MIMO Measurements in accordance with EN 300 328 and EN 301 893

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Abstract - Wireless communication protocols are becoming increasingly more broadband and complex. Featuring multiple inputs and outputs (MIMO), bandwidths of up to 320 MHz and modulation schemes up to 4096 QAM on. This power meter is designed to address this increasing complexity and variability in wireless LAN systems while maintaining accurate measurements in accordance with the specified standards to 320 MHz and modulation schemes up to 4096 QAM on 4096 carriers simultaneously across 16 streams (WiFi 7). EN 300 328 and EN 301 893 specifies the timing conditions that an RF modulated signal must adhere to. This paper presents a novel and unique RF power meter concept developed by Raditeq: the RadiPower RPR3008W series, power meters which are capable of measuring complex RF signals within a frequency range of 10 MHz to 8 GHz. This with a power range of -50 to +10 dBm, utilizing an RMS responding detector. The paper demonstrates the power meter's capability to accurately measure power, regardless of channel bandwidth and crest factor.

I. INTRODUCTION

The EN 300 328 and EN 301 893 standards describe the radio and spectrum parameters for a broadband signal at 2.4 GHz and 5 GHz. This power meter is capable of conducting measurements in accordance with both EN 300 328 and EN 301 893 standards. Furthermore, this power meter is capable of measurements up to 8 GHz, making it suitable for measurements at 7.125 GHz for WiFi 6 and even WiFi 7.

II. DATARATES AND BANDWIDTHS

The EN 300 328 and EN 301 893 standards refer to broadband transmission systems. Wireless LAN systems utilizing the 802.11 standards must adhere to this standard. The 802.11 protocol is becoming increasingly complex, employing higher bandwidths (up to 320MHz), higher frequencies (up to 7.125GHz), more complex modulation (up to 4096QAM), and a denser spectrum (up to 4096 carriers simultaneously). The table below provides an overview of the various options:

TABLE I. WI-FI TYPES

Wi-Fi Type	Wi-Fi 7	Wi-Fi 6E	Wi-Fi 5
Output specialty	Extreme high throughput	High Efficiency	Very High Throughput
Supported Bands (GHz)	2.4 - 7.125	2.4 - 7.125	2.4 - 5.925
Bandwidth (MHz)	20,40,80,160,320	20,40,80,80+80,160	20,40,80,80+80,160
Transmission type	OFDM & OFDMA	OFDM & OFDMA	OFDM
Sub-carrier Spacing (kHz)	78.125	78.125	312.5
Guard interval	0.8 µs, 1.6 µs, 3.2 µs	0.8 µs, 1.6 µs, 3.2 µs	0.4 µs, 0.8 µs,
Spatial Streams	16x16 MU-MIMO	8x8 MU-MIMO	8x8 MU-MIMO
Modulation	4096QAM 12Bit	1024QAM 10Bit	256QAM 8Bit

This power meter is designed to address this increasing complexity and variability in wireless LAN systems while maintaining accurate measurements in accordance with the specified standards.

III. REQUIREMENTS

New WIFI systems nowadays use transmitting frequencies up to 7.125GHz for WiFi 7. Moreover, the used WIFI bandwidth is increasing up to 320 MHz for WiFi 7.

IV. DESIGN CONSIDERATIONS

Design considerations encompass a range of crucial factors that guided the development process to ensure optimal functionality, efficiency, and performance of the final product. In the context of the previous discussed requirements on power meter testing and the EN 300 328 and EN 301 893 standards, some design considerations include:

A. Frequency Range and Bandwidth

Ensuring the power meter's design accommodates the specified frequency range from 2GHz to 7.125GHz and the varying modulation bandwidths (up to 320MHz) required for accurate measurements across different wireless communication standards.

B. Modulation Support

Designing the power meter to handle complex modulation schemes, such as 12 bit - 4096 QAM, to accurately capture and analyze the signal's characteristics.

C. Sampling Rate and Resolution

Selecting appropriate analog-to-digital converters (ADCs) and signal processing techniques to achieve the required minimum sampling rate of 1 MS/s RMS measurements.

D. Burst Detection and Analysis

Implementing algorithms and circuitry to detect bursts within the signal, identify their start and stop times, and calculate average RMS values for each burst, considering the 20 dBc flank threshold.

E. Synchronization

Developing synchronization mechanisms to ensure precise alignment and coordination of multiple power meters when measuring signals from different stream channels, while adhering to the specified synchronization tolerance.

F. Total Transmit Power Calculation

Incorporating circuitry or algorithms to compute the total transmit power accurately by summing up individual port powers for each burst and accounting for any potential phase or timing differences.

G. User Interface and Data Presentation

Designing an intuitive user interface that displays measurement results, burst characteristics, and any relevant metrics, allowing users to interpret and analyze the data effectively.

H. Calibration and Accuracy

Incorporating calibration routines or mechanisms to maintain measurement accuracy over time, accounting for factors like drift, temperature changes, and component aging.

I. Signal Integrity and Impedance Matching

Ensuring proper signal integrity by employing appropriate impedance matching techniques and minimizing signal reflections, which can impact measurement accuracy.

J. Compact and Robust Hardware Design

Designing the power meter's hardware with compactness, robustness, and thermal considerations in mind to facilitate practical usage and longevity.

K. Software Integration

Developing software interfaces or APIs that enable seamless integration of the power meter with testing setups, data analysis tools, and reporting systems.

L. Compliance with Standards

Verifying that the power meter design adheres to relevant industry standards, such as EN 300 328 and EN 301 893, ensuring accurate and consistent measurements.

These design considerations, among others, guide the development of a power meter that meets the demanding requirements of measuring complex RF signals within the specified frequency range and modulation schemes, as outlined in the EN 300 328 and EN 301 893 standard.

V. POWER METER DESIGN

The Power meter, RPR3008W, uses the following process to achieve its Power measurement. The RF signal power is linearly converted to an RMS DC voltage using a detector. The RMS responding detector ensures a correct DC representation is given for the RF input whether complex modulation is applied or not.

The output of this detector is sampled using a high-speed AD converter. The samples are then processed by a Digital Signal Processor (DSP) to calculate the average power of individual bursts according to the EN 300 328 and EN 301 893 standard. The DSP is equipped with a large memory block capable of storing burst information for up to 100,000 individual bursts.

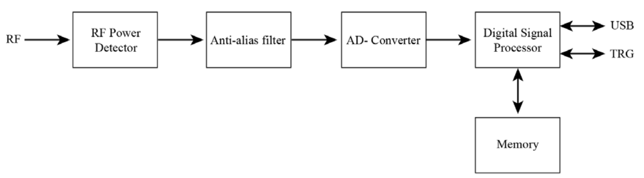

Fig.1 Simple schematic of Power Meter

The power meter can be connected to a PC via mini USB and can transfer the stored samples to the PC at a high data rate. To synchronize multiple power meters, it is possible to connect multiple power meters using a daisy chain arrangement. This arrangement uses dedicated trigger ports which allow to synchronized measurements with up to 16 power meters simultaneously.

For the RF input, a precision N-type connector has been utilized. Furthermore, significant attention has been paid to ensuring a robust connection between the connector and the detector, guaranteeing excellent matching across the entire frequency range and thereby minimizing uncertainties.

All of these components are housed within a completely custom-made metal enclosure. This design choice results in a remarkable robustness of the power meter. Additionally, the metal housing acts as a Faraday cage, effectively isolating the power meter's electronics from external RF interference while serving as a heat sink.

VI. DETECTOR

The EN 300 328 standard specifies that each sample must be RMS, and to achieve this, there are several options:

1) Thermal Power Meter: In this approach, the RF power is directed through a resistor, and the resulting temperature rise of the resistor is measured to determine the power. The heat generated is directly proportional to the total applied power (whether complex modulated or not). However, thermal power meters suffer from a limited dynamic range and are intrinsically slow.

2) Peak Detector with ADC Sampling: This method involves high speed sampling of the peak detector using an ADC and then using a digital signal processing (DSP) techniques to calculate the RMS power. While the peak detector has a larger dynamic range, it is not inherently RMS. Due to the need for post-processing, oversampling is required. With a 320MHz bandwidth, the sample rate should be at least 640Msamples (Nyquist is required), but a significantly higher oversampling rate is required for accurate RMS response.

3) RMS Detector: This detector provides an RMS voltage response at the output of the detector. The RMS detector converts the RF input signal into an DC voltage which is proportional to the RMS value of the input signal.

As a result, the choice was made to utilize an RMS detector. The RMS detector is then sampled by a high accuracy high speed AD-converter, capable of measuring at 1 or 5 MS/s. These measurement rates have been incorporated into the standard. Furthermore, the power meter itself even offers a 33Msample speed mode.

The final detector design results in a frequency range of 10 MHz to 8 GHz and a dynamic range of –50 dBm to +10 dBm. These specifications increase the versatility of the power meter for various applications. With this frequency range, along with its exceptionally high measurement speed and RMS responding detector, this power meter stands out in multiple aspects.

VII. POWER CALCULATION OF A BURST WITH ONE TRANSMIT CHAIN

The EN 300 328 standard describes how to calculate the RMS power of a burst, both for single-port and multiple-port (MIMO devices) scenarios. Since the detector provides a voltage representing the RMS power at the input, the RMS power of the burst can be calculated as follows: Where a valid sample (Pn) is considered to be a value that falls within 20dBc (from the highest RMS value).

$$P_{Burst,total} = \frac{\sum (P_n)}{n}$$

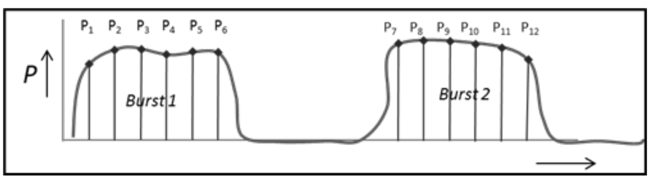

Fig. 2 Example of 2 bursts and samples made

To compress the data, not every sample is sent out. The DSP stores the average value of the burst along with the start and stop times of the first and last samples (the 20dBc points). This compression provides enough data for conducting measurements according to the EN 300 328 standard while enabling faster data transmission. Additionally, the power meter has the capacity to store 100,000 bursts.

VIII. POWER CALCULATION OF A BURST WITH MULTIPLE TRANSMIT CHAINS

For measurements on devices with multiple ports, the EN 300 328 standard mandates that, at any given moment in time, the sum of the powers must be computed and stored. The following example illustrates a scenario where 3 ports each have distinct burst information:

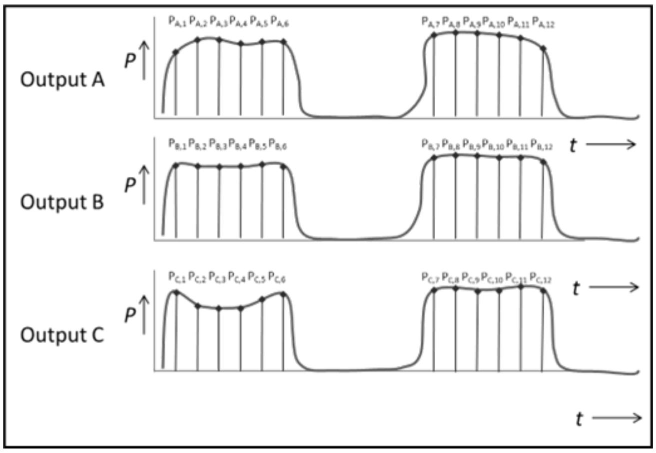

Fig. 3 Example of burst with multiple chains

The total power of the 3 power meters can then be calculated using the following equation:

$$P_{Burst,total} = \frac{\sum (P_{A,n} + P_{B,n} + P_{C,n})}{n} \ [W]$$

The standard requires that the RMS power of the burst across multiple ports be computed in the same manner as for a single port. However, the power meter only stores the average power and the start and stop times of individual ports its burst. When the formula is rearranged, we observe the following:

$$P_{Burst,total} = \frac{\sum P_{A,n}}{n} + \frac{\sum P_{B,n}}{n} + \frac{\sum P_{C,n}}{n} \ [W]$$

Hence:

$$\frac{\sum (P_{A,n} + P_{B,n} + P_{C,n})}{n} = \frac{\sum P_{A,n}}{n} + \frac{\sum P_{B,n}}{n} + \frac{\sum P_{C,n}}{n}$$

This demonstrates that averaging each power meter's burst, divided by the number of power meters, is equivalent to individually summing the samples per power meter and then dividing by the number of samples. This process is carried out for each power meter and subsequently divided by the number of power meters.

IX. SYNCHRONISATION AND USER INTERFACE

The calculation of the total power is not performed by the power meters themselves. The power meter itself stores the average RMS value along with the start and stop times. By daisy-chaining and triggering the power meters, synchronization is achieved.

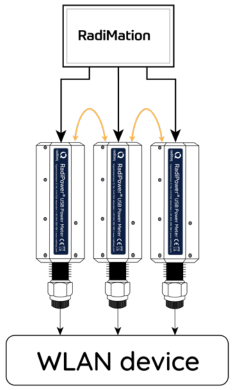

Fig. 4 Synchronisation of power meters

The triggering, synchronization within half the sample rate, and retrieval of stored data from each power meter can be managed using RadiMation software (free). With this software, additional calculations can be carried out, and compensation can be applied for factors such as antenna gain and beam-forming gain. Furthermore, RadiMation determines the parameters required according to the EN 300 328 and EN 301 893 standard, such as EIRP (Effective Isotropic Radiated Power), RF output power, Duty Cycle, Tx-sequence, Tx-gap, and Medium Utilization over the observation time.

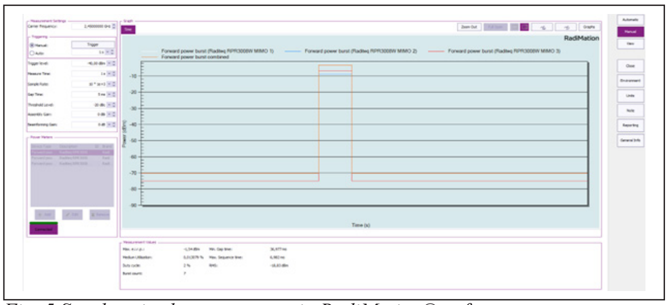

Fig. 5 Synchronized measurement in RadiMation® software

X. 802.11 MEASUREMENT DESCRIPTION

Measurements on 802.11 signals where carried out, to demonstrate the RadiPower RPR3008W's capability to measure the bandwidth and complexity of 802.11 WiFi signals with an RMS response.

Tests were conducted comparing the RadiPower RPR3008W to a thermal power meter. A generator capable of generating complex WiFi signals was used as the generate the complex modulated signals.

The following equipment was utilized for this purpose:

- R&S SMBV100B
- Marconi 6960 with thermal power head
- RadiPower RPR3008W

At a frequency of 2.4GHz, signals with bandwidths of 20, 40, 80, 160, and 320MHz were generated. Initially, the power meter deviation between the two meters was determined without modulation, serving as the baseline. Subsequently, modulation was activated, and the power meter delta was examined. The deltas of both power meters should be in close proximity.

As previously discussed, the dynamic range of a thermal power meter is limited. For accurate measurements, it is essential that the Peak Envelope Power (PEP) does not exceed the maximum measurable power of the meter.

Additionally, the total signal bandwidth should significantly surpass the power meter's noise floor to ensure that the meter measures the actual signal rather than its own noise. To achieve accurate measurements, it is crucial that the signal peak consistently falls within the power meter's measurement range. Furthermore, the signal often becomes very weak; in such cases, it is necessary for the signal to remain detectable and thus remain above the noise floor.

The tests were performed at -20 dBm this test level was used to ensure the precision of results when measuring Peak Envelope Power (PEP), while mitigating the impact of the noise floor.

TABLE III. COMPARISON @ 20 MHZ

2,4 GHZ 20 MHZ 802,11 SIGNAL			
	CW (dBm)	Modulated (dBm)	delta (dB)
Marconi	-20,4	-20,5	-0,1
RadiPower	-20,4	-20,2	0,2
		Imbalance (dB)	**0,3**

TABLE IV. COMPARISON @ 40 MHZ

2,4 GHZ 40 MHZ 802,11 SIGNAL			
	CW (dBm)	Modulated (dBm)	delta (dB)
Marconi	-20,5	-21,1	-0,6
RadiPower	-20,4	-20,8	-0,4
		Imbalance (dB)	**0,2**

TABLE V. COMPARISON @ 80 MHZ

2,4GHZ 80MHZ 802,11 SIGNAL			
	CW (dBm)	Modulated (dBm)	delta (dB)
Marconi	-20,5	-21,8	-1,3
RadiPower	-20,4	-21,7	-1,3
		Imbalance (dB)	**0,0**

TABLE VI. COMPARISON @ 160 MHZ

2,4GHZ 160MHZ 802,11 SIGNAL			
	CW (dBm)	Modulated (dBm)	delta (dB)
Marconi	-20,6	-22,7	-2,1
RadiPower	-20,4	-22,5	-2,1
		Imbalance (dB)	0,0

TABLE VII. COMPARISON @ 320 MHZ

2,4GHZ 320MHZ 802,11 SIGNAL			
	CW (dBm)	Modulated (dBm)	delta (dB)
Marconi	-20,6	-23,8	-3,2
RadiPower	-20,4	-23,8	-3,4
		Imbalance (dB)	-0,2

Tables III - VII summarize the comparison between the Marconi thermal power meter and the RadiPower RPR3008W for various signal configurations at 2.4 GHz. The values presented include Continuous Wave (CW) power, Modulated power, Delta (difference) in power, and Imbalance between the power meters.

These tests demonstrate the RPR3008W is capable of accurately measuring the power of modulated WiFi signals with varying bandwidth, showcasing its capability to handle the complexity of 802.11 signals with an RMS response.

XI. CONSIDERATIONS

Because communication signals often have short-duration ON periods, it's crucial for the power meter to accurately measure the RMS power over a signal that is intermittently turned ON and OFF.

The signal generator is configured for pulse modulation, with a pulse width of 250 µs for both the ON and OFF states, as well as a separate configuration with a pulse width of 25 µs for both ON and OFF states, resulting in a 50% duty cycle.

TABLE VIII. COMPARISON PULSE MODULATED SW SIGNAL

Power meter	Measurement results	
	250 µs pulse 50% DC	25 µs pulse 50% DC
Marconi 6960	-3.17 dBm	-3.16 dBm
RPR3006W	-3.09 dBm	-3.03 dBm
Imbalance (dB)	0,08	0,13

XII. AWGN

In addition to the WiFi signals and pulse modulated signals, the RMS behavior was also observed with the presence of Additive White Gaussian Noise (AWGN), using bandwidths of 10, 20, and

TABLE IX. AWGN @ 10 MHZ

Power meter	**2,4GHz 10MHz AWGN**		
	CW (dBm)	Modulated (dBm)	delta (dB)
Marconi	-20,5	-18,85	1,7
RadiPower	-20,4	-18,1	2,3
		Imbalance (dB)	**0,6**

TABLE X. AWGN @ 20 MHZ

Power meter	**2,4GHz 20MHz AWGN**		
	CW (dBm)	Modulated (dBm)	delta (dB)
Marconi	-20,5	-18,9	1,6
RadiPower	-20,4	-18,3	2,1
		Imbalance (dB)	0,5

TABLE XI. AWGN @ 100 MHZ

Power meter	**2,4GHz 100MHz AWGN**		
	CW (dBm)	Modulated (dBm)	delta (dB)
Marconi	-20,5	-18,7	1,8
RadiPower	-20,4	-18,6	1,8
		Imbalance (dB)	**0,0**

XIII. CONCLUSION

In conclusion, the RPR3008W power meter has demonstrated exceptional capabilities in measuring complex modulated signals. The accuracy is proven by design, through rigorous testing and comparison with a thermal power meter. The power meter has proven its accuracy and reliability across a wide range of signal bandwidths and complex modulated signals.

By effectively addressing challenges posed by signal modulation and intermittent ON/OFF periods, these power meters deliver precise measurements for a variety of applications, including those that require compliance with the EN 300 328 and EN 301 893 standards. When used in combination with the RadiMation software (freeware), the power meters offer comprehensive parameter analysis, making them a versatile and valuable tool in the field of RF power measurement.

The incorporation of features such as a wide frequency range (10 MHz to 8 GHz), high measurement speed, RMS responding detector, and precision N-type connector highlights the advanced engineering and design of these power meters. The custom metal enclosure not only ensures durability but also provides effective shielding and heat dissipation.

In essence, the RPR3008W power meters excel in their ability to accurately measure complex signals, exhibit robustness, and offer practical solutions to meet the demands of modern communication technology.

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