APP NOTE

Solving High Dynamic Range Measurements for Wide Area Base Stations with SC-PSD

LITEPOINT

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Introduction

Purpose

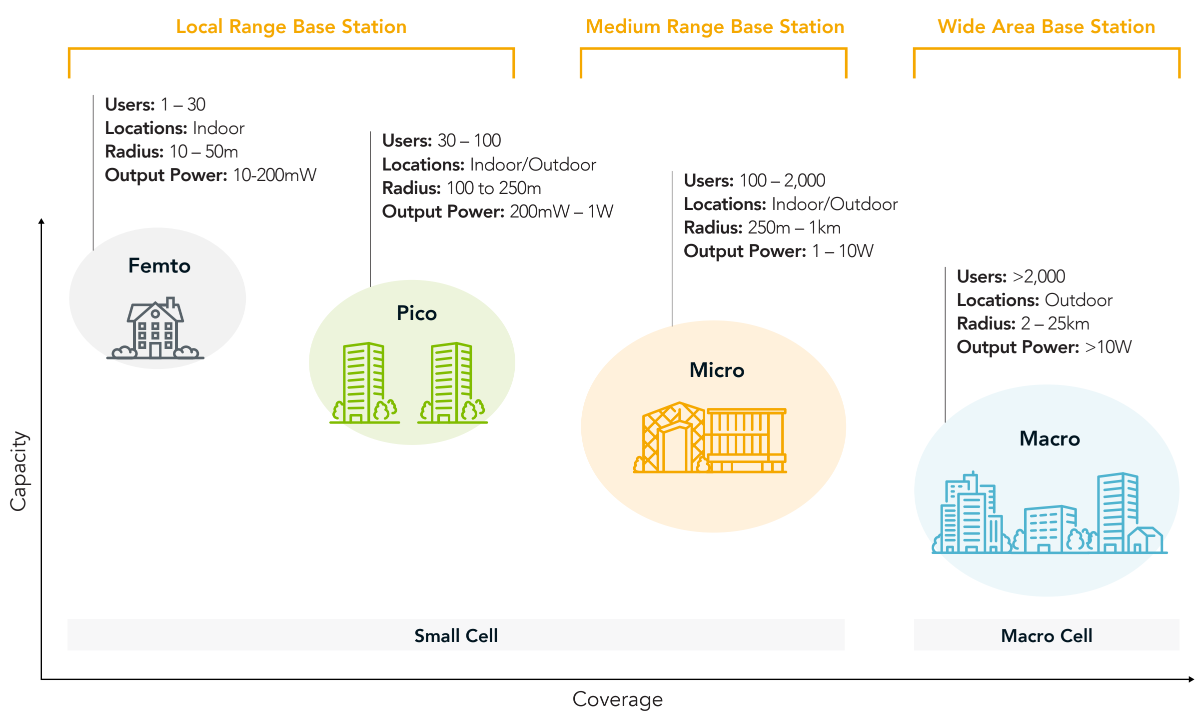
This application note is to provide essential guidance for RF testing of Wide Area New Radio (NR) Base Stations, specifically addressing the unique challenges posed by the high output power and to clarify the critical differences in test setup considerations compared to lower-power base station classes and present effective strategies for achieving safe, accurate, and reliable measurements in such high-power environments.

Background

3GPP standards define the base station classes primarily by their maximum rated output power (Prated), which directly correlates to their intended coverage area. These classes include:

- **Local Area Base Station:** Often deployed as Femto Cells or Pico Cells for small, localized coverage.
- **Medium Range Base Station:** Typically associated with Micro Cells.
- **Wide Area Base Station:** Primarily used as Macro Cells for broad geographic coverage.

The significantly higher output power of Wide Area Base Stations is the most distinguishing characteristic among these classes, enabling their extensive coverage range. However, this high power presents a crucial challenge for conductive RF testing, demanding specialized setup configurations to ensure both the safety of personnel and equipment, and the accuracy of critical RF performance measurements.



Rated carrier output power limits for BS type 1-C

	Wide Area BS	Medium Range BS	Local Area BS
$P_{rated, c, AC}$ (Mean Power per Antenna Connector)	No upper limit	≤ 38 dBm (6.3096W)	≤24 dBm (0.2512W)

Figure 1 Base Station Classes

Practical Test Setup Example

In this application note, consider a practical test scenario involving a LitePoint IQFR1-RU Vector Signal Analyzer (VSA) and a Wide Area NR Base Station (RU).

Key specifications for this example include:

- **LitePoint IQFR1-RU VSA:**
  Maximum safe input power: +34 dBm (average) / +36 dBm (peak)
- **Wide Area Base Station (RU):**
  Typical output power: +47 dBm (average) / +59 dBm (peak)

Given these parameters, a significant amount of attenuation is critical to protect the VSA's sensitive input circuitry. Specifically, an attenuator with an insertion loss greater than 23 dB is required to prevent damage to the VSA and ensure test safety when measuring the base station's maximum output power. Throughout this application note, a 30 dB attenuator will be utilized in example setups to illustrate the necessary signal conditioning for high-power Devices Under Test (DUTs).

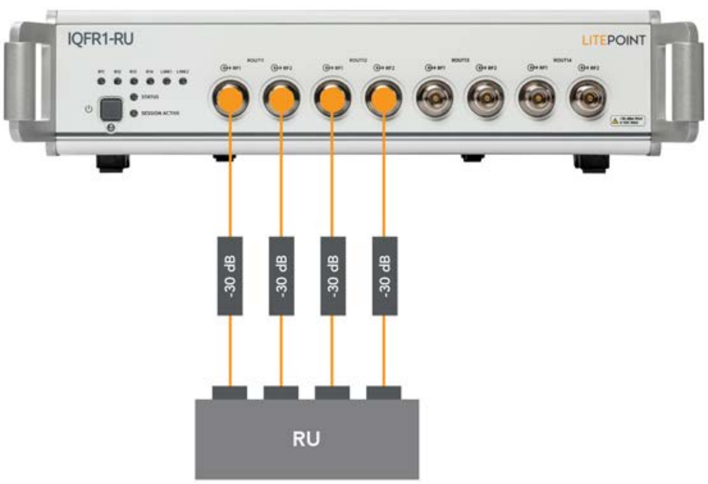


Figure 2 IQFR1-RU Standard Setup

VSA Instantaneous Dynamic Range

Instantaneous Dynamic Range (IDR) is the strongest and weakest input signal components that a VSA can measure simultaneously, without losing fidelity (i.e., without compression or being buried in noise). When testing high-power devices like Wide Area NR Base Stations, a sufficient VSA instantaneous dynamic range becomes critical for the out-of-band measurements or the measurements for signal OFF period.

Impact of Measurement System Effective Dynamic Range

An attenuator inserted before the VSA shifts the effective dynamic range of the measurement system. As shown in the Figure 3 Measurement System Effective Dynamic Range, after 30 dB of attenuation, the RU's inherent unwanted signals (e.g., noise, spurs, OFF power, out-of-band emissions) are attenuated to a level that is below the VSA's noise floor. When this occurs, VSA's noise contribution to power measurement would be larger than the input signal lowest component. Therefore, the measured "RU unwanted" power will be covered by the VSA's noise floor. This condition signifies an inability to characterize DUT's performance accurately in this regime, as the measurement is limited by the VSA's noise rather than the DUT's actual emissions.

This reduction in the measurable lower limit severely impacts the ability to accurately measure low-level signals such as:

- **Adjacent Channel Leakage Ratio (ACLR)**
- **Operation Band Unwanted Emission (OBUE)**
- **Spurious Emissions**
- **Transmitter OFF Power**

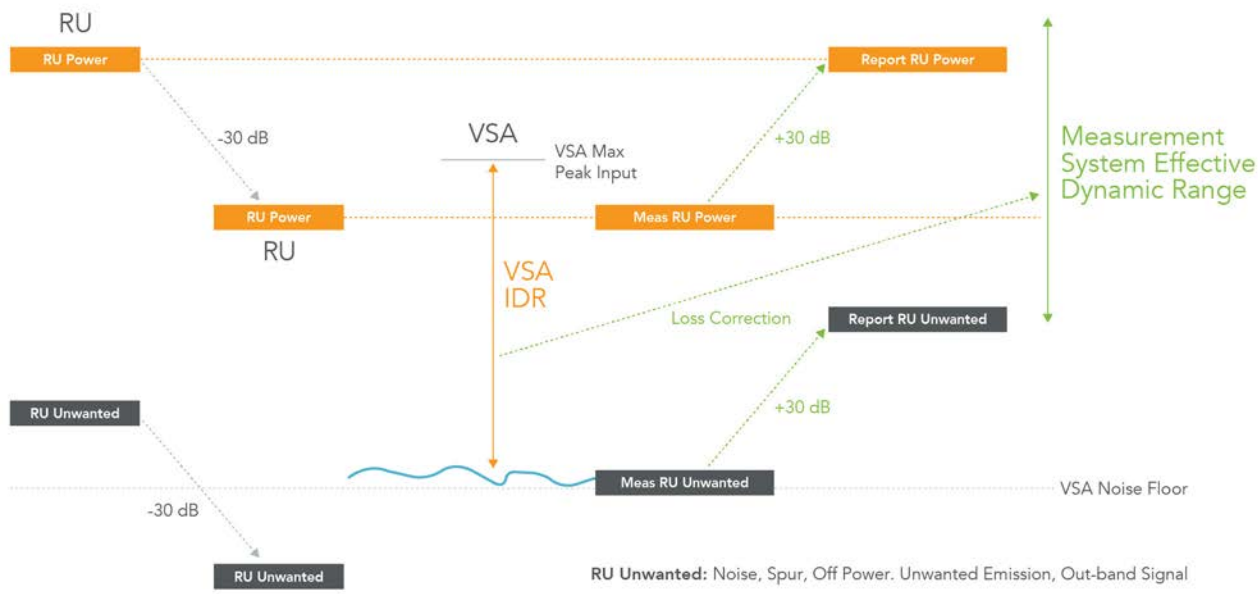


Figure 3 Measurement System Effective Dynamic Range

Traditional Strategies for Optimizing Measurement System Effective Dynamic Range

This section details strategies to overcome these limitations and achieve reliable measurements. To effectively manage high-power signals and optimize measurement system effective dynamic range in Wide Area NR Base Station testing, several specialized RF components are critical:

RF Power Limiter

An RF power limiter is a passive or active device designed to protect sensitive test equipment by restricting the maximum power level of an input signal to a safe, predetermined threshold. When the input power exceeds this threshold, the limiter's impedance changes rapidly, diverting or reflecting the excess power, thus preventing damage to downstream components. They are crucial for guarding against high peak powers, especially during signal transients or accidental overloads.

Low Noise Amplifier (LNA)

A Low Noise Amplifier (LNA) is an active RF component placed early in a receiver chain, close to the signal source, to amplify very weak signals while adding minimal noise. Its primary function is to improve the overall noise figure of the measurement system. By boosting the signal level significantly above the inherent noise floor of subsequent instruments (like a VSA), an LNA enables the accurate measurement of extremely low-level signals that would otherwise be undetectable or buried in noise.

Notch Filter

A Band-Stop Filter, also known as a Notch Filter, is a passive RF filter designed to strongly attenuate (reject) signals within a specific, narrow frequency band while allowing signals outside that band to pass through with minimal loss. In the context of RF testing, they are particularly useful for selectively suppressing a very strong, unwanted signal (e.g., the main carrier or a strong interferer) to prevent saturation of the test equipment or to unmask much weaker signals that are close in frequency but outside the rejected band, thereby improving the effective dynamic range for those specific measurements.

Dual-Path Measurement Strategy for Enhanced Dynamic Range

To accurately measure both high-power in-band signals and challenging low-level unwanted signals (e.g., adjacent channel power, transmit OFF power, spurious emissions), a dual-path measurement strategy is one option. This approach optimizes each path for its specific measurement range and avoids the high requirement of the instantaneous dynamic range.

- **ON Path (High-Power / In-Band Signal Measurement):** This path is dedicated to handling the full output power of the DUT. A high-value attenuator (e.g., -30 dB) is utilized to safely reduce the high average and peak power of the main transmission to levels acceptable for the VSA. This path is primarily used for measurements such as Output Power, Error Vector Magnitude (EVM), and Frequency Error.
- **Unwanted Signal Paths (Low-Level / Out-of-Band Signal Measurement):** These paths are designed to limit the peak input power and reduce the input signal dynamic range for very weak signals that would be buried in noise at the high power ON path. An RF switch at the DUT output allows selection between the ON path and specific unwanted signal paths.

Dual-Path Measurement Strategy for ACLR, OFF Power Measurements

These measurements involve characterizing both the high-power main channel and relatively weak, spectrally close adjacent/alternate channels (for ACLR), or very low-level signals during the Transmit OFF period (for TOOP). Since adjacent channels cannot be filtered out without affecting the measurement integrity, a dedicated approach is necessary.

As illustrated in Figure 4 Dual-Path Measurement for ACLR and OFF Power, the unwanted signal path typically employs a -10 dB attenuator placed before an RF power limiter. This initial attenuation is critical to ensure the input power to the limiter does not exceed its maximum safe operating level, preventing potential damage. While this unwanted signal path inherently has less attenuation than the ON path, its total insertion loss (approximately 15 dB, including the -10 dB attenuator and limiter's intrinsic loss) may still limit the detection of very faint signals.

In such cases, a Low Noise Amplifier (LNA) may be strategically inserted as a preamplifier after the limiter. The LNA's primary role is to boost the low-level unwanted signals, effectively improving the overall system noise figure and enabling higher measurement sensitivity for accurate ACLR and Transmitter OFF Power characterization. When incorporating an LNA, it is crucial to carefully select its gain and ensure that the amplified peak power does not exceed the VSA's maximum safe input level.

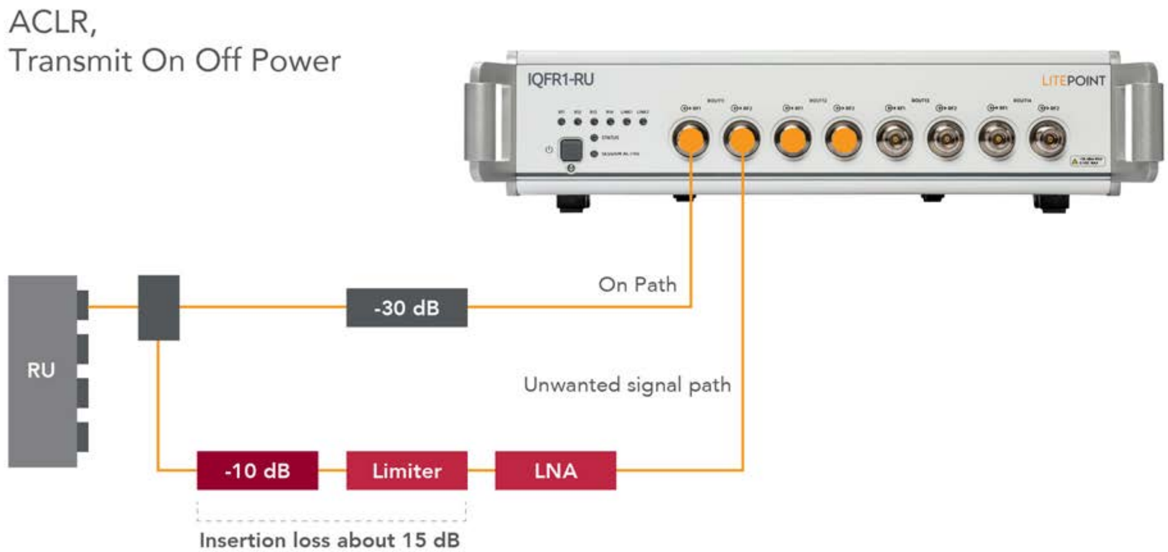


Figure 4 Dual-Path Measurement for ACLR and OFF Power

Dual-Path Measurement Strategy for OBUE and Spurious Measurements

OBUE and spurious measurements focus on unwanted signals emitted outside the operational frequency band. These often require extremely high sensitivity and the suppression of the very strong in-band carrier. The Notch Filter is precisely tuned to the main carrier frequency, providing deep attenuation of the in-band signal while allowing out-of-band signals and spurious emissions to pass. This protects the VSA's input, prevents compression, and minimizes the VSA's own intermodulation distortion, thereby reducing the requirement of the VSA instantaneous dynamic range for detecting very weak signals far from the carrier. It is critical to ensure the DUT's power does not exceed the maximum input level of the Notch Filter. Therefore, a -10 dB attenuator may be inserted before the Notch Filter to provide essential protection. In such a configuration, the total insertion loss for this unwanted signal path (from the attenuator and notch filter's passband) could be around 12 dB.

Furthermore, to ensure the weakest of these unwanted signals are measurable above the measurement system's effective noise floor, a Low Noise Amplifier (LNA) may also be included in this path to boost the unwanted signal level, thereby further improving the system's measurement power range.

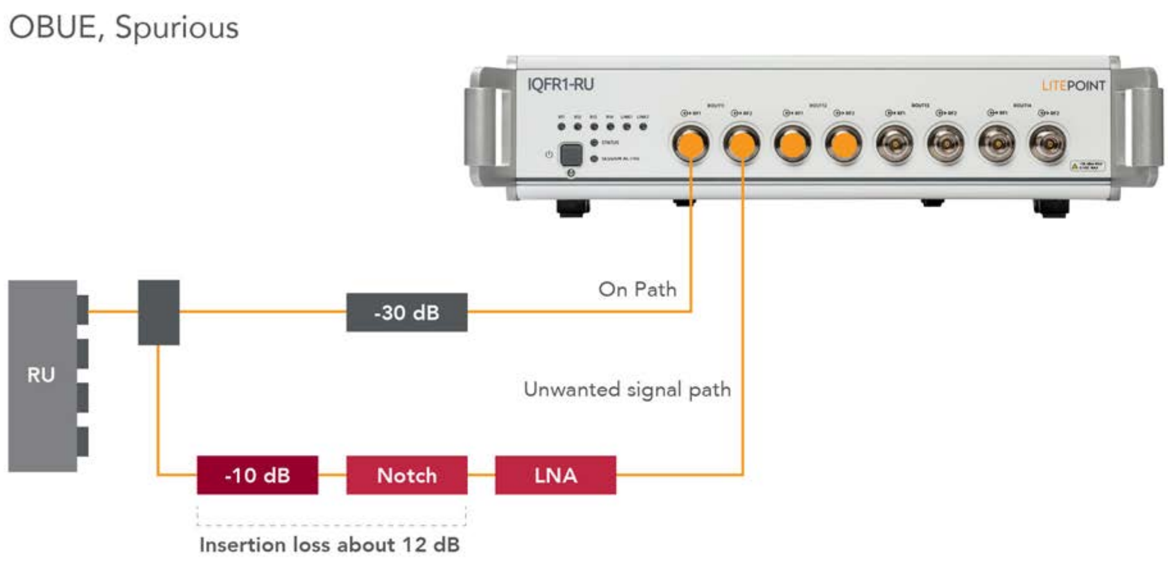


Figure 5 Dual-Path Measurement for OBUE and Spurious

Challenges and Limitations of Traditional Dual-Path Strategies

While dual-path measurement strategies, incorporating components like Limiter, LNA and Notch Filters significantly help measurements, their practical implementation introduces several complexities and limitations:

- **Increased Setup Complexity and Management:** Implementing multiple paths require careful design and introducing additional hardware components, such as RF switches. Managing these paths, ensuring proper connection, and switching between them for different measurements adds complexity to the test setup.
- **Calibration Challenges:** Each distinct path introduces its own unique insertion losses and frequency responses. Accurate measurements demand precise and often separate calibration for each path, which can be time-consuming and prone to error, particularly across a wide frequency range.
- **Component Selection Difficulties:**
  High-Power Component Availability: Selecting RF power limiters and Notch Filters capable of handling the high input power of Wide Area NR Base Stations (e.g., +59 dBm peak) while maintaining linearity and desired electrical characteristics presents a significant challenge. Such high-power components are often specialized, have limited commercial availability, and can be expensive.
  Filter Specificity and Inventory: Notch filters are inherently band specific. This means that for a base station capable of operating across multiple NR bands (e.g., n77, n78, n79), the user would typically need to acquire and manage an inventory of multiple distinct notch filters, each precisely tuned to the carrier frequency of the band being tested. This adds substantial cost, complexity, and setup time as filters must be manually swapped for each band.

These inherent challenges in traditional hardware-based dynamic range enhancement highlight the need for a more streamlined, flexible, and cost-effective approach to comprehensively test Wide Area NR Base Stations.

LitePoint SC-PSD

SC-PSD background

SC-PSD (SNR Compensated Power Spectral Density) is an innovative feature designed to significantly enhance the Vector Signal Analyzer (VSA) instantaneous dynamic range through advanced digital signal processing. This technique precisely characterizes and effectively removes noise contributions inherent to the VSA's measurement path, critically, without distorting or subtracting the actual input signal from the Device Under Test (DUT).

SC-PSD thereby dramatically improves the accuracy and sensitivity of critical 5G base station measurements, including GPRF spectrum and power analysis for OBUE, OFF power measurements and 5GBS measurement for ACLR measurements. For challenging use cases such as Wide Area Base Station testing, where high insertion loss attenuators are mandatory for safety and equipment protection, SC-PSD directly compensates for the resulting degradation in the effective dynamic range of the measurement system.

SC-PSD can improve the VSA instantaneous dynamic range by more that 10dB in the cases having been verified. This enhancement enables the VSA to accurately measure the RU's true unwanted signal levels (e.g., noise, spurs, OFF power) even after significant attenuation, pushing these previously buried signals above the measurement system's effective noise floor. Figure 6 SC-PSD Enhanced Measurement System Effective Dynamic Range.

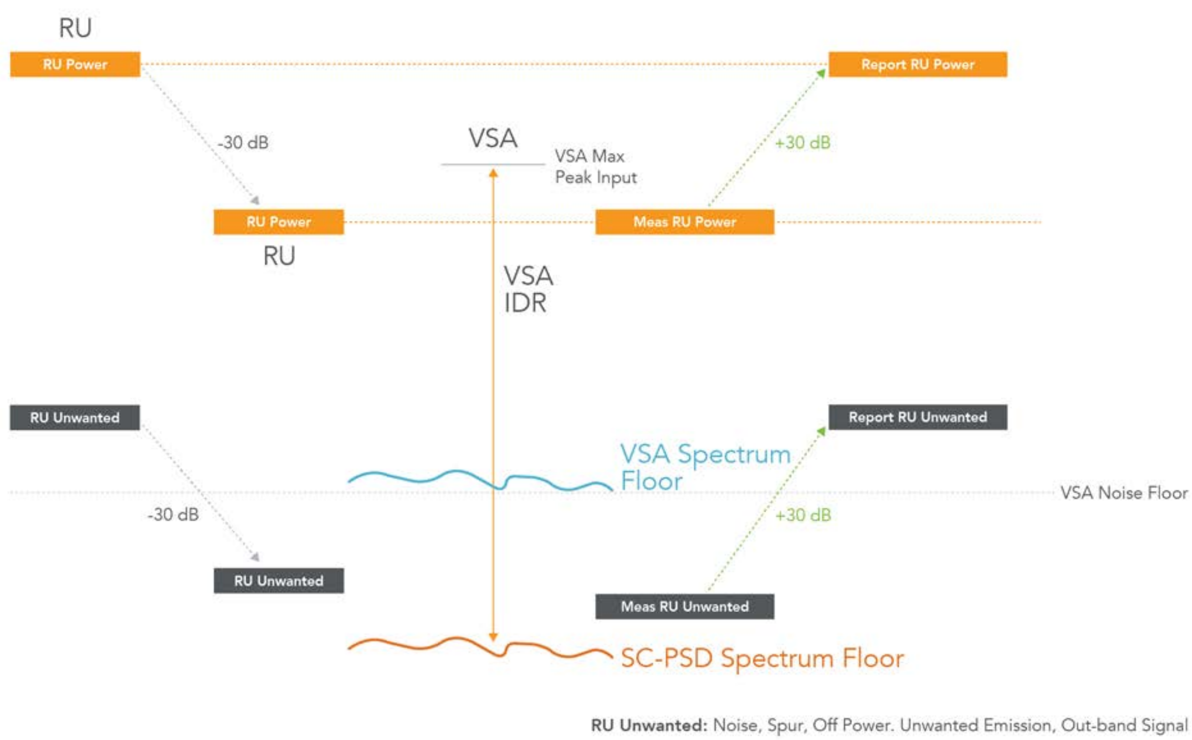


Figure 6 SC-PSD Enhanced Measurement System Effective Dynamic Range

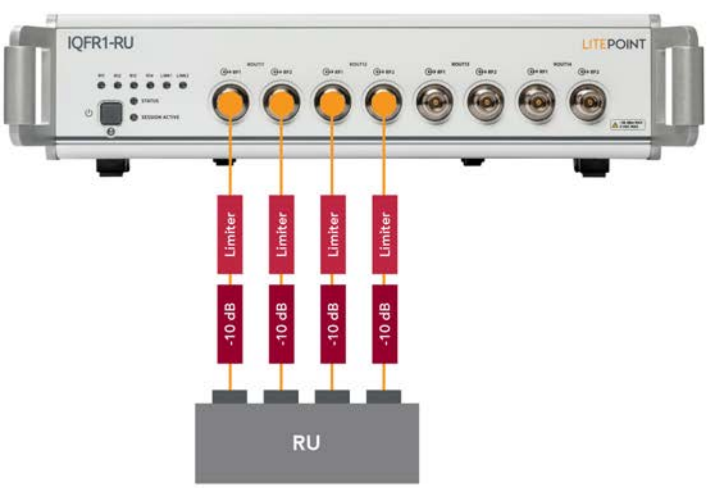
Simplified Setup and Broad Measurement Support with SC-PSD

The revolutionary aspect of SC-PSD is its ability to deliver a superior instantaneous dynamic range avoiding the need for complex, multi-path hardware setups, or an inventory of specialized external components like RF limiter and multiple notch filters. Figure 7 IQFR1-RU Wide Area Base Station Simple Setup with SC-PSD Aided illustrates the dramatically simplified test setup enabled by SC-PSD, often requiring only a single attenuated path from the RU to the IQFR1-RU VSA.

6.2 Output Power	V
6.3.3 TPDR	V
6.4.1 Transmitter OFF Power	
6.4.2 Transmitter transient period	V
6.5.2 Frequency Error	V
6.5.3 EVM	V
6.5.4 Time alignment error	V
6.6.2 Occupied bandwidth	V
6.6.3 ACLR	V
6.6.4 OBUE	V
6.6.5 Transmitter spurious emission	V
6.7 Transmitter intermodulation	V
7.6 Receiver spurious emission	V

Figure 7 IQFR1-RU Wide Area Base Station Simple Setup with SC-PSD Aided

Although SC-PSD gained more than 10dB VSA instantaneous dynamic range the measurement system, even with a 30 dB attenuator and SC-PSD, might still present a 15 dB effective dynamic range reduction (compared to an ideal, unattenuated VSA) that can be challenging for the very stringent -85 dBm/MHz 3GPP spec requirement for OFF power. For this measurement the user can have a separated setup in Figure 8 IQFR1-RU Wide Area Base Station OFF Power Measurement Setup with SC-PSD Aided which minimize the measurement path attenuation to achieve the very tough measurement requirement of OFF POWER.



6.2 Output Power	
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6.6.4 OBUE	
6.6.5 Transmitter spurious emission	
6.7 Transmitter intermodulation	
7.6 Receiver spurious emission	

Figure 8 IQFR1-RU Wide Area Base Station OFF Power Measurement Setup with SC-PSD Aided

With SC-PSD enhancing the VSA's instantaneous dynamic range, the traditional two-path test setup can be simplified to a single-path configuration, with an optional dedicated setup remaining for very low OFF Power measurements as required.

SC-PSD 5GBS ACLR Data

In Figure 9 5GBS SC-PSD ACLR, a 30 dB attenuator is used to evaluate how SC-PSD improves ACLR measurements. The relatively small improvement observed in the adjacent channel ACLR is primarily due to the DUT's inherent performance, which is already around -51 dBc. This indicates that the measurement is limited by the DUT itself, rather than by the VSA's noise floor.

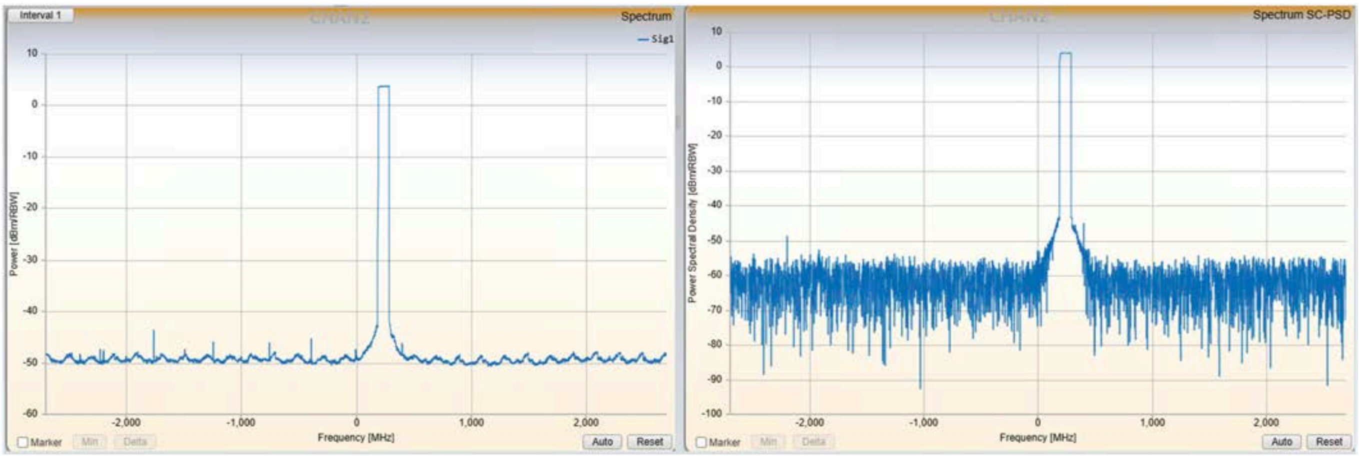
However, the alternate channel ACLR shows a significant improvement, from -52 dBc to -65 dBc, which can be directly attributed to the enhanced instantaneous dynamic range provided by the SC-PSD feature. This contrast highlights how SC-PSD is particularly beneficial in scenarios where the VSA's dynamic range becomes the limiting factor, such as in alternate channel measurements.

Note: The scale of the Spectrum SC-PSD is deeper to highlight enhanced dynamic range.

Figure 9 5GBS SC-PSD ACLR

SC-PSD GPRF Spectrum Data for OBUE and Spurious

In Figure 10 TX Spurious SC-PSD we can see the out-band spectrum is improved by more than 10dB in below two spectrum plot.



Note: The scale of the Spectrum SC-PSD is deeper to highlight enhanced dynamic range.

Figure 10 TX Spurious SC-PSD

Conclusion

Testing Wide Area NR Base Stations presents a significant challenge due to their high output power and the stringent requirements for measuring extremely low-level unwanted emissions. Traditional measurement strategies, while effective, lead to complex test setups involving multiple RF components like limiters, LNAs, switches, and an inventory of specialized notch filters. This complexity results in increased cost, longer setup times, and intricate calibration procedures.

LitePoint's innovative SC-PSD (SNR Compensated Power Spectral Density) fundamentally transforms this testing paradigm. By leveraging advanced digital signal processing, SC-PSD significantly enhances the VSA's instantaneous dynamic range, effectively lowering the measurement system's noise floor for attenuated signals without relying on complex external hardware. Unlike traditional preamplifiers such as LNAs, SC-PSD achieves this dynamic range extension without the risk of overdriving the VSA's input, eliminating the need to carefully manage amplified peak signal levels.

This unique approach simplifies the test setup dramatically, reducing hardware costs, setup time, and calibration complexity while ensuring accurate and reliable measurements for critical 3GPP test items. SC-PSD empowers test engineers to meet the demanding requirements of Wide Area NR Base Station testing with unprecedented efficiency and confidence.

SC-PSD is available on both the LitePoint IQFR1-RU and IQxstream-5G+ platforms, empowering test engineers to meet the demanding requirements of Wide Area NR Base Station testing with greater efficiency and confidence.

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Doc: 1075-0440-001
July 2025 Rev 1