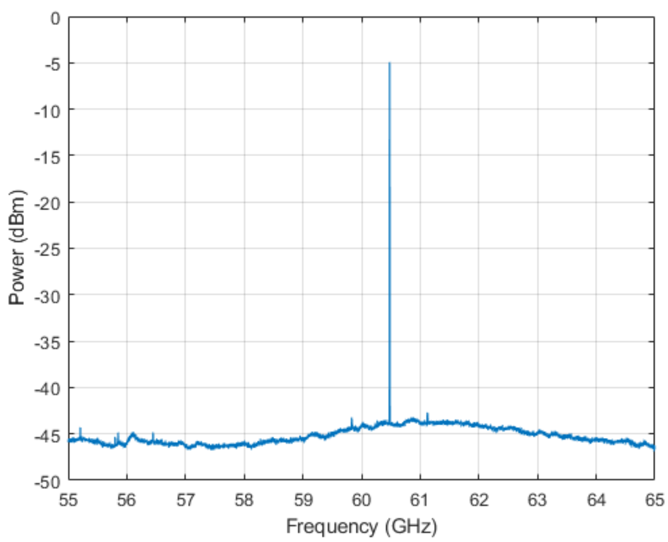

Fig. 5: 10GHz spectrum measured over 6667 number of points, 100 stirrer positions and 3MHz RBW

Fig. 6 zooms in on a 10 MHz spectrum measured over 2001 frequency points and 100 stirrer positions for various RBW settings. For a larger RBW of 3 MHz, no spectral information is visible, but it provides a good estimation of the total power as it captures all radiation from the DUT, including sidebands. When the RBW is lowered, a 1 MHz RBW still gives an accurate estimation as the power does not drop. However, at 91 kHz RBW, which is automatically set by the SA for this span, the peak begins to drop, indicating an underestimation of the total power. This happens because the RBW is too narrow to capture the full extent of the DUT's emission. Further decreasing the RBW reveals not a single peak but multiple peaks, showing that the DUT is drifting. This illustrates that the choice of RBW is dependent on what needs to be measured. Lower RBW settings are particularly useful for inspecting spectral behavior near the carrier frequency, allowing for detailed analysis of nearby spectral components, while higher RBW settings are better for measuring the total transmitted power accurately.

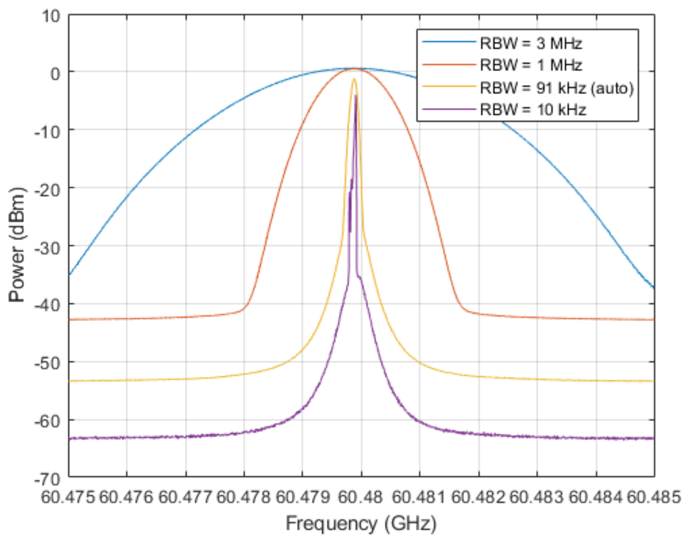

Fig. 6: 10MHz spectrum measured over 2001 number of points and 100 stirrer positions for various RBW settings

Beyond displaying the spectrum, the system also provides an uncertainty estimation for each measurement. The reported uncertainty is calculated as twice the standard error, given by:

$$\text{Uncertainty} = 2 \times \frac{\sigma_{\text{sample}}}{\sqrt{N}}, \quad (4)$$

where σ_{sample} is the sample standard deviation of the measured power over all stirrer positions, and N is the total number of stirrer positions. This uncertainty captures variations due to stirring, DUT variations and instrument drift. The sample standard deviation (σ_{sample}) describes how much individual measurements vary, while the reported uncertainty represents twice the standard deviation of the mean. Since the standard deviation of the mean is simply the sample standard deviation divided by the square root of N, increasing the number of stirrer positions reduces the uncertainty.

The reported uncertainty corresponds to two sigma of the mean. Therefore, the 95% confidence interval is equal to $\pm$uncertainty. It is important to note that this measure reflects precision rather than absolute accuracy.

Summary

This application note introduced all that is involved in preparing and performing a spectrum measurement with the Wireless Connector®. Detailed instructions on how to execute each step can be found in the manuals [3][4] or in additional application notes [5].

A quick recap of a step-by-step spectrum measurement:

1. **Build the setup**
   Connect the necessary components, including the SA, RC, and DUT, according to the configuration diagram in Fig. 1.
2. **Calibrate the chamber loss**
   Perform a chamber loss calibration either using the SA and calibration module or by using the VNA.
3. **Calibrate the external path**
   Measure the loss of the entire external path and upload it as the external calibration file.
4. **Calibrate the reference antenna**
   Determine the efficiency of the reference antenna and upload it as the antenna efficiency file.
5. **Configure the settings of the SA and RC**
   Set the appropriate measurement settings as discussed in this application note, depending on the signal type and measurement goal.
6. **Perform the measurement**
   Execute the spectrum measurement through the GUI or remote control.

References

[1] "IEEE Recommended Practice for Antenna Measurements," in IEEE Std 149-2021 (Revision of IEEE Std 149-1977) , vol., no., pp.1-207, 18 Feb. 2022, DOI: 10.1109/IEEESTD.2022.9714428
[2] “Accurate and Fast Power Characterization at a Fixed Frequency”, Application Note, Antennex, 2025
[3] “User Manual The Wireless Connector®”, Antennex, 2024
[4] “Programming Manual The Wireless Connector®”, Antennex, 2024
[5] "Calibration Techniques for The Wireless Connector®", Application Note, Antennex, to be released in April 2025

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