Measurement of Beamforming Antenna in Transmit Mode
Application Note

Products:

- R&S®ZVA
- R&S®NRP
- R&S®FSV
- R&S®Quickstep

Rapid and accurate verification of beamforming weights is required for example, for codebook generation or beamforming algorithm development or verification. This document describes the unique application of Rohde & Schwarz VNA (Vector Network Analyzers) to fully characterize the passive part of multi-element antennas intended for beamforming.

A range of R&S VNA models are optionally equipped with multiple independent sources, whose relative amplitude and phase may be arbitrarily controlled ("defined coherence mode"), in addition to frequency and true time delay. These sources may be connected to individual elements of a multi-element antenna to derive and verify transmit (Tx) mode beamsteering and beamforming operation.

The R&S®ZVA in "Defined Coherence Mode" can electronically be switched to / from the conventional S-parameter mode. Therefore, S-parameter and beamforming measurements may be performed efficiently within a single connection cycle of the antenna.
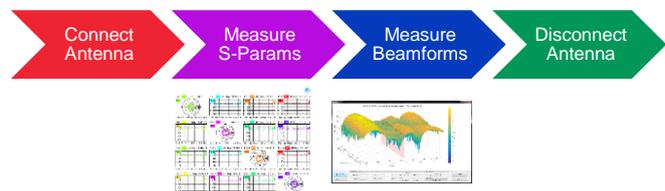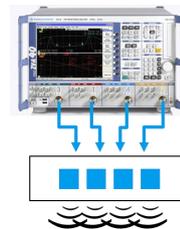
Multiple VNA may be daisy-chained, to extend the concept shown to support an arbitrary number of ports.

Note:

Please find the most up-to-date document on our homepage
http://www.rohde-schwarz.com/appnote/1MA278

This document is complemented by software. The software may be updated even if the version of the document remains unchanged

ROHDE & SCHWARZ

Table of Contents

This application note uses the following abbreviations for Rohde & Schwarz products:

ı   The R&S®FSV Signal and Spectrum Analyzer is referred to as FSV.

ı   The R&S®ZVA Vector Network Analyzer is referred to as ZVA.

ı   The R&S®NRP Power Sensor Module is referred to as NRP.

ı   The R&S®QuickStep software tool is referred to as Quickstep.

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1 Introduction

1.1 Background

S-parameter measurement is defined with only one stimulated port, while waves reflected from that stimulated port, and transmitted to other ports, are measured. Therefore, many network analyzers use only a single source.

At the high end of the market, the ZVA network analyzer product line is optionally specified with multiple internal sources, which are activated in "defined coherence mode" [1].

In that mode, the multiple internal sources are simultaneously active, and may be programmed to have arbitrary frequency, phase and amplitude offsets. These precision controlled, multiple sources may be connected to individual ports or elements of a multi-element antenna.

This uniquely enables beam steering with very fine resolution and beamforming measurements to be made in antenna transmit (Tx) mode, while enabling S-parameter measurement in the same connection cycle.
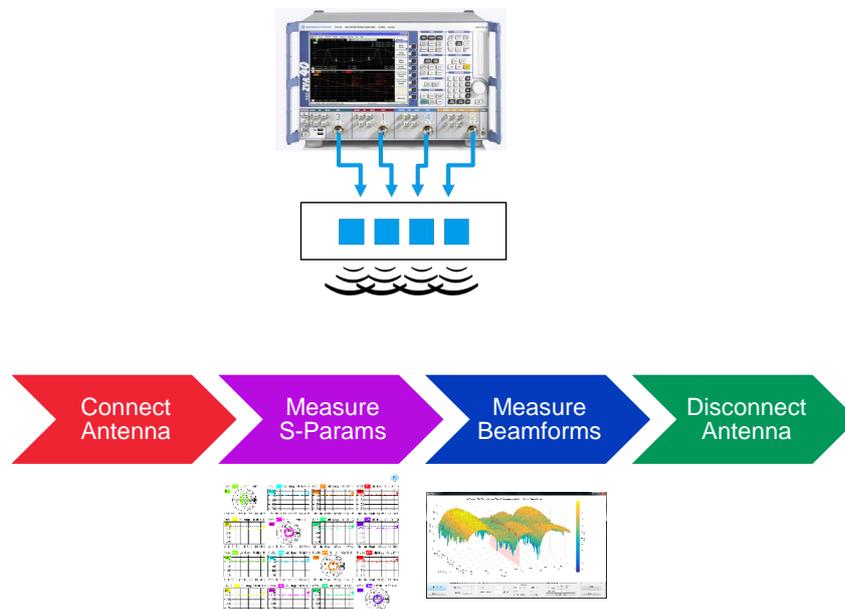

Fig. 1-1: Test flow of the multiple radiator (e.g. beamforming) antenna

Furthermore, multiple network analyzers may be daisy-chained to extend the number of ports available for beamforming characterization.

1.2 Reader's Guide

Chapter 2 describes an exemplary test set-up to measure multi-element antenna in transmit mode. This Application Note is accompanied by software enabling rapid measurement of antenna using the R&S® QuickStep software.

Chapter 3 presents measurements made on a novel X-band hybrid intentional-parasitic antenna array, with four elements. With just a single connection cycle, the antenna is evaluated for both S-parameters and Tx-mode beam**steering** verification.

Chapter 4 presents measurements made on a simple Ka-band 4x10 antenna array. In this case, single-connection-cycle S-parameter and Tx-mode beam**forming** measurements are made with four active elements. Further, daisy-chaining of multiple ZVA is used to demonstrate the Tx-mode beamsteering concept to a greater number (7) of ports.

Chapter 5 illustrates post-processing of the measurement results using the provided MATLAB executable.

In addition to the Application Note itself, the following items are made available for download from the link given on the front page of this document:

ı   A Quickstep test executive project, enabling rapid measurement and control of the ZVA, FSV and turntable (described in Chapter 2.3)

ı   A MATLAB executable, for easy post-processing of the measurement result output from the Quickstep project (as described in Chapter 5).

ı   An example measurement file (in MATLAB .mat format), with measurements taken in a laboratory environment on the antenna described in Chapter 4.4.

2 Getting Started

2.1 Description

A general test setup for the application is shown in Fig. 2-1. This set-up uses a single, stationary, receiver with the transmitting antenna located on a turntable. This configuration would often be preferred during design and development of the antenna.

A variety of alternative configurations are possible, depending on the testing purpose. For example, using a mechanically static test environment with multiple receivers, using power meters, etc.
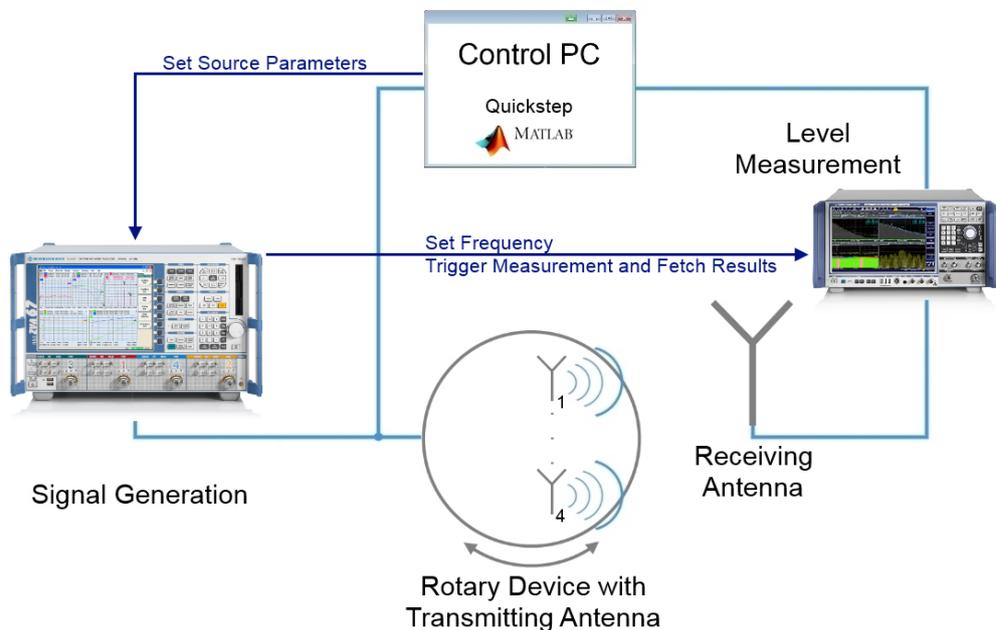
Fig. 2-1: An exemplary beamforming antenna test up, based on a single receiver and turntable.

S-parameter measurement of the antenna, using the conventional multi-port VNA will not be discussed here. Suffice to say that the critical "defined coherence mode" and "single source S-parameter" mode may be rapidly and electronically interchanged.

Characterizing the antenna for beamforming operation requires the independent sweeping of several variables, including:

∎ Differential amplitude (between at least two sources)

∎ Differential phase (between at least two sources)

∎ Frequency

∎ Azimuth

To that end, the test configuration to demonstrate this application comprises:

▪ ZVA

- provides multiple, defined coherence signals
- 1 x ZVA provides 4 port capability up to 24, 40 or 67 GHz
- may be daisy-chained to provide increased number of ports

▪ AUT Turntable (optional)

- when mechanical azimuthal sweep of the antenna under test (AUT) is required

▪ Receiving Antenna(s)

- a single, 10dB rectangular standard gain horn is used in this illustration (in case of power meter use, a higher directive gain antenna may be preferable).
- may be complemented by, or even replaced with, multiple receivers; in conjunction with a turntable, test times may be reduced even further.

▪ FSV or NRP

- A spectrum analyzer or power meter may be used, depending on the need for (for example) frequency discrimination, dynamic range, etc.

▪ Quickstep (software)

▪ MATLAB (software)

The optimum configuration for the air interface, needs to be optimized on a case-by-case basis.

For example, for antenna developments in the laboratory, it might be preferential to leverage the frequency filtering capability of the spectrum analyzer. For high speed testing, detailed azimuthal sweeping might not be appropriate and the turntable may be replaced by multiple receive antenna with power meters at fixed spatial locations.

The Quickstep software project distributed with this Application Note drives an Arduino controlled stepper motor, within the turntable.

2.2 Calibration of the ZVA

In defined coherence mode, the four sources of the ZVA (or 2 sources dependent on the instrument configuration) generate signals with a user defined relative amplitude and phase relation.
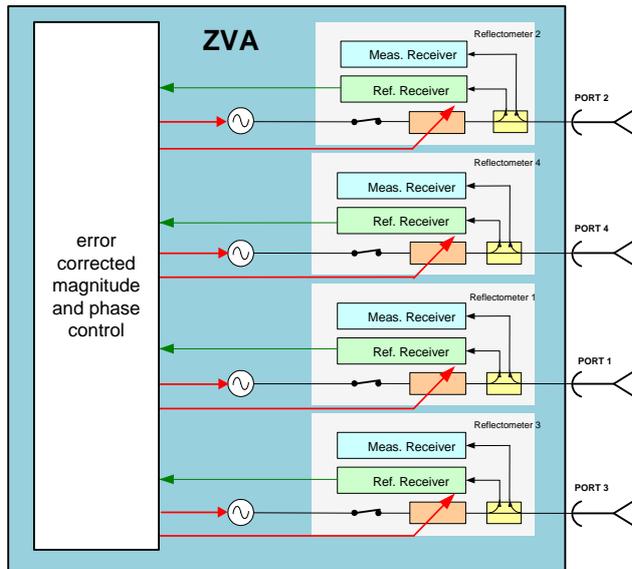
Fig. 2-2: Functional schematic of the multiple source ZVA

The source ports and the properties of the coherent signals are all defined in the Defined Coherence Mode dialog. One port is selected as a reference port. The amplitude and phase of all coherent signals are defined relative to the reference port.

A full 4-port calibration has to be applied to obtain the phase and magnitude relationship in the reference plane at the end of the test port cables used to connect the AUT. Thus it is not necessary to use phase matched cables with identical attenuation. The cables should only be stable in magnitude and phase when they are moved between calibration and measurement.

The same calibration can be also used to measure the S-parameters as described in 4.2.

With daisy chained ZVAs (Fig. 4-6) the calibration is performed in two steps. The reference port (in Fig. 2-3 Port 1 is selected for both instruments as reference port) of the first ZVA (ZVA1) is connected to the Source In port of Direct Generator Receiver Access of the second ZVA (ZVA2).
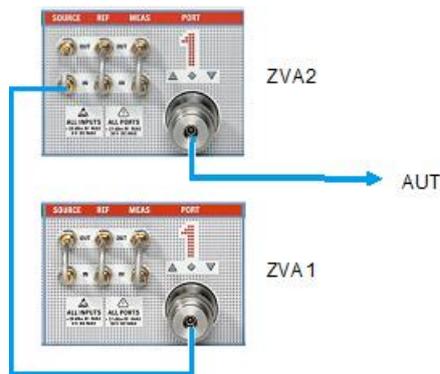
Fig. 2-3: Daisy-chaining multiple ZVA

The signal of ZVA1 runs through the directional coupler to the test port 1 of the ZVA2 and with a cable to the AUT. This is still Port 1 of ZVA1. A four-port calibration is now applied to the 4 ports of ZVA1 by using a calibration unit or a mechanical calibration kit. These four ports provide the amplitude and phase relation as defined in the coherence mode dialog of ZVA1.

To calibrate ZVA2 the connection from port 1 of ZVA1 to Source In of ZVA2 is removed and the loop between Source In and Source Out is closed. Then ZVA2 is calibrated between all four ports. The ports of ZVA2 provide the amplitude and phase relation as defined in its coherence dialog referred to port 1 of ZVA2 as well.

Now both instruments are switched to coherence mode, and port 1 of ZVA1 is connected to Source In of ZVA2 again. ZVA1 tunes amplitude and phase of its sources in respect of the measured reference signal derived from the coupler of port 1 of ZVA1, and ZVA2 tunes amplitude and phase of its sources in respect of the measured reference signal at port 1 of ZVA2.

Because port 1 of ZVA2 gets the signal from port 1 of ZVA1, magnitude and phase relation of all sources is established in respect of source 1 of ZVA1.

To achieve higher accuracy, an attenuator, e.g. 6 dB or 10 dB is recommend at the Source IN port of ZVA2 (and it is present for both calibration and measurement) to ensure nearly identical raw source port match of the test port 1 of ZVA2 for both calibration steps and for the measurement. Thus both calibrations are valid also when the configuration was changed between calibration and measurement.

This procedure can be extended to three and more instruments. It is recommended to use a common reference frequency for all instruments.

2.3 Quickstep Test Executive

The installation of the Quickstep software should be performed prior to moving to the next step. Instructions for installing can be found at the Quickstep homepage.

2.3.1   Project Installation

There are two projects shipped with this application note:

▪ *Antenna_Scan_Analyzer*: Use a signal analyzer for measuring the received level

▪ *Antenna_Scan_PowerMeter:* Use a power meter for measuring the received level

The *UserBlocks* and *Projects* folder for this application, should be copied to the existing QuickStep default directory; *C:\Users\Public\Documents\Rohde-Schwarz\QuickStep.*

After starting QuickStep, a dialog asking the user to select a test project shows up. Any project can be opened by clicking the appropriate button, as shown in Fig. 2-4.
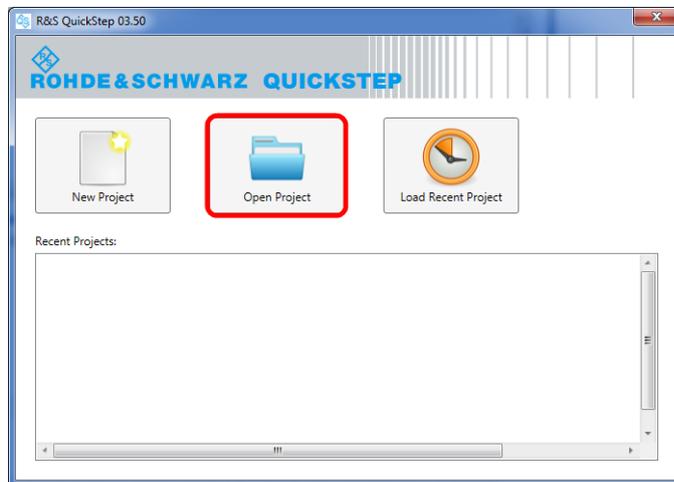
Fig. 2-4: Opening the provided Quickstep project

2.3.2   Process

Performing a measurement consists of the following steps:

1.   Setup all devices and connections as described.

2.   Configure all devices using the system configurator.

3.   Configure the test steps.

4.   Start the measurement.

5.   Evaluate the results using MATLAB®.

2.3.3 Configuration

Use the system configurator is used to set all devices up and define the basic measurement parameters. Access it by clicking the "System Configurator" tab, and is shown Fig. 2-5.
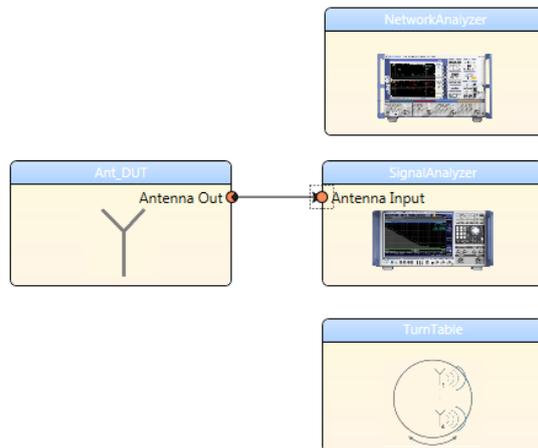

Fig. 2-5: System Configurator View

Clicking on the block of each instrument shows all available settings:

Network Analyzer

∎ *IP Address ZVA*: Visa resource string of the network analyzer. E.g.: "TCPIP::192.168.0.2"

∎ *Start Freq.*: Start frequency of the frequency sweep in MHz

∎ *Stop Freq.*: Stop frequency of the frequency sweep in MHz

∎ *Freq. Step*: Step width between start and stop frequency in MHz. A smaller step width means more points and thus a longer measurement time

∎ *Level*: Transmit level in dBm

∎ *Load Cal. File*: Name of the calibration to be loaded from the cal. Manager menu. This calibration should be valid for the frequency range defined above!

Signal Analyzer

∎ *IP Address Signal Analyzer*: Visa resource string of the signal analyzer. E.g.: "TCPIP::192.168.0.2"

∎ *Reference Lvl*: Reference power level used for all measurements in dBm

∎ *Level Range*: Amplitude range used for all measurements in dBm

∎ *No. of Averages*: Number of measurements over which the analyzer averages

- *Channel Bandwidth*: Bandwidth of the channel measured in order to obtain the channel power in kHz

- *Freq. Span*: Frequency span used for the measurement in kHz

Turn Table

- *Com Port Turn Table*: Virtual com port used to connect to the turntable device. An up to date Arduino driver has to be installed for this purpose!

- *Steps per Test Step*: Defines how many steps the turntable will take after all test steps for one angle have been performed. If one step of the turntable equates 0.6° and 2 steps per test step are defined, this means that the angle resolution will be 1.2°

- *Initial Rotation Steps*: Defines the angle of the first measurement that will be taken. If this value is for example set to 150 and each step equates 0.6°, the measurement will start at -90°.

Do not forget to modify the total number of repetitions in the TPR Options in the Testplan Editor tab (described later in this section) upon changing the step count.

2.3.4 Testplan Editing

This view is used to configure all test steps that should be performed during a measurement. Every test step defined in this editor will be executed once per angle.

Settings

Fig. 2-6 shows an excerpt of the possible test step settings. Changes are limited with the trial license, but of course, are fully programmable with the full license.

Due to the single line sweep over the phase of port 2 in the second test step, there are actually 11 test steps per angle. For every test step a frequency sweep over the defined range is performed. In this example, there will be 11 frequency sweeps with different settings for port two at each angle.

Test Step Settings				NetworkAnalyzer\Phase Coherence exec. CW Sweep													
Id	Enable	Breakpoint	Test Procedure	Rel. Ampl. P.1	Rel. Ampl. P.2	Rel. Ampl. P.3	Rel. Ampl. P.4	Rel. Phase P.1	Rel. Phase P.2	Rel. Phase P.3	Rel. Phase P.4	P.1	P.2	P.3	P.4	Referen
1	1	☑	☐	Test Procedure	0	0	0	0	0	0	0	0	☑	☑	☑	☑	
2	2	☑	☐	Test Procedure	0	0	0	0	0	0..180:20	0	0	☑	☑	☑	☑	

Fig. 2-6: Example Test Step Settings

The complete set of available parameters is explained below

- *Rel. Ampl. P.1 - 4:* Defines the relative amplitude offset of port one to four in dB with regard to the reference port. The setting for the reference port is ignored

- *Rel. Phase P.1 - 4:* Sets the relative phase offset of port one to four in degrees with regard to the reference port. The setting for the reference port is ignored

- *Rel. Freq P.1 - 4:* The relative frequency offset of port one to four in Hz with regard to the reference port. The setting for the reference port is ignored

- *P.1 - 4:* Enables output of the respective port if the box is checked

- *Reference P:* Defines the reference port for this test step.

- *Delay P.1 - 4:* Sets a user defined delay in picoseconds to the independent source ports

TPR Options

On the right side of the Quickstep GUI is a view that displays all test step settings by default. The setting *Repetitions* can be accessed by clicking on the tab *TPR Options* highlighted in Fig. 2-7.

This setting corresponds to the total number of turntable steps and thus, the azimuth range covered by the measurement. In this example, all test steps will be performed 301 times. If the resolution was set to 0.6 degrees per step, this equates to an azimuth range of -90° to +90°.
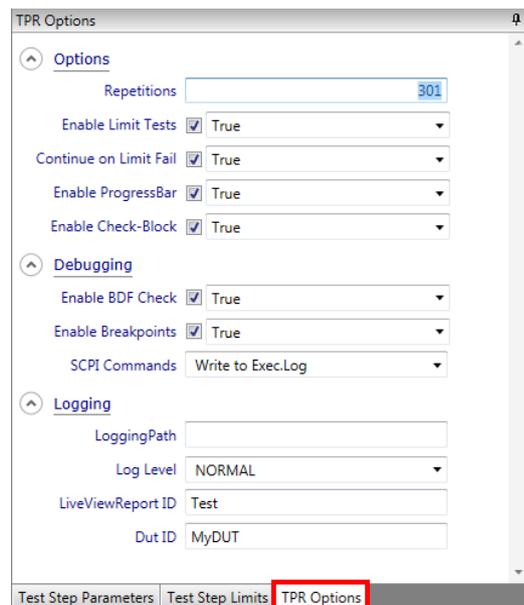
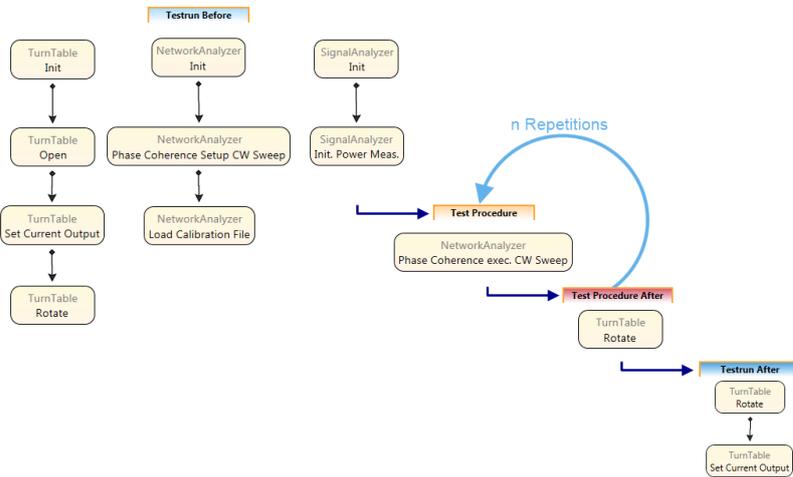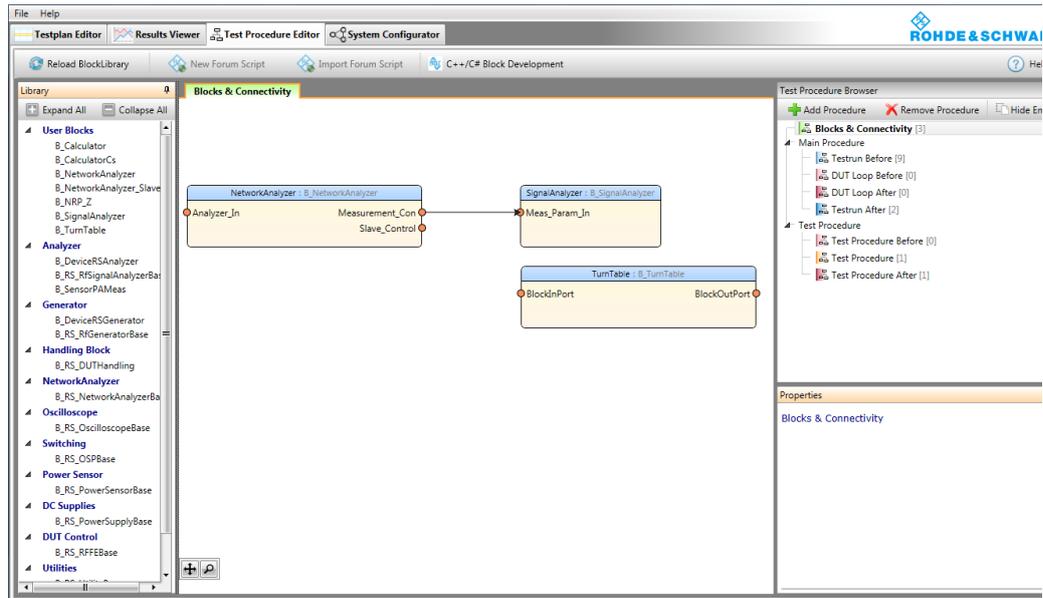**Fig. 2-7: Turntable step count configuration**

Fig. 2-8: Creating a Test Procedure in Quickstep

Fig. 2-9 shows two test steps with different settings per RF chain. These test steps can be repeated multiple times. In each repetition, every block function in *Test Procedure Before*, *Test Procedure* and *Test Procedure After* is called anew.

Fig. 2-9: Example Test Plan

3 X-band Parasitic Array Measurement

3.1 The Antenna

The first test object in this study is an X-band prototype array, described in [3].

This antenna comprises 4 driven (intentional) radiators, each with 4 switched parasitic radiators.

The test setup and antenna is shown in Fig. 3-1.
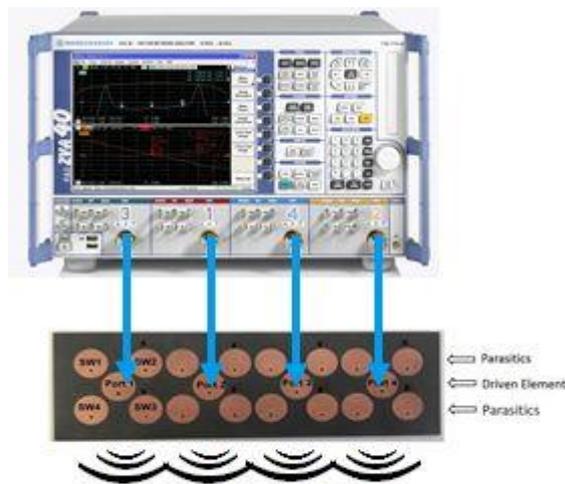
Fig. 3-1: Photo of the X-band 4-element array, connected to the 4-port ZVA (receiver not shown)

3.2 S-parameters

Measurement of the S-parameters may be performed with ZVA in its conventional mode.
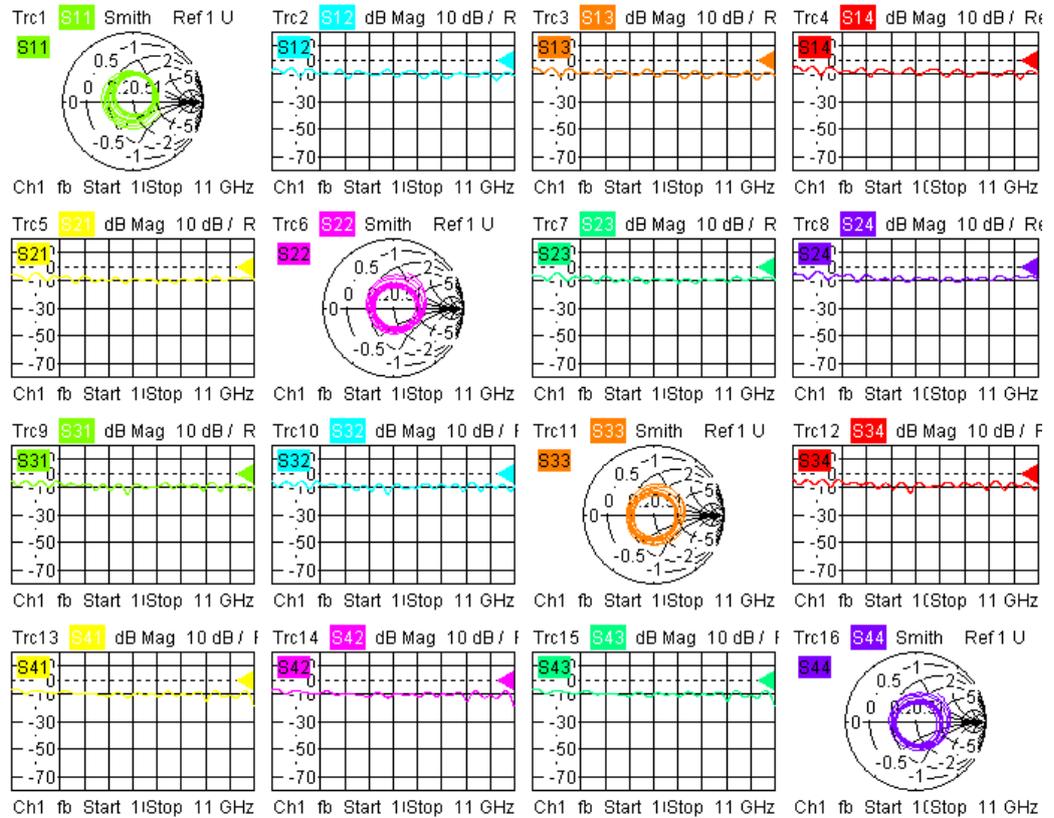
Fig. 3-2: 4-port S-parameter measurement of the X-band antenna

3.3 4-port Beamsteering

The test antenna's parasitic radiators were configured (with hard wired switches) to optimize for a fixed 41 degree beam steer.

To complete that beamsteering configuration, the 4-ports needed to be stimulated with signals with phase offset of 228 degrees between each element. Those signals need also to be amplitude aligned.

By switching (electronically) from S-parameter to defined coherence mode in the ZVA, it becomes possible to stimulate the multiple sources simultaneously.

Fig. 3-3 shows the beamsteering verification measurement post-processing result.
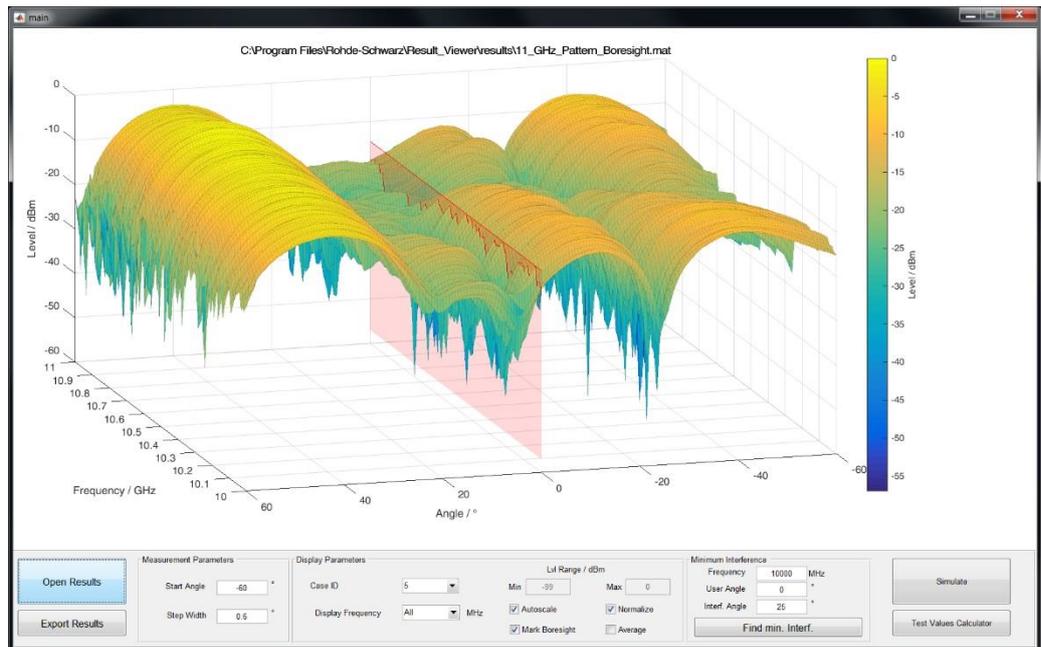
Fig. 3-3: 4-port Tx-mode beamsteering verification

The beamsteering measurement result demonstrates a clear maxima in directive gain at the 40 degree azimuth, with significant suppression of the gain on boresight. Very fine phase resolution of the analyzer's Defined Coherence Mode allows to verify by slight parameter variation, if the design-phase was hit to the degree desired.

4 Ka-band Simple Array Measurement

4.1 The Antenna

The basic antenna parameters for the Ka-band array are:

▪ Frequency Range: 26 ~ 30 GHz

▪ Radiators: 4 x 10 array

▪ Inter-radiator Spacing: 5 mm

The array, with 4 elements connected is shown in Fig. 4-1.
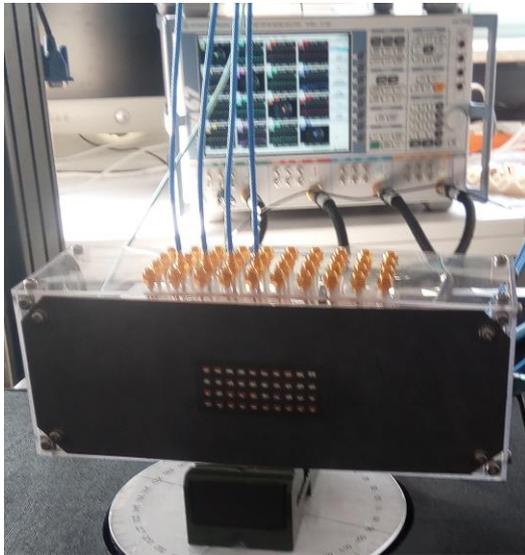
Fig. 4-1: 4 x 10 K-band array, with 4 elements connected to a ZVA

4.2 S-parameter and Tx-Mode Beamsteering Measurement

In this section, a simple beamsteering and S-parameter measurement will be taken within a single connection cycle.

Conventional radiation pattern measurements (Fig. 4-2) were taken for some of the individual radiators in the array, at 28GHz in a professional chamber.
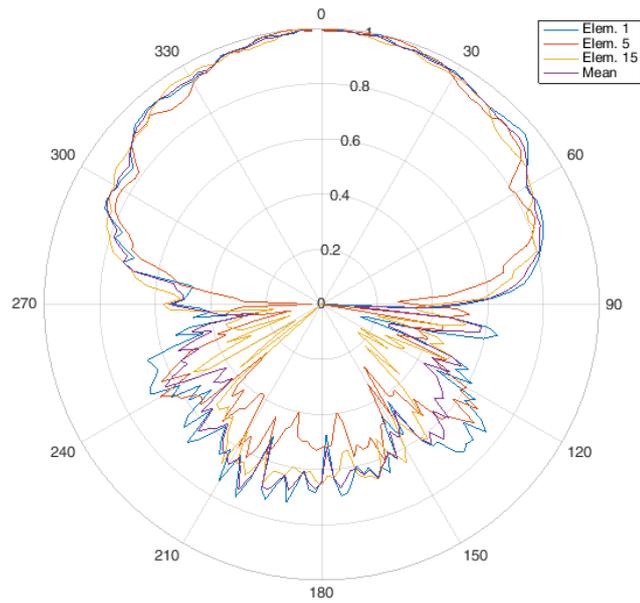
Fig. 4-2: Radiation patterns for selected individual radiators in the array

The radiation pattern (Fig. 4-2) can be used to calculate the effect of four radiating elements (Fig. 4-3).
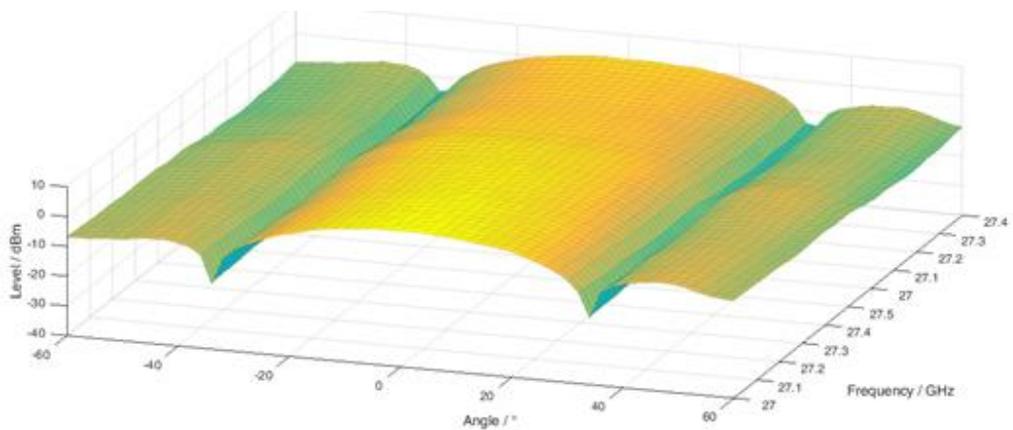
Fig. 4-3: Pattern for 4 radiating elements, CACULATED from a single MEASURED element.

Using the test setup, the calculated value may now be verified with measurement.
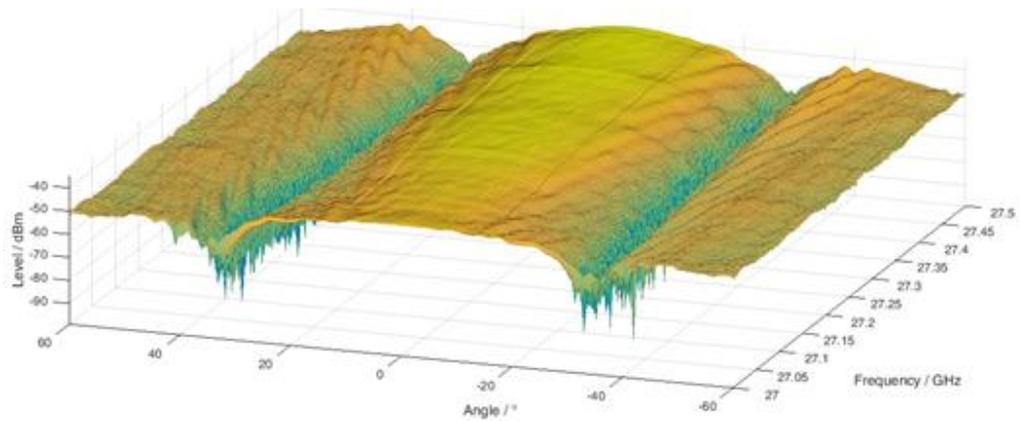
Fig. 4-4: VERIFIED by MEASUREMENT pattern for 4 radiating elements

The full 4-port S-parameters (illustrating cross-coupling values, reflection and return losses, delivered powers, for example) are measured and presented (Fig. 4-5).
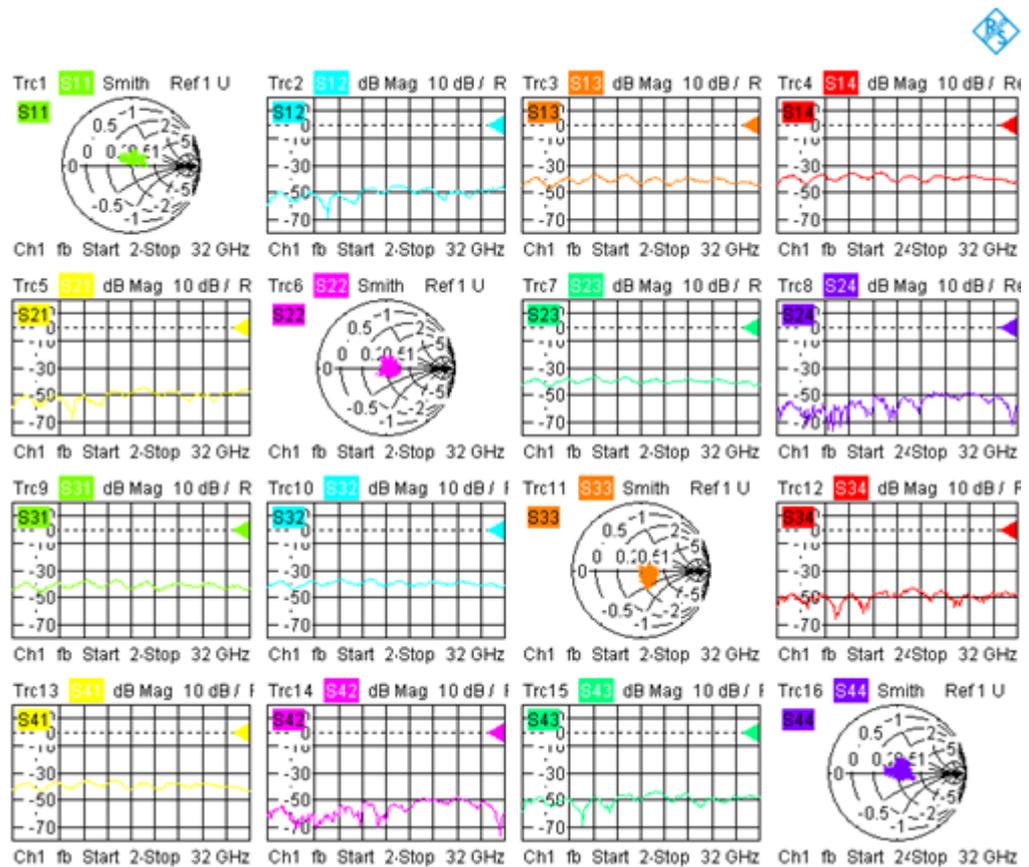
Fig. 4-5: Full S-parameters for the four connected array elements, electronically switched from "Defined coherence" mode

4.3 7-element Tx Mode Beamsteering

In this section, 2 ZVA will be daisy-chained to extend the number of ports over which the beamsteering and beamforming measurement can be made.

The ZVA may be daisy-chained to extend the concept to any number of ports. In this case, 2 ZVA were used to create a 7 port system (Fig. 4-6).
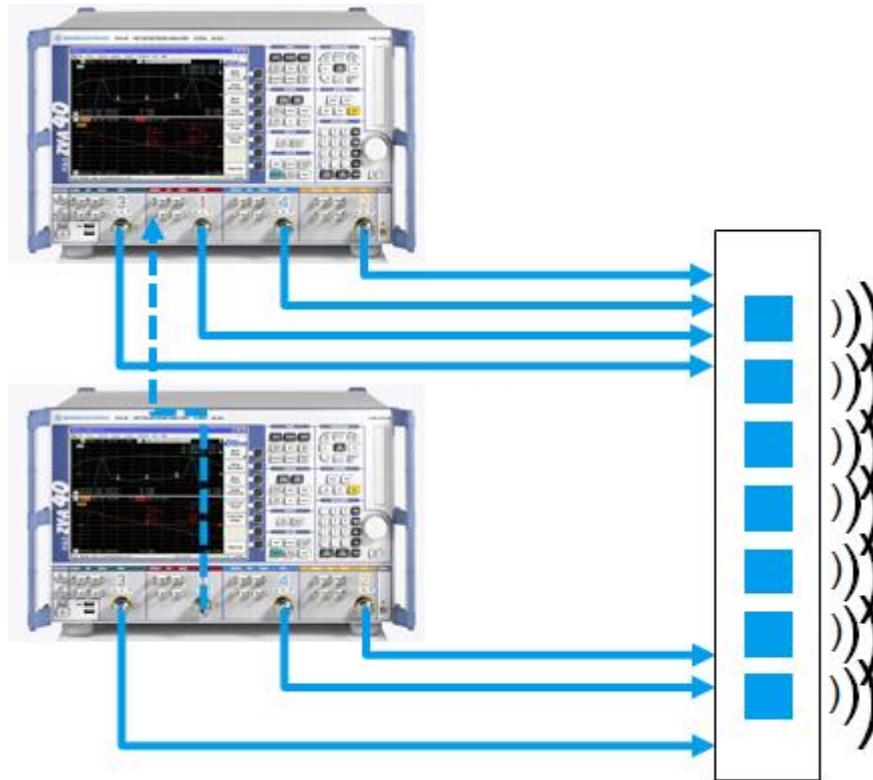
Fig. 4-6: Daisy chaining of ZVA, to extend single connection Beamforming and S-parameter concept to n-ports

Connection of seven ports of the reference antenna allowed for example, verification measurement of phase-aligned boresight (Fig. 4-7) and beam steered (Fig. 4-8).

Beam**forming** measurements, using arbitrary amplitude and phase may be made.
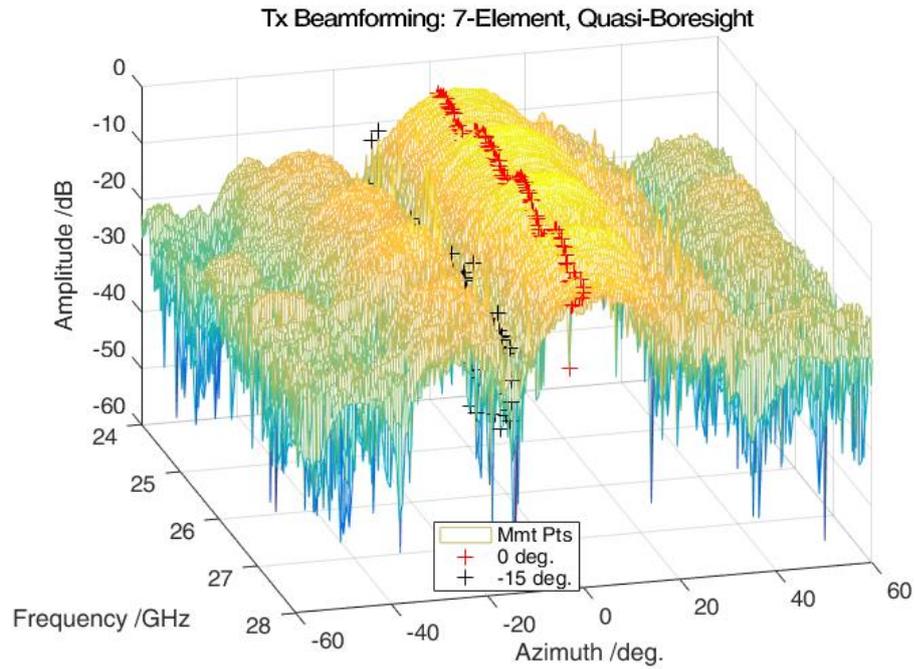
Fig. 4-7: Reference antenna with in-phase (boresight) stimulation of 7 ports simultaneously, with swept azimuth and frequency
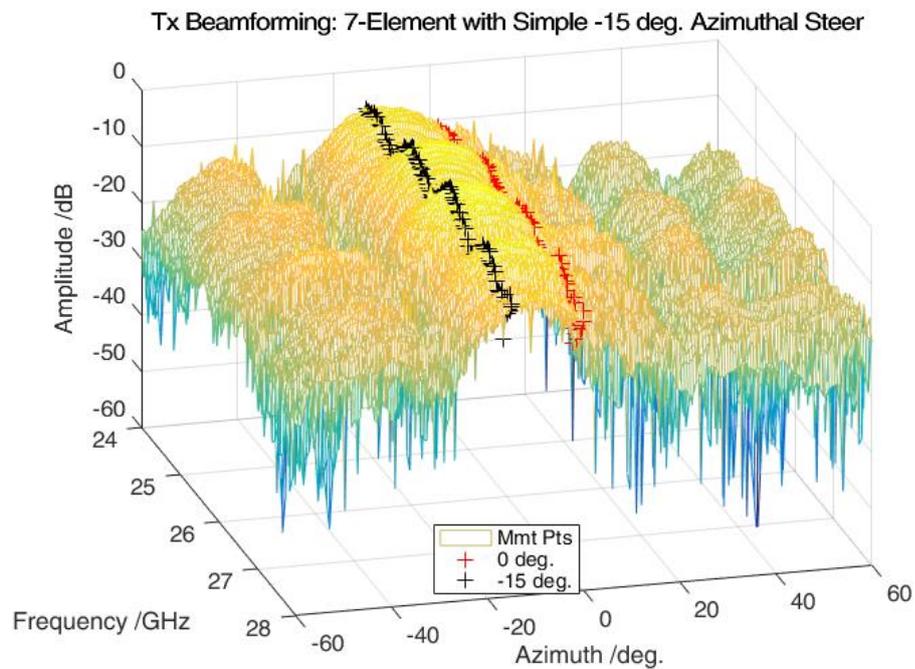
Fig. 4-8: Reference antenna with intended beamsteering of -15 degrees, with swept azimuth and frequency (using only a fixed phase offset between the elements)

4.4 4-element Tx-Mode Beamforming

Beamsteering as defined earlier, is the intentional directing of maximum directive gain. The flipside of this, is that the directive gain in other directions is disregarded.

Beamforming however, prioritizes directional discrimination over directive gain.

For example:

▪ Beamsteering would directing beam to an intended user located (for example) at -30 degrees azimuthal offset from boresight. Using this is achieved merely by applying a fixed phase offset between equally spaced elements across an array.

▪ Beamforming would simultaneously maximize the difference between that intended user (at -30 degrees) and an interferer located (for example) at + 20 degrees. This level difference, called discrimination, may be achieved for example by weighting the relative amplitudes of the elements, in addition to the phases.

In some cases, it is desirable to characterize the antenna with a series of amplitude and phase weightings to be used, according to specific directions of intended and interferer.

A simple implementation would be to use a 2D LUT (look-up-table) - or a "fit" to values in the table. Values of course, are best derived by measurement.

These weighting values are stored in a so-called codebook.

To illustrate the concept, the antenna of was subjected to a massive sweep of amplitude, phase, frequency and azimuth across four elements.

The data was collected and post-processed using MATLAB.

In this example codebook entry, it is supposed that the user is located at an azimuth of 18 degrees and frequency of 26 GHz. The interferer is located at -18 degrees.

In the basic case, shown in Fig. 4-9, with equal phase and amplitude across the array, the boresight pattern is generated. The dB level values are normalized to the maximum observed signal level at any frequency/azimuth.

Rejection of the interferer, compared to the user, is 8,9 dB.

Radiation Pattern, User = -11.8 dB, Interferer = -20.7 dB, No Beamsteering
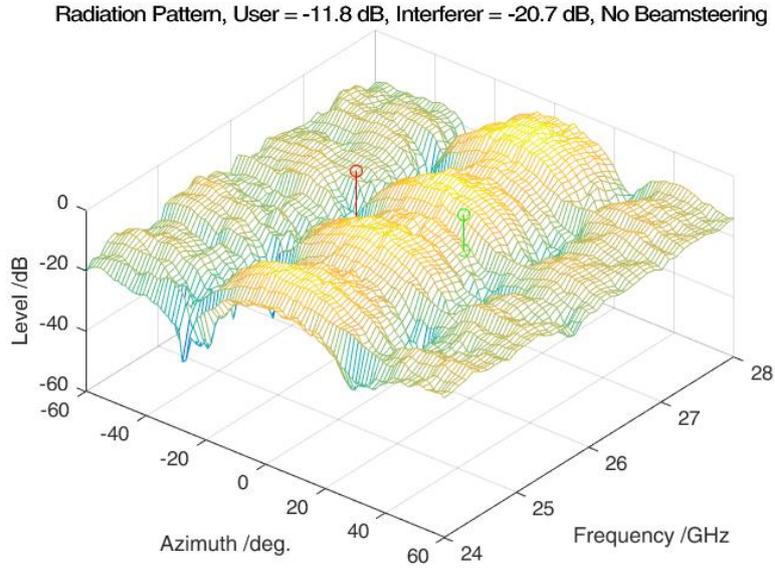
Fig. 4-9: Equal weightings across the array. User located at 18 degrees azimuth and 26GHz. Interferer at -18 degrees.

The application of a 40 deg. phase difference between each array element creates a beam steer (Fig. 4-10). The user located at 18 degrees observes a link enhancement.

Radiation Pattern, User = -7.1 dB, Interferer = -15.7 dB, Beamsteering 40 deg.
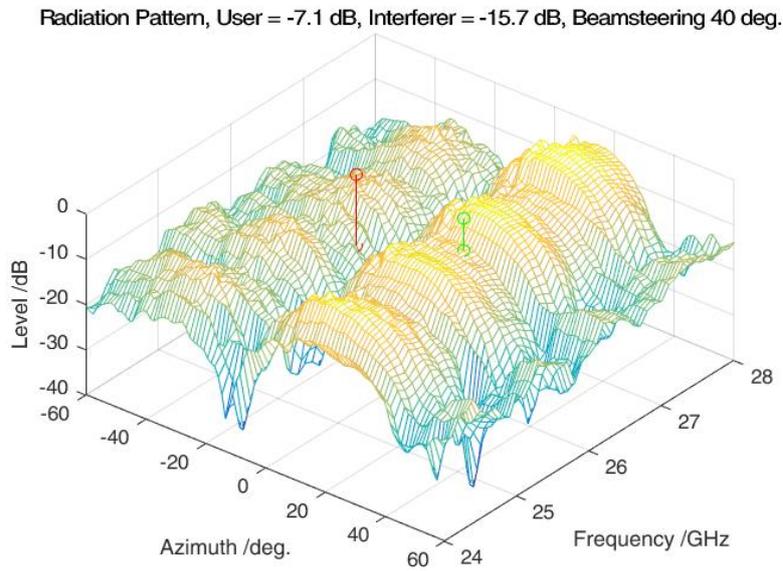
Fig. 4-10: Phase difference of 40 degrees applied between each of the 4 elements, creates a steer and improves link

Rejection has been reduced to 8,6 dB. So, unfortunately, whilst purely steering the beam, the interferer's link has been enhanced more than the intended user's.
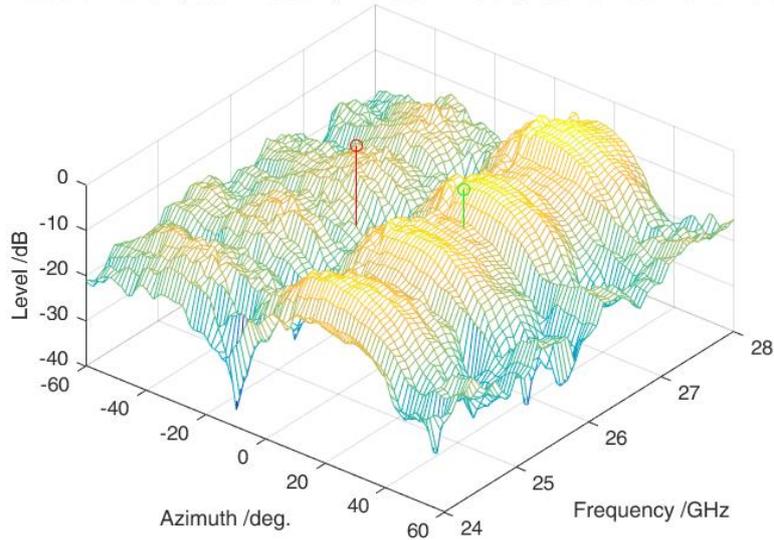
Fig. 4-11: Varying amplitude and phase across the four element array, shapes the beam and provides increased rejection of the interferer

In this case, the application of complex weightings (amplitude and phase) across the four element array such that the relative amplitudes are set to [-2 dB, 0 dB, 0dB, -2dB] (and, in this case, phase difference of 40 degrees maintained) between successive elements allows for an improved discrimination.

This is shown in Fig. 4-11.

Rejection of the interferer has increased to 13,5 dB and the output level of the antenna has also been reduced.

A comparison of the three cases (unmodified, beam**steered** and beam**formed**) is presented in Table 4-1.

Unmodified, Steered & Formed Beam Comparison				
Beam Type	**User Level (dB)**	**Interferer (dB)**	**Discrimination (dB)**	**Radiated Power (dB)**
Unmodified	-11.8	-20.7	8.9	0
Steered	-7.1	-15.7	8.6	0
Formed	-9.5	-23	13.5	-0.9

Table 4-1: Summary of the performance of the user and interferer experience for raw antenna, beamsteered and beamformed operation.

5 Post-Processing

5.1 Preparation

This Application Note is shipped with a "Result Viewer Post-processor" (a MATLAB executable), which may be used to post-process the result files generated by the Quickstep test executive. Running this executable requires that (the free) MATLAB Runtime is installed. (Some of the results shown in this document have already been produced with the tool.)

If the installer does not detect MATLAB Runtime, it will attempt to download and install it, as part of the overall install process.

The result files generated by the Quickstep test executive are stored in ASCII format and the user is free to perform additional or other processing as appropriate.

5.2 Post-processing Measurement Results
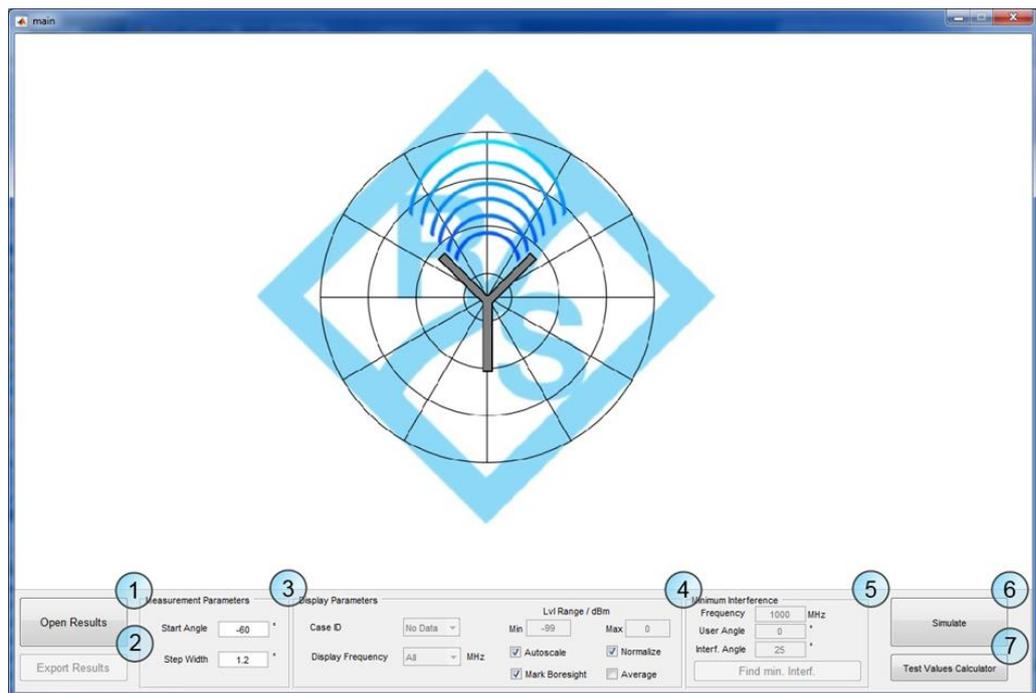
Fig. 5-1: Main Window of the Result Viewer

Referring to Fig. 5-1, the bottom bar provides all necessary controls to load and configure the view of measured data as well as simulate linear antenna arrays.

The following section explains the function of all controls in detail:

1   *Open Results*

Results can either be imported as QuickStep traces or .mat files that were exported by the Result Viewer.

▪   Importing Quickstep traces: Opens a dialog in order to choose the **path** of the measured trace data.

An example path would be:

```
    C:\Users\Public\Documents\Rohde-
Schwarz\QuickStep\Projects\Antenna_Scan\Results\yyyy_mm_dd_Resul
t\1_MyDUT\Traces
```

After the correct folder has been chosen, the measured data is displayed. It is important to drill down into the hierarchy to the "Traces" sub-directory.

▪   Import .mat files: Opens a dialog in order to choose the file of the previously exported data.

The file contains following vectors:

```
    amp_values: Amplitude values over frequency and angle for
all IDs

    idCell: Cell containing all test IDs

    freq_Vector: Vector containing the test frequencies

    angle_Vector: Vector containing the test angles
```

2   *Export Results*

Exports the results in a .mat file with the structure described in 1. Exported data can be used in own scripts or imported into the result viewer.

3   *Measurement Parameters*

Set parameters that cannot be inferred from the dataset.

▪   *Start Angle*: Antenna angle where the first measurement sweep was performed. e.g. -90°

▪   *Step Width*: Incremental azimuth step angle. e.g. 1.2°

4   *Display Parameters*

If a measurement has been loaded successfully, all controls in this panel become responsive.

▪   *Case ID:* Allows the selection of all different test cases defined in Quickstep. The assignment of the case IDs and settings can be obtained from the QuickStep result viewer:

- yyyy_mm_dd_hh_mm_ss_ms_Name → 1_MyDUT → TestStepsResults.log: This log stores all settings of every test step and the respective settings used.

■ *Display Frequency:* Enables display all measured data in a 3D plot or single frequencies.

■ *Lvl Range / dBm:* Allows to set a smaller range of amplitudes in order to pronounce certain areas of interest in the signal. Only enabled if the Autoscale option is deactivated.

■ *Autoscale:* If this option enabled, the plot data is automatically scaled for best viewing.

■ *Normalize:* The dataset is normalized to the highest measured value, which is set to 0 dB.

■ *Mark Boresight:* The 0 deg. azimuth boresight is highlighted in the plot.

■ *Average:* A moving average filter is applied to the raw dataset.

5 *Minimum Interference:*

Calculate the minimum interference for a given dataset of measurements. Larger result datasets will give better results. For singular datasets, the tool will show the only measurement taken under those conditions.

■ *Frequency:* Frequency for which the source settings of minimum interference will be calculated

■ *User Angle:* Angle of the user position corresponding to the displayed graph

Interf. Angle: Angle of the interferer position corresponding to the displayed graph

Clicking on "*Find min. Interf.*" opens a new window that shows the test case that was found to deliver the best results and thus the greatest rejection given the above settings. An example is displayed in Fig. 5-2 for a frequency of 26.4 GHz, a user angle of 20° and an interferer angle of -6 deg.
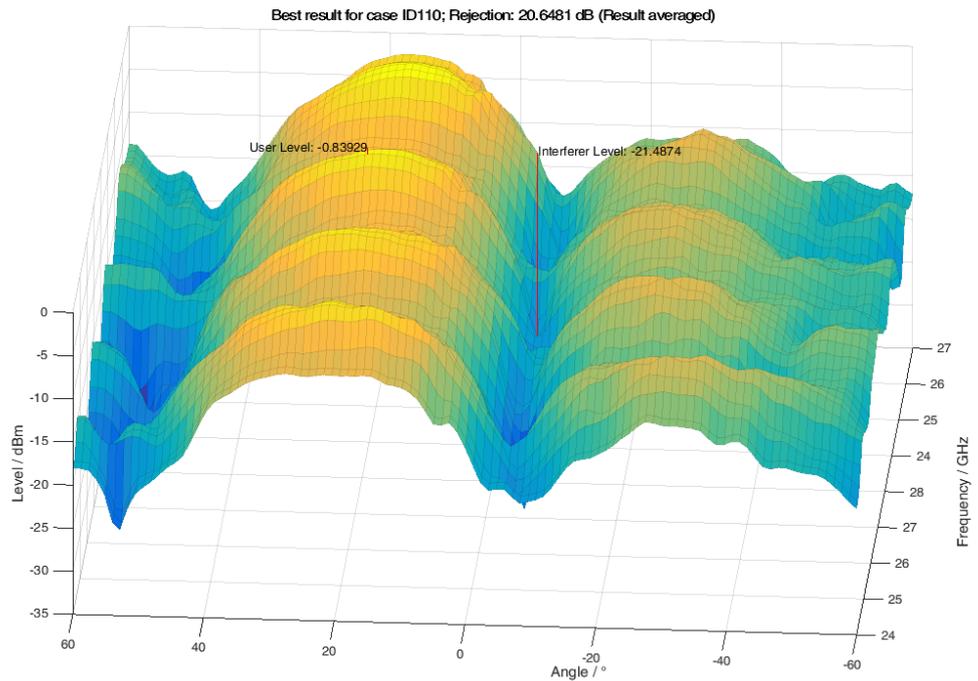
Fig. 5-2: Interference level extraction from the measurement dataset.

6   *Simulate*

Opens a new figure that is described in detail in the next section.

7   *Test Values Calculator*

Opens the dialog shown in Fig. 5-3. This view helps to calculate phase shift or time delay values for different antenna architectures. In this example, the main beam of an antenna array with equidistant elements spaced 68 mm apart should be steered to an angle of 10°.

Thus, all elements must be set to a phase offset of about 34°.
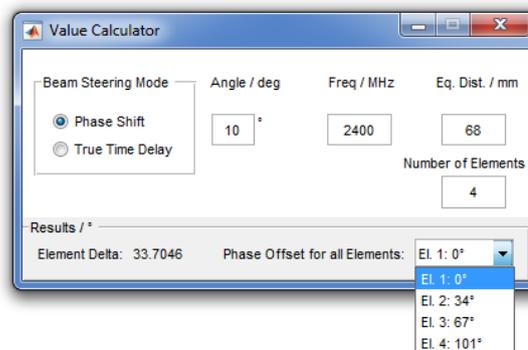
Fig. 5-3: Test Values Calculator window

5.3 Calculating Radiation Patterns

The view shown in Fig. 5-4 is opened by clicking the button *Simulate* in the main dialog.
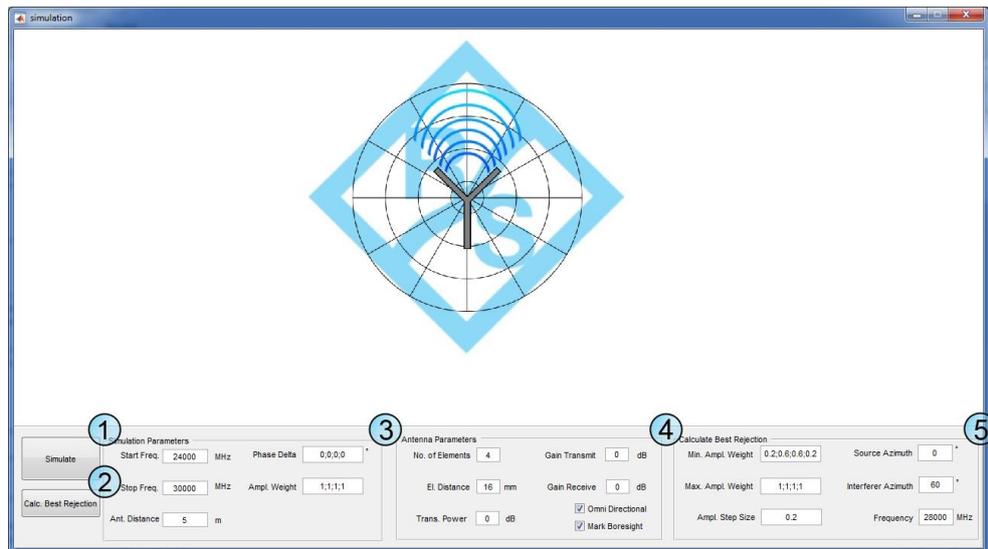
Fig. 5-4: Simulation view

1   *Simulate*

     Calculates the approximated array pattern for the Parameters defined in 2 and 3.

2   *Calc. Best Rejection*

     Determines the best rejection ratio for an interfering signal. Parameters for this calculation can be set in 5. The result provides the optimum amplitude weights for the given settings, as shown in Fig. 5-5. While determining the optimum weights for each element, all weights are swept from the minimum to the maximum value.

     The x-axis corresponds to the angle of the wanted signal while the y-axis corresponds to the angle of the interfering signal. The expected rejection ratio in dB is coded by the color bar on the right side.

     In the example shown below, the wanted signal's level is 26.5 dB higher than the interferer signal's level at 60°
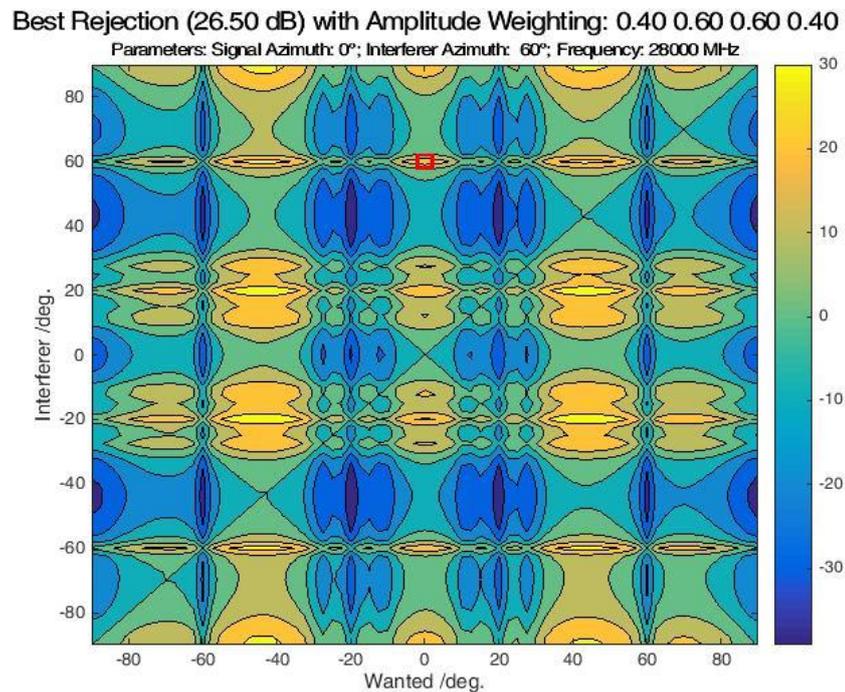
Fig. 5-5: Calculation of Best Rejection Ratio

3   *Calculation Parameters*

This tab together with 4 allows to set the parameters used for the radiation pattern calculation.

   ▪   *Start Freq.:* Sets the start frequency in MHz

   ▪   *Stop Freq.:* Sets the stop frequency in MHz

   ▪   *Antenna Distance*: This value sets the antenna distance in meters and is used to calculate the free space attenuation

   ▪   *Phase Delta*: Allows definition of individual phase offsets for each element. The unit of the values is degrees. Thus "0;45;90;135" means that the second element has a phase offset of 45° degrees with regard to the first element while the third is offset by 90° degrees and so on.

   ▪   *Ampl. Weight*: The individual amplitude weights of each element can be set using this control.

4   *Antenna Parameters*

This tab together with 3 allows to set the parameters used for the radiation pattern calculation.

   ▪   *No. of Elements:* Number of single elements in the linear antenna array

   ▪   *El. Distance:* Equidistant spacing of all elements in millimeters.

■ *Trans. Power:* Transmitted power in dB. Used for calculation of the free space attenuation

■ *Gain Transmit:* Gain of the transmit antenna in dB. Used for calculation of the free space attenuation

■ *Gain Receive:* Gain of the receive antenna in dB. Used for calculation of the free space attenuation

■ *Omni Directional:*

▪ If this checkbox is checked, an omnidirectional radiation pattern is assumed for each antenna element.
▪ If the checkbox is unchecked, the program uses actual measurement data for one element to improve the approximated result.

The measurement result has to be stored in the file Element_Pattern.mat in the current directory\files\.

■ Element_Pattern.mat is a structure that contains the following fields:

■ Amplitude: The measured amplitude values in dBm.

■ vAngle: The angle of the measured amplitude values in degrees.

■ vFrequency: The frequency of the measured amplitude values in GHz

■ *Mark Boresight:* This option will highlight the antenna boresight by marking the 0° angle

5　*Calculate Best Rejection*

This tab allows to configure the parameters for the calculation of the best rejection ratio as described in 2

■ *Min. Ampl. Weight:* The individual minimum amplitude weights of each element that may be used to determine the best rejection. The sweep through all allowed amplitude values starts with the weight defined in this setting.

■ *Max. Ampl. Weight:* The individual maximum amplitude weights of each element that may be used to determine the best rejection. The sweep through all allowed amplitude values ends with the weight defined in this setting.

■ *Ampl. Step Size: T*he step size of the amplitude weights while sweeping from the minimum to the maximum allowed value.

■ *Source Azimuth:* Azimuth of the wanted source signal.

■ *Interferer Azimuth:* Azimuth of the interfering signal.

■ *Frequency:* Frequency for which the best rejection ratio should be determined.

6 Conclusions

Beamforming antenna are used in an increasing number of applications (e.g. Satellite Communications) and will form the backbone of 5G.

This document illustrates how, uniquely, both the development and manufacturing processes (e.g. sub-sample verification) of antenna intended for beamforming applications (regardless of control) can be vastly improved, especially in regard of test throughput.

Until now, the antenna itself could only be tested accurately for S-parameters, before integration with the radio module itself. Derivation of coding algorithms, across the spectrum from static codebooks to pure dynamic weighting, had to be developed "blind".

This application changes that model.

At design time, the beamforming antenna development process is now emancipated:

▪ Designers may now for example, quickly and accurately compare different antenna prototype designs or develop beamforming algorithms and strategies.

▪ Identifying these beamforming behaviors allows the rest of the radio to be optimally developed, reducing development time and cost, whilst maximizing performance.

At production time:

▪ in addition to simple S-parameters, individual antenna modules may now be directly and accurately verified for beamforming performance.

▪ this verification test step may be performed before further integration of the antenna into the front-end, thus improving yield and reducing costs.

7 References & Further Reading

[1] Rohde & Schwarz, "R&S®ZVA / R&S®ZVB / R&S®ZVT Vector Network Analyzers Operating Manual", 1145.1084.12 – 29, pp. 399-401.

[2] Reil, M., Lloyd, P. G., "Millimeter-wave Beamforming: Antenna Array Design Choices & Characterization: White Paper", Rohde & Schwarz, 2016.

[3] Allayioti, M.; Kelly, J. R., "Side lobe level reduction for beam steerable antenna design", 10th European Conference on Antennas and Propagation (EuCAP), 2016, Davos.

[4] Kottkamp, M., Rowell, C., "Antenna Array Testing - Conducted and Over the Air: The Way to 5G: White Paper", Rohde & Schwarz, 2016.

8 Ordering Information

Designation	Type	Order No.
Vector Network Analyzer 4 ports, 67 GHz, 4 internal sources	R&S®ZVA67	1305.7002.04
Vector Network Analyzer 4 ports, 40 GHz, 4 internal sources	R&S®ZVA40	1145.1110.48
Vector Network Analyzer 4 ports, 24 GHz, 4 internal sources	R&S®ZVA24	1145.1110.28
True Differential Measurements	R&S®ZVA-K6	1164.1540.02
Signal and Spectrum Analyzer, 10 Hz to 30 GHz	R&S®FSV30	1321.3008.30
Three-Path Diode Power Sensor, 10 MHz to 33 GHz	R&S®NRP33SN	1419.0070.02
QuickStep: License dongle and key card for software options	R&S®QuickStep	1528.9003.02

Contact your local R&S representative to discuss evaluation license opportunities for Quickstep.

Glossary

Beamforming: control of radiated signal levels in two or more specific directions, by controlling individual radiating element's weightings (i.e. signal amplitude and phase).

Beamsteering: a primary, or main lobe, intentional beam (highest directive gain) whose direction is controlled by modification of phases between radiating elements.

Codebook: values for amplitude and/or phase difference to be applied to different antenna elements in order to achieve a specific beam pattern, usually improving spatial rejection or discrimination at the expense of directive gain.

Glossary

Rohde & Schwarz

The Rohde & Schwarz electronics group offers innovative solutions in the following business fields: test and measurement, broadcast and media, secure communications, cybersecurity, radiomonitoring and radiolocation. Founded more than 80 years ago, this independent company has an extensive sales and service network and is present in more than 70 countries.

The electronics group is among the world market leaders in its established business fields. The company is headquartered in Munich, Germany. It also has regional headquarters in Singapore and Columbia, Maryland, USA, to manage its operations in these regions.

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▮ Energy efficiency and low emissions

▮ Longevity and optimized total cost of ownership

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