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Phased Array Characterization with The Wireless Connector®

Introduction

Phased arrays are becoming highly integrated, and necessitate the characterization and testing of the combination of the active circuitry together with the antenna system. Characterization in an anechoic chamber is cumbersome and typically requires special skills and setup time beyond the skills for RF conductive test engineers. The Wireless Connector® overcomes these challenges and makes the characterization of the key performance factors of phased arrays accessible for RF test engineers, who are used to deal with conductive testing.

In this short note a commercial available evaluation kit, EVK06005[1], is used to demonstrate some of the key characterization and diagnostic capabilities of The Wireless Connector® for phased array testing. These illustrations are only a subset of the capabilities of The Wireless Connector®. For example, the short note limits itself to the continuous radiation at a single frequency of the demo device.

The demo component by Itself has been used at many occasions already in many circumstances. The shown results are not representative for the performances of a newly purchased evaluation kit. The only purpose is to illustrate The Wireless Connector® capabilities.

Key performance factors of a phased array

In general, a phased array consists of a series of paths containing active components, each path connected to an antenna element. Each path can be changed in scalar gain (amplitude) and phase or delay by controlling it in one way or another. A path can be deactivated, e.g. active components can be explicitly switched off. This does not necessarily mean that the corresponding antenna element does not radiate, but the deactivated path will not contribute power to the radiation. The antenna element can still radiate, as power can leak from an activated path into a deactivated path.

A state of a phased array refers to a specific combination of activated and deactivated paths, along withscalar gain and phase or delay settings.

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[1]https://www.sivers-semiconductors.com/5g-millimeter-wave-mmwave-and-satcom/wireless-products/evaluation-kits/evaluation-kit-evk06005-2/

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For a phased array, it is important to know whether each path is contributing correctly to the power budget of the overall array for different states and whether the total array is generating the required power in each state. This capability allows to test the power functionality of every path independently. If this can be done quickly, fast diagnostic conclusions can be made.

Not only the power budget is important, but also the correctness of the radiating frequency, the spurious (spurious emissions), LO power leakage and in-band (e.g. noise power ratio) and out-of-band (e.g. ACLR, ACPR, harmonics) distortions. All these power characteristics can be measured with The Wireless Connector®, including noise figure characterization. This can be performed for each state of the phased array antenna.

The setup

In this short note, the performance of the demo device under test (dDUT), radiating at 62.64 GHz in the chamber, is illustrated using a spectrum analyzer (Keysight PXA Signal Analyzer N9030A – other spectrum analyzers are also supported) with a frequency extender (Fig. 1). The evaluation kit is provided with a graphical user interface, control software and a beamformer codebook for some frequencies, including 62.64 GHz. Therefore, the performance for different beamformer positions can be illustrated.

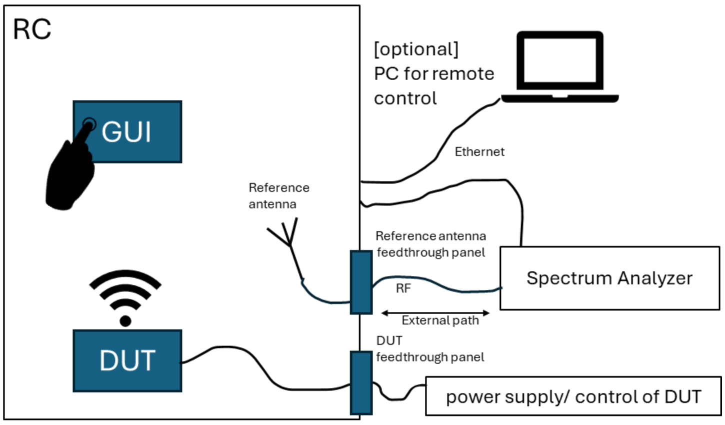

Fig. 1. Setup with dDUT = EVK06005.

The position of the dDUT in The Wireless Connector® is not important, in contrast to the elaborate alignment procedures required in the anechoic chamber (Fig. 2).

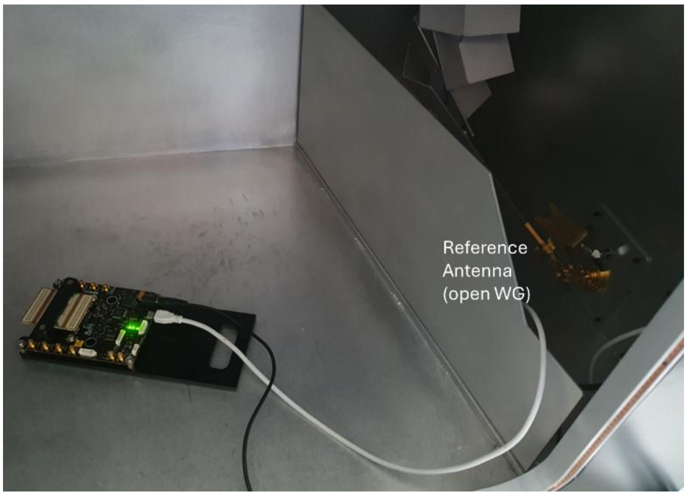

Fig. 2. dDUT inside The Wireless Connector®.

The Wireless Connector® has been calibrated around the frequency of interest (62.64 GHz) following the documented procedure ([1] and [3]).

Power Spectrum as function of beam steering angle

Using the control software provided with the dDUT, the transmit (Tx) mode of the array is activated at 62.64 GHz, while the dDUT is positioned in the chamber without moving the stirrers.

The spectrum analyzer settings are optimized to visualize the power spectrum on the spectrum analyzer (Fig. 3). The resolution bandwidth (RBW) is reduced to make the spectral skirts around the radiating frequency visible, while the peak power at radiating frequency is maintained constant for changing RBW.

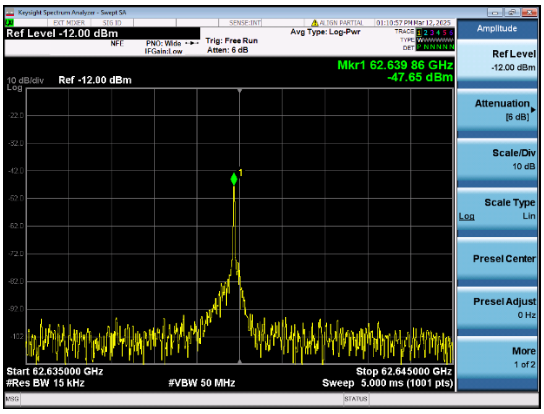

Fig. 3. Optimized settings for measuring power spectrum and skirts at radiating frequency.

These settings (Fig. 3)will be used by The Wireless Connector® (see Advanced SA Settings in the User Manual) : RBW : 15 kHz, VBW : 50 MHz (maximum avoiding smoothing as function of frequency), Ref Level : -12 dBm (to capture noise floor).

The power spectrum, measured by The Wireless Connector®, is corrected for the external connection from the chamber to the spectrum analyzer, for the efficiency of the reference antenna, and the path losses in the chamber, including the impact of placing the dDUT inside the chamber.

Using the provided beamforming codebook, the beam will be steered from approximately -39.0 degrees to 39.0 degrees in steps of approximately 5.7 degrees (64 positions available across 90 degrees – the smallest step is 1.4 degree). The power spectrum is measured for each beam position. The extreme positions are replaced with the position at 0 degree angle to verify changes as function of chip temperature. For the measurement at each beam position, the horizontal and vertical stirrers in the chamber are stepped enough times in rotation angle while measuring per stirrer position the spectrum and then processing all measurements into one power number per frequency point ([1]). This results into the total radiated power at given frequency for the given beam position. For a well-functioning antenna, the total radiated power should be similar for all angles (Fig. 4). The spectral skirts demonstrate consistent behavior across different beamformer positions.

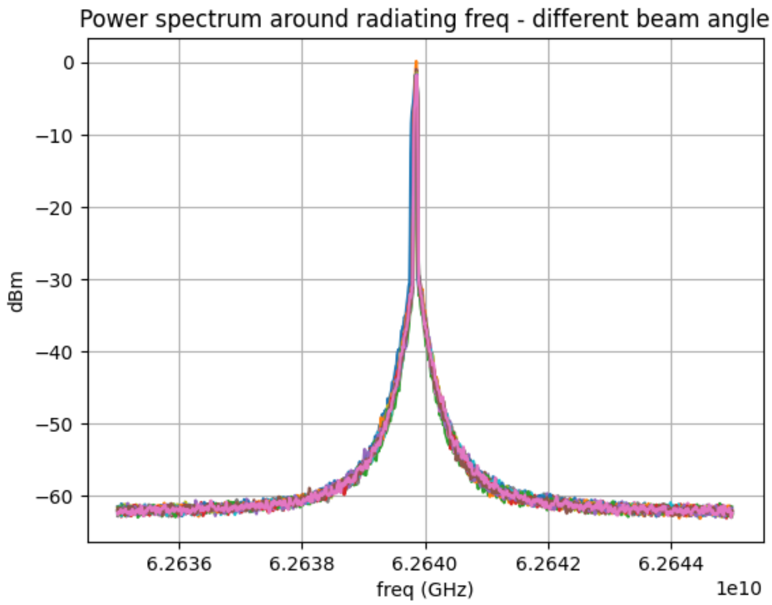

Fig. 4. Power spectra for every 5.7 degree of steering angle.

Zooming into the power at the radiating frequency one can observe a large fluctuation in power around -2.0 dBm (Fig. 5). The power spectrum was first measured for beam position with 0 degree angle. The beam position with 0 degree angle was re-measured stepping the beam position from approximately -40 degree to 40 degree and was measured again at end of sweep to check the impact of temperature drift.

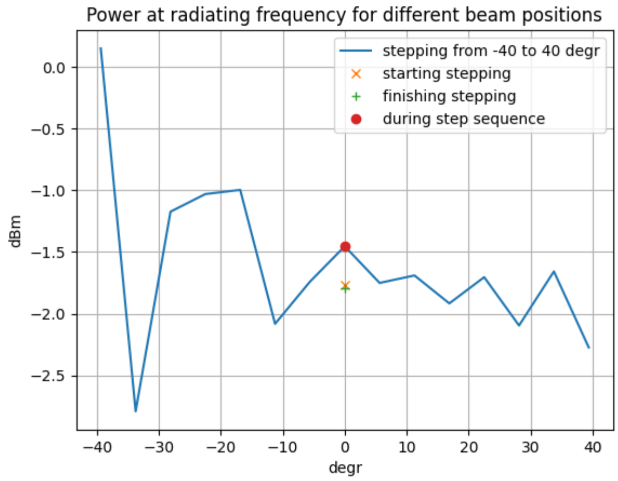

Fig. 5. Power at radiating frequency as function of beam position.

This variation can be caused by the change in beam steering angle but also by temperature variation of the dDUT as the Tx mode is switched on in the beginning of stepping the beam. Using the control software of the dDUT the chip temperature is monitored at end of the measurement per beam position (Fig. 6). It is observed that the dDUT is still warming up.

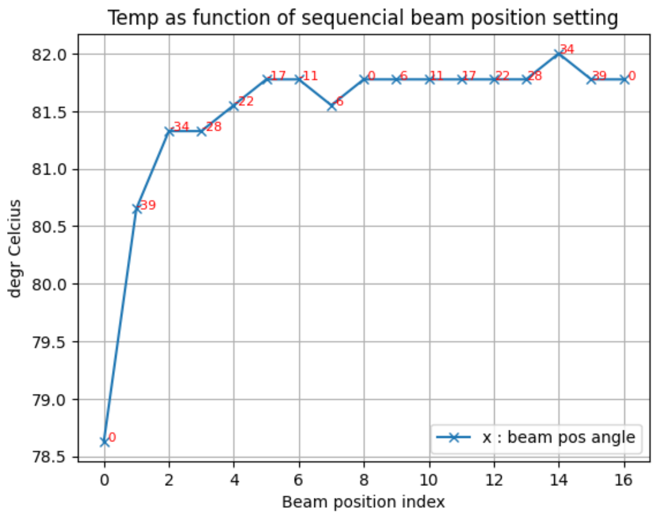

Fig. 6. Temperature per steering angle.

The measurement time per beam position is approximately 1 minute to accurately provide a total radiated power spectrum.

It would be great to reduce the measurement time further to get even faster insight in the essential functionality of the phased array. In many cases one is first interested in the power functionality at one radiating frequency. Therefore the spectrum analyzer can be used in a more efficient measurement mode in combination with The Wireless Connector® which also will use a more efficient way of rotating the stirrers.

Fast characterization at radiating frequency as function of beam steering angle

The spectrum analyzer is now used in zero span mode with the center frequency at the radiating frequency. The settings are adapted according the documented procedure ([2]). Per beam steering angle the spectrum analyzer is configured to capture approximately 3.5 seconds resulting in enough power points while the stirrers rotate continuously. These power points are processed into one power number.

The power will be measured as function of beam steering angle for all settings of the beam forming codebook (64 positions from -45 degree to 45 degree) (Fig. 7). On Fig. 7 one observes 3 markers. All three are measured at 0 degree beam steering angle. One (x) is measured at the beginning of the sweep, one (•) during the sweep and finally one (+) is re-measured at the of the sweep to check variability across temperature fluctuations. One observes very good correspondence indicating that impact of temperature variations across the sweep are minimal. The chip temperature remains reasonably stable between 79 and 81 ºC (Fig. 8).

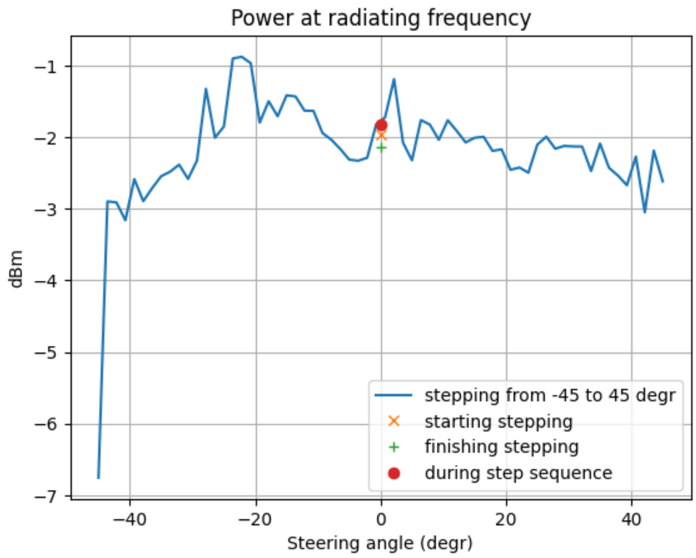

Fig. 7. Power at radiating frequency as function of steering angle.

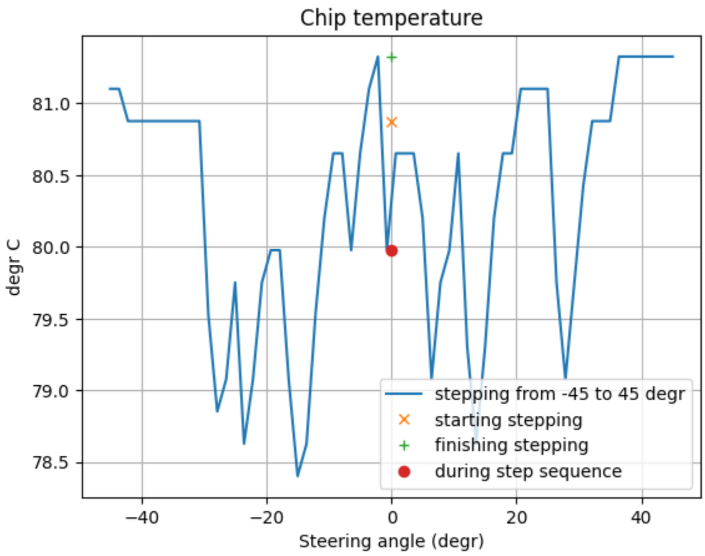

Fig. 8. Temperature fluctuation during beam steering.

Due to the dip at -45 degree beam steering angle, which is an anomaly, the measurement is repeated between -45 and -20 degrees while repeating at the beginning and end of the sweep the 0 degree beam steering position (Fig. 9).

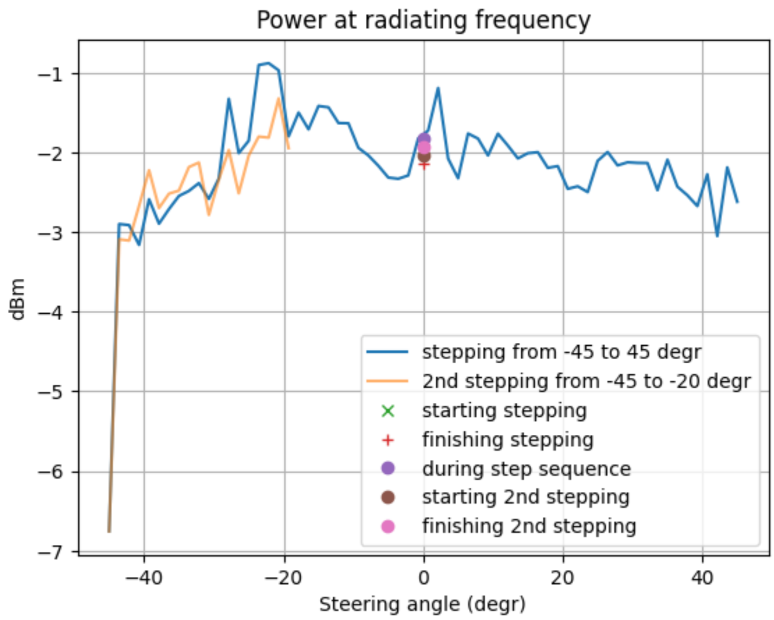

Fig. 9. Repeated measurement from -45 to -20 degree combined with first measurement.

It can be observed that at -45 degrees the anomaly remains and would require some attention.

The measurement time per beamforming setting is reduced to approximately 10 seconds for a beamforming setting.

Additionally, one could characterize at the radiating frequency path per path by switching off all paths and turning on only one path. This allows fast detection of any malfunctioning path before testing the spectrum with The Wireless Connector®.

Only when the power performance is characterized and no anomalies are identified, it makes sense to switch to a more time consuming and complex setup like an anechoic chamber to characterize for example the radiation pattern.

Deep insight in phased array behavior in a short time

The above reported measurements using the evaluation kit demonstrate the core measurement capability of The Wireless Connector® acquiring insight in the dDUT behavior across the frequency and specifically on one selected frequency. As example these characteristics were extracted for different beam steering angles (or beam positions) using the provided beamformer codebook.

By applying the same methodology for different well selected states of the phased array more deep insight can be gained in a very short time, similar to what one would measure in the conductive world.

First one focuses on the radiating frequency and performs the following diagnostics:

- Investigate power functionality of each path by turning off all elements and turning on only one path scanning all paths. All paths will be set to the same state. Large power variations between paths and failing paths are identified very quickly. This provides mainly information on the power amplifiers and roughly that the scalar gain and phase or delay control is functional.
- Investigate the power efficiency and scalar gain by incrementing the power in only one path while other paths are off. Compression characteristics can be extracted for each path and efficiency as function of power settings.
- Turning on element per element for the same setting should incrementally augment the power. This measurement could indicate potential crosstalk problems or unexpected interference problems.

Once the power characteristics at the radiating frequency are satisfactory, one should focus on the power spectral content related to LO leakage, spurious, harmonics, in-band (e.g. NPR) and out-band distortions (e.g. ACLR). Depending on the hardware architecture, these measurements can be done on a sub-set of states per path.

Thanks to the fast and accurate measurement capability and easy setup, RF test engineers, skilled in RF conductive testing, will be able to build up very quickly deep insight in the power behavior of a phased array.

Where is the Antennex system used?

- R&D: Multifunctional, easy to customize with API, many metrics covered for in-house testing. Easy to integrate with existing setups.
- Characterization and validation: Validate device-to-device variations. Map characterization tests to production results.

- Pre-compliance: Speed up development by performing in-house pre-compliance tests needed for regulatory approval.
- Production Line Test: Quick pass-fail analysis with higher accuracy, enabling higher yield.
- Post-tech support: Failure analysis and RMA.

Overall benefits

A new solution for wireless RF testing to offload anechoic chambers and to bring more tests in-house. Solution exclusive to Antennex with proprietary knowledge and algorithms.

- Performs most anechoic chamber tests in a fraction of the time with greater accuracy (seconds vs hours), multifunctional system.
- Tabletop (>90% space reduction).
- No expert operator needed, better engineering resource allocation.
- Reliable and faster due to fewer moving parts.

Other system specs

- Chamber can be used between 5-170 GHz.
- Built-in calibration modules are available between 18-140 GHz. Other frequencies can be calibrated using most Keysight or R&S VNAs.
- Custom feedthrough panels for RF, data, power.
- API which is compatible with Keysight and R&S VNAs and SAs, all algorithms and example scripts included.
- Full tech support included in first year when purchasing a system.

References

[1] "Performing spectrum measurements using The Wireless Connector®", Application Note, Antennex, 2025

[2] "Accurate and Fast Power Characterization at a Fixed Frequency", Application Note, Antennex, 2025

[3] "User Manual The Wireless Connector ®", Antennex, 2024

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For more information, please feel free to contact Marc Vanden Bossche (marc.vandenbossche@antennex.eu)

Marc has acquired extensive expertise and practical experience from design to production in realistic vector characterization of the nonlinear behavior of high-frequency components and systems, with conductive and over the air interfaces. He is RF characterization expert at Antennex, specializing in combining RF instruments with The Wireless Connector®, enabling customers in the Aerospace/Defense, Wireless and Automotive industries with setting up their in-house characterization and production tests. Before bringing his expertise to Antennex, he was at National Instruments a fellow and technical lead of forth looking projects using the PXI platform related to realistic wideband and over the air characterization, and R&D manager at Agilent Technologies, leading the large-signal network analyzer development.

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