

ATS1000: Passive Antenna Measurement and Nearfield - Farfield Transformation Application Note

Products:

- R&S®ATS1000
- R&S®AMS32
- R&S®ZVA

This application note describes how to measure the antenna pattern of a mm-Wave device in the R&S®ATS1000 shielded chamber. This includes the required calibration of the measurement setup and a possible near field to far field transformation when measuring larger devices.

Note:

Visit our homepage for the most recent version of this application note (<http://www.rohde-schwarz.com/apnote/1MA304>).

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1 Introduction

Antenna measurements often require large chambers in designated rooms or halls. With the R&S®ATS1000 (ATS1000), Rohde & Schwarz offers a compact measurement chamber with high shielding effectiveness and internal wall absorption, which can be equipped with a highly accurate positioner. The small footprint allows a placement in any lab environment or directly next to the work bench of the RF engineer. With a width of only 90 cm, the chamber even fits through most typical office doors.

Moving to higher frequencies like 28 GHz or 38 GHz, far field measurements with smaller measurement distances get feasible. Also, Rohde & Schwarz addresses measurement challenges for near-field measurements with direct near-field to far field (NF-FF) transformation build into the measurement software AMS32. AMS32-K50 enables NF-FF fast and accurate transformation for passive antenna. Rohde & Schwarz offers turnkey solutions for antenna measurements, covering the measurement chamber and all required devices as well as the software for measuring, evaluating and, if necessary, transforming the antenna pattern.

Especially the use of mm-wave frequencies requires sophisticated test solutions for different measurement scenarios. Rohde & Schwarz offers a wide portfolio of measurements scenarios for the different aspects of OTA tests. With different measurement chambers, positioners and software tools, Rohde & Schwarz products aid antenna designers and system engineers working in cellular radio develop the latest mmWave antennas and frontends for 5G and other standards to come. With fast measurement speed even for full 3D antenna patterns, the antenna test systems by Rohde & Schwarz make the development for antenna and components faster and more efficient.

This application note guides the reader through an antenna pattern measurement of a mmWave antenna under test (AUT) using the R&S®ATS1000 Antenna Test System with an R&S®ZVA network analyzer and the R&S®AMS32 OTA Performance Measurement Software. A 28 GHz antenna is used as DUT in this application note.

The following sections give a short overview of antenna pattern measurements with focus on near field to far field transformation.

1.1 Antenna Measurements

Antenna pattern measurements, antenna parameter determination, and simulation validation are integral parts of developing radio equipment during antenna design, prototyping or system integration. Accurate measurements in a controlled environment are essential to determine the antenna pattern and parameters like total radiated power (TRP), antenna efficiency, directivity and gain. To measure the antenna directivity pattern, the antenna is placed in a shielded chamber and probed with a calibrated setup.

1.2 Far Field vs. Near Field

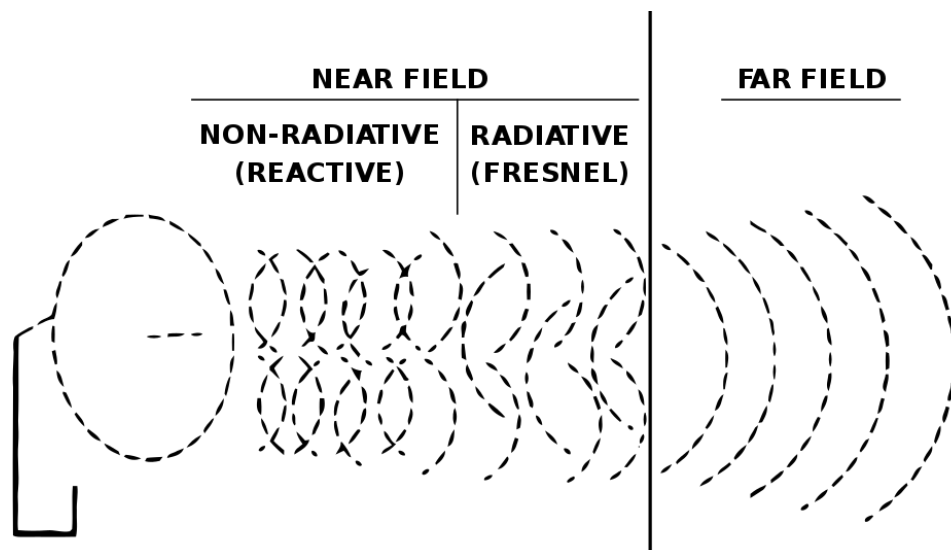


Figure 1-1: Regions of the electromagnetic field of a transmitting antenna

Figure 1-1 shows the different transmission regions of an antenna. Generally, antenna patterns have to be measured in the far field region of the antenna. The far field distance therefore often rules the minimum size of the measurement chamber.

The distance between near field and far field is not simply defined for every antenna. However, far field is assumed at distances over $2D^2/\lambda$, where D is the diameter of a sphere enclosing the antenna completely and λ is the wavelength. Following the equation, increasing size of an antenna relative to the used wavelength has more effect on the far field distance than increasing the frequency. With higher frequencies, the antennas tend to be much smaller. When focusing on mmWave, like for 5G New Radio, small chambers are often sufficient for measuring antennas due to their smaller size and therefore smaller far field distance.

No matter the frequency, if the far field distance is larger than the measurement distance in the chamber, the measured near field data must be transformed to far field for further use. For millimeter wave, this can be the case when using large antenna arrays, or when measuring a "black box DUT", where the exact location of the antennas is not known.

For far field measurements, ATS1000 is therefore recommended to be used for "white box DUTs". For near-field measurements, AMS32 offers NF-FF transformation algorithms and probe correction (to compensate for the measurement probe) and can therefore be used to get highly accurate transformations of the far field antenna pattern from near field measurement data.

1.3 Used Hardware and Software

In this application note, the R&S®ATS1000 shielded chamber is used with a conical cut high precision positioner and the R&S®ZVA network analyzer. The R&S®AMS32 controls the chamber, positioner and measurement devices, performs the measurement and is used for visualization, reporting and postprocessing including near field to far field transformation.

2 Physical Setup: ATS1000 and ZVA

The ATS1000 shielded chamber features multiple defined feedthrough points for establishing connectivity from the outside into the chamber. In this application note, a standard gain horn is used for every measurement. In general, horn antennas are also the best solution for calibration and reference measurements. It is assumed that the chamber and positioner are fully assembled.

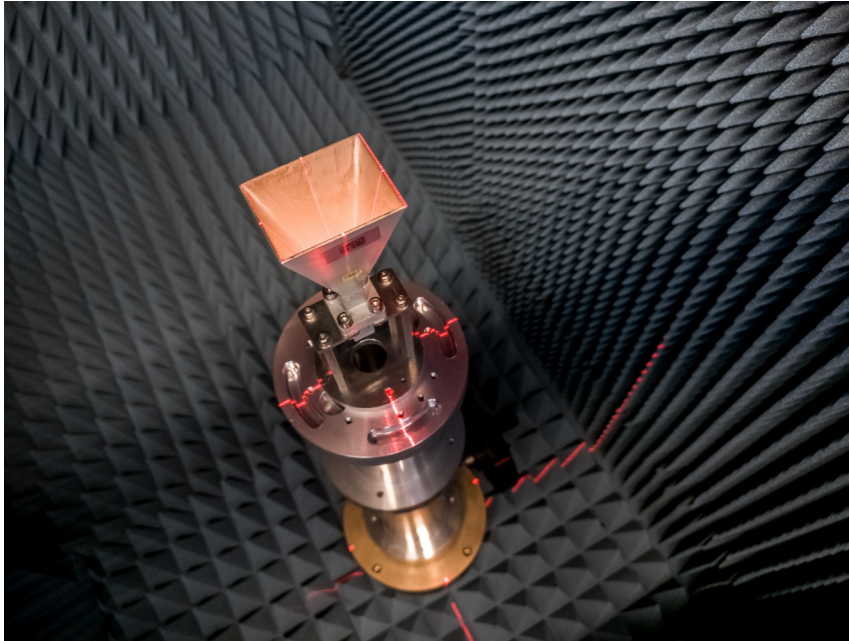


Figure 2-1: Reference antenna in ATS1000 with alignment using lasers

Setup ATS1000 for calibration with the following steps:

1. Place the reference antenna on the azimuth rotation table. Use the laser alignment to position the antenna at the correct height (c.f. Figure [Figure 2-1](#)).
2. Connect the ZVA to the connectors for the probe antenna and the DUT feed on the left face of the ATS1000 (c.f. Figure [Figure 2-2](#)).
3. E.g., connect port 1 to the DUT, and port 2 and port 3 to the probe antenna.
4. Identify the horizontal and vertical polarization. The horizontal polarization in the ATS1000 is parallel to the ground at 90° elevation of the elevation positioner (c.f. Figure [Figure 2-3](#)). The direction of the polarization vector is identified by the feeds of the probe antenna. In the ATS1000, the vertical polarization is in the "front-back" axis and the horizontal polarization in the "left-right" axis when looking through the open door of the ATS1000.
5. Note the port numbers for both polarizations for setting up the AMS32 software in the next step.



Figure 2-2: Probe antenna cables feedthrough at left face of ATS1000

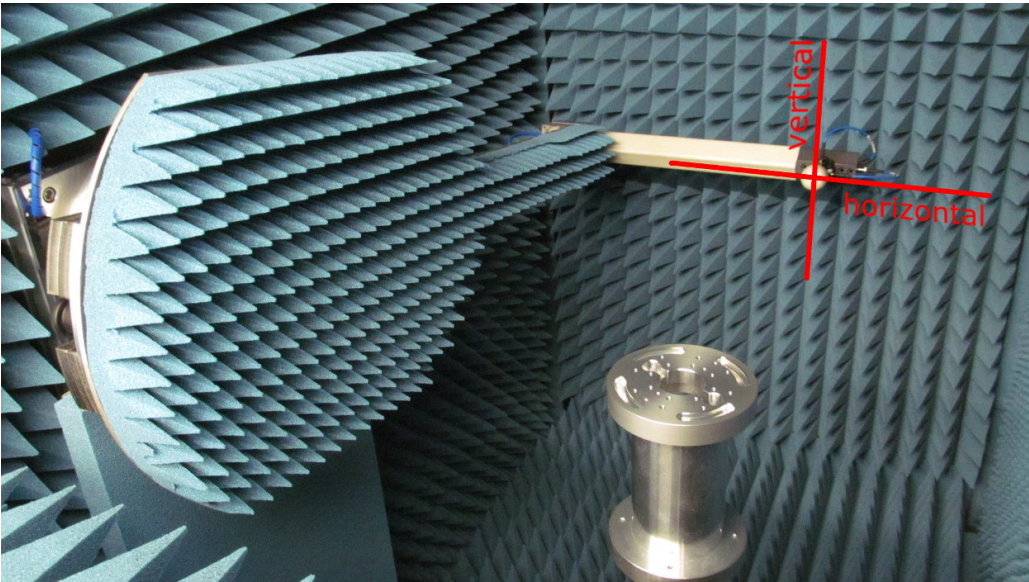


Figure 2-3: Probe antenna polarization in ATS1000

3 Virtual Hardware Setup in AMS32

To start a measurement on a calibrated setup, the information about the setup has to be defined in AMS32. The physical setup has to be described as a hardware setup in the AMS32 software including one or more used instruments and positioners. Then, the calibration information is stored in the path before the test parameters are set in individual test templates for this hardware setup.

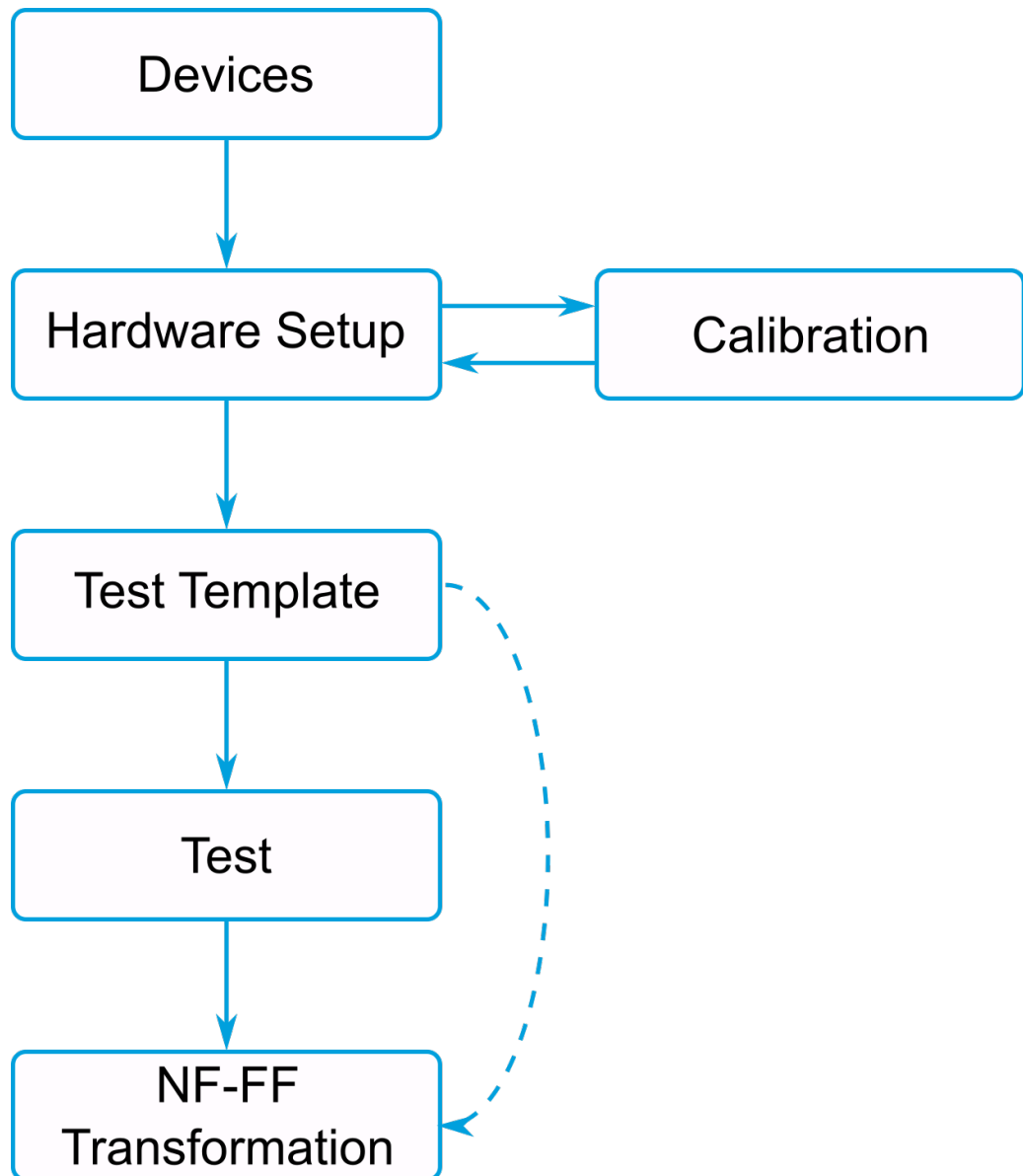


Figure 3-1: Schematic view of relations between devices, hardware setup, test templates and tests in AMS32

3.1 Devices Configuration

First, the devices are configured globally in AMS32:

1. Open the "device list" (F9) to configure the used devices for the setup.
 - *Maturo NCD Azimuth*
 - *Maturo NCD Elevation*
 - *ZVx for OTA*
 - *Antenna*
2. For each device, open the device configuration by double clicking on the device in the list.
3. Specify the IP address of each device and connect to the device by activating the "Physical" state.



Make sure that all devices are reachable in the network. Especially take different subnets of the instruments into account and adjust the IP addresses and subnets of the host PC if necessary.

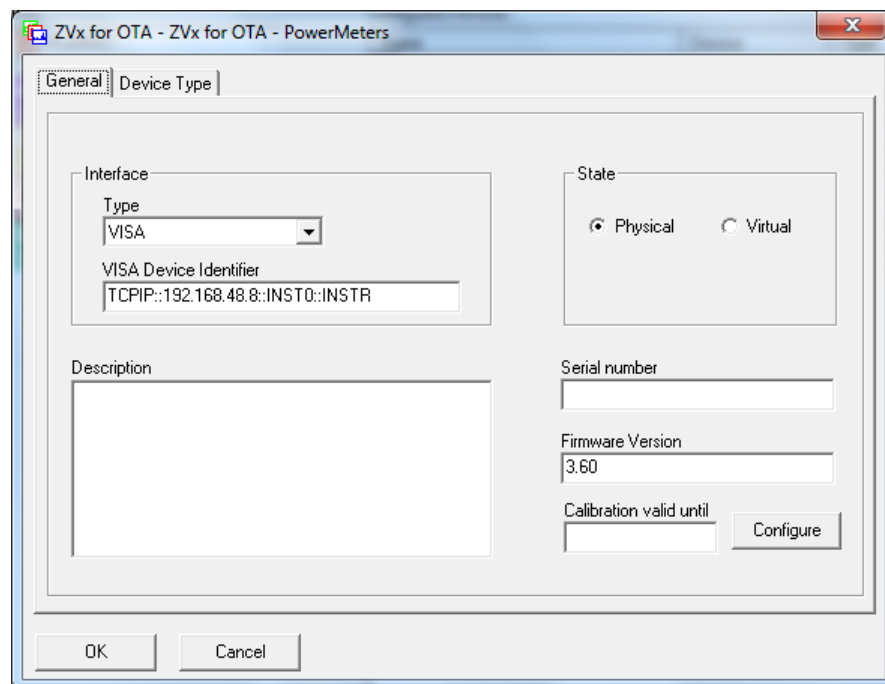


Figure 3-2: ZVx for OTA Setup Window



After setting up the devices or after a fresh program start, click the "Self-Check" button (🔍) for a quick way to verify that all devices are connected (in "Physical" mode) and are ready to be used.

3.2 Hardware Setup Definition

With all devices configured, create a hardware setup in the "EMC32 Explorer" :

1. Make sure that the EMC32 Explorer is set to "All Files" by selecting the folder icon in the bottom toolbar in the EMC32 Explorer.
2. Browse to *AMS32* → *System* → *Hardware Setups* → *OTA Measurements*, right click OTA Measurements and select "New File".
3. If visible, disable "Radiated Power", "Sensitivity" and "Conducted MIMO" tabs by removing the respective "Available" checkbox. Only use the "Passive Antenna" tab.

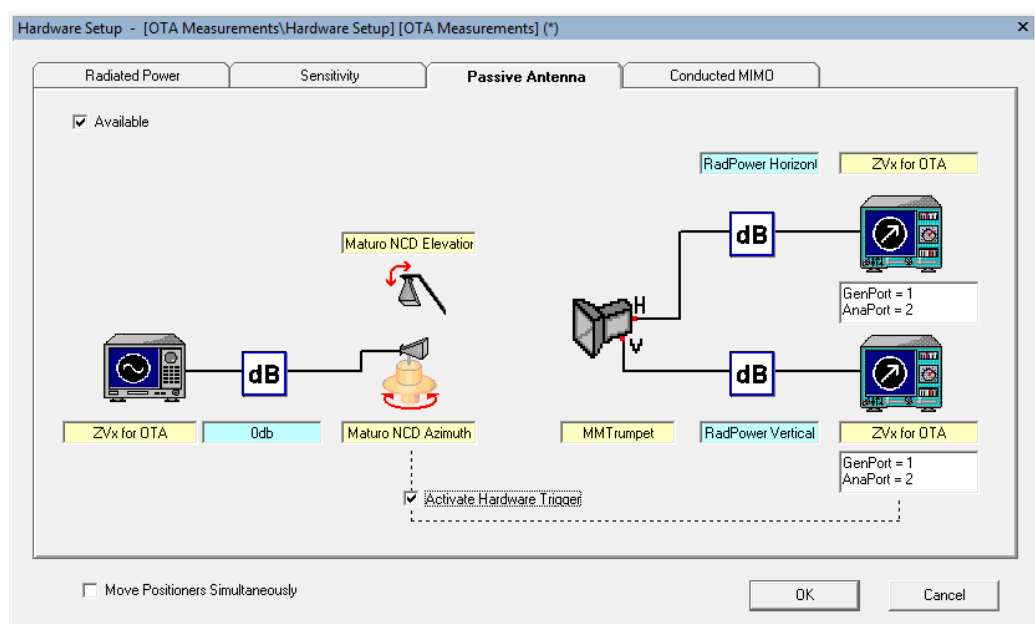


Figure 3-3: Hardware Setup Window

On the left, the transmit device is shown, followed by the transmit path, positioner, probe antenna, and receive paths and devices for horizontal and vertical polarization.

1. First, select the correct positioners by right clicking the positioner icons and selecting the previously defined Maturo NCD positioners for elevation and azimuth.
2. Right click the first receive device (top right) and select "ZVx for OTA". Repeat for the second receiver. "ZVx for OTA" is automatically set as transmit device.
3. Left click both receive devices and select "Show Setup..." and define the generator and analyzer ports. The generator port has to be identical for both polarizations, with different analyzer ports for horizontal and vertical polarization. The defined ports have to match the real ports used to connect the ZVA to the ATS1000 connectors (c.f. Chapter [Chapter 2, "Physical Setup: ATS1000 and ZVA"](#), on page 6).

Note: Make sure that the polarizations are set up to correctly match the used ports at the measurement device.

Finally, the paths have to be defined. The physical setup consists of a single TX path from the ZVA to the DUT and two receive paths for both polarizations. While the different paths can be measured individually, a single calibration routine is used here for simplification. If the input power to the DUT must be known or an active DUT is used, this simplification may not be applicable.

1. Right-click the TX path (on the left) and select "<new path>".
2. Type a name for the new path. As the path is set to constant 0 dB, type *0dB* and click "OK". The new path is created and by default features a constant attenuation of 0 dB. Consecutively, the physical TX and RX paths are calibrated to the RX paths in AMS32.
3. To prepare the RX paths for calibration, create paths for horizontal and vertical polarization by right-clicking each path icon and selecting "<new path>".
4. Left click the path icon to open up the path dialog window, select "Table", click "Add Table" and close the window with "OK".
5. Repeat for the other polarization path. Now, both polarizations have an empty attenuation table attached to the RX paths for both polarizations.
6. Close the Hardware Setup by clicking "OK" and **save** the setup.

Now, the setup is created and known to AMS32. In the next step, the missing the calibration data which will be saved to the empty path tables in the next step.

4 Calibration of Measurement Setup

The first action with for a new hardware setup (e.g. after changing the cables or instruments) is the calibration. Given the combination of high required precision for both electrical and mechanical parameters of the setup, correct calibration is the key for precise antenna measurements. After calibration, the calibration is valid until the actual physical hardware setup is changed. Switching the DUT does not have any influence on the calibration data.

The required calibration routine depends on the exact setup and measurement type to be performed. Examples for different measurement setups are the usage of active or passive antennas, CW or modulated signals, required dynamic range. Also the measurement quantities of interest change the required calibration routine: are absolute values of interest or is only a relative directivity required?

At the most basic level, calibrations can be split into two categories: absolute *pathloss calibration* for far field measurements and relative *channel balance calibration* for near field measurements. The pathloss calibration is used to establish the absolute path loss values of the system, excluding the antenna used for calibration, for which the exact gain values have to be known. For near field measurements, both vertical and horizontal measurement of the same impinging linearly polarized field by one or the other polarization probe must yield similar results in both magnitude and phase. For dual polarized measurements probes like used in ATS1000, the differences between both polarization therefore have to be measured and stored as channel balance calibration data, including phase information for NF-FF transformation.

In the following sections, the basic calibration procedure for passive antenna measurements with CW signal is described. For highest flexibility in later measurements, the setup is calibrated for absolute path loss including phase information on both paths. Therefore, the calibration data can be used for both far field and near field measurements.

4.1 Setup Physical Setup for Calibration

As done in [Chapter 2, "Physical Setup: ATS1000 and ZVA"](#), on page 6, set the elevation positioner to the top position (0° elevation), and align the phase center of the reference antenna to the rotation center using the laser alignment system. Make sure that the reference antenna polarization is aligned with a major axis of the azimuth table (0°, 90°, 180° or 270°).

4.2 Setup Calibration in AMS32

The path calibration can be started in AMS32 and creates path tables that are used in subsequent measurements. To calibrate the AMS32 hardware setup, a reference antenna has to be used as AUT. The setup is calibrated including the used reference

antenna. Afterwards, the known antenna gain can be removed from the calibration file in AMS32.


As a reference antenna with known gain is used for calibration, the antenna gain over frequency has to be applied in AMS32. To import the gain table of the reference antenna,

1. create a correction table: "File" → "Table open/new" → "Attenuation Correction Table".
2. fill in the values from the reference antenna data sheet.
3. save and close the table.



All correction tables in AMS32 store **attenuation** in dB. Therefore, negate the antenna gain values in the AMS32 "attenuation correction table" to get the attenuation: if the antenna has 20 dB **gain** at 30 GHz, the table must contain *-20 dB attenuation* at 30 GHz.

The calibration process is used to measure and save attenuation and phase data of the paths in the hardware setup.

1. Open the hardware setup. As defined in [Chapter 3, "Virtual Hardware Setup in AMS32"](#), on page 8, each path symbol () must have a path assigned.
2. Double click either the horizontal or vertical path symbol.
3. Select the single table entry and click "Calibrate..."

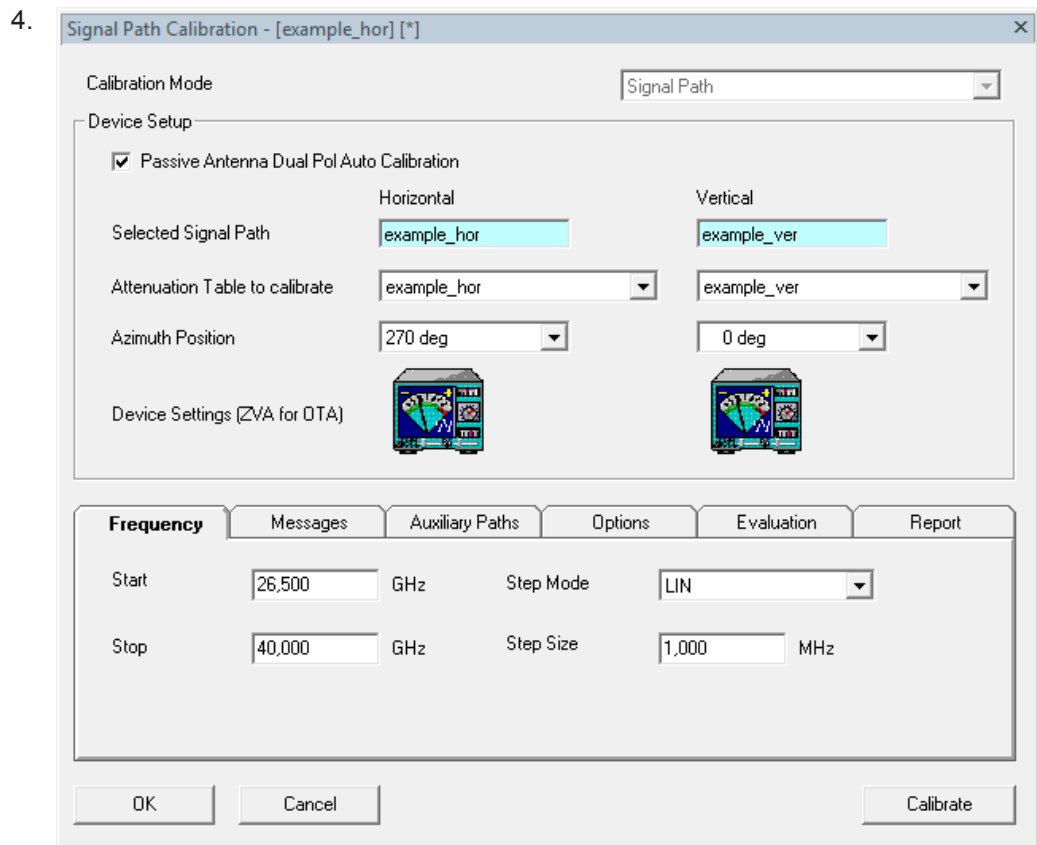


Figure 4-1: AMS32 Calibration Window

In the signal path calibration window, select "Passive Antenna Dual Pol Auto Calibration" to calibrate both polarizations at once.

AMS32 reads the horizontal and vertical path from the hardware setup file. Make sure to select the correct attenuation table for each signal path.

5. Select the azimuth position of the reference antenna to align with the horizontal and vertical probe antenna. The polarization of the ATS1000 probe antenna is given in Figure 2-3. Note the azimuth angles, at which the reference antenna is aligned with the horizontal and vertical polarization of the probe antenna. For the standard gain horn, set the azimuth position to 270 deg and 0 deg for horizontal and vertical polarization, respectively.

Note: For NF-FF transformations, especially make sure that the direction of polarization (E-field vector direction) is correct. As a reference, use the antenna feeds of the probe antenna to define a fixed "direction", for example *the polarization points in direction of the feed cable*. If the probe antenna feed points towards azimuth 270° (for horizontal) and azimuth 0° (for vertical), use exactly these values in AMS32 for calibration. Using 90° (for horizontal) instead of 270° together with 0° for vertical would cause an inverted direction and therefore wrong transformation results.

Note: Remember to set the elevation arm back to 0° (top) for calibration.

- Under "Frequency", set start and stop of the calibration range to 26.5 GHz and 40 GHz, respectively, to fit the reference antenna's frequency range.

Note: Only calibrate the frequency range for which gain data of the reference antenna are available.

- Select linear "Step Mode" ("LIN") and set step size to 1 MHz.

Note: At least 3 measurement points per falling slope of the phase are required to correctly interpolate the phase. Given the frequency and maximum travel time of the signal through the complete setup from generator to analyzer, $e^{-j2\pi ft}$ can be used to determine the maximum step size to fulfill the time convention.

- Under "Options", select the created reference antenna correction table as "Antenna Factor to subtract". As the TX path is set to 0 dB, a normalization table is not required. Select an empty table (all 0 dB for the required frequency range). If no such table exists, create a table, add two rows for the start and stop frequency and set the attenuation to 0 dB.

- Click "Calibrate".

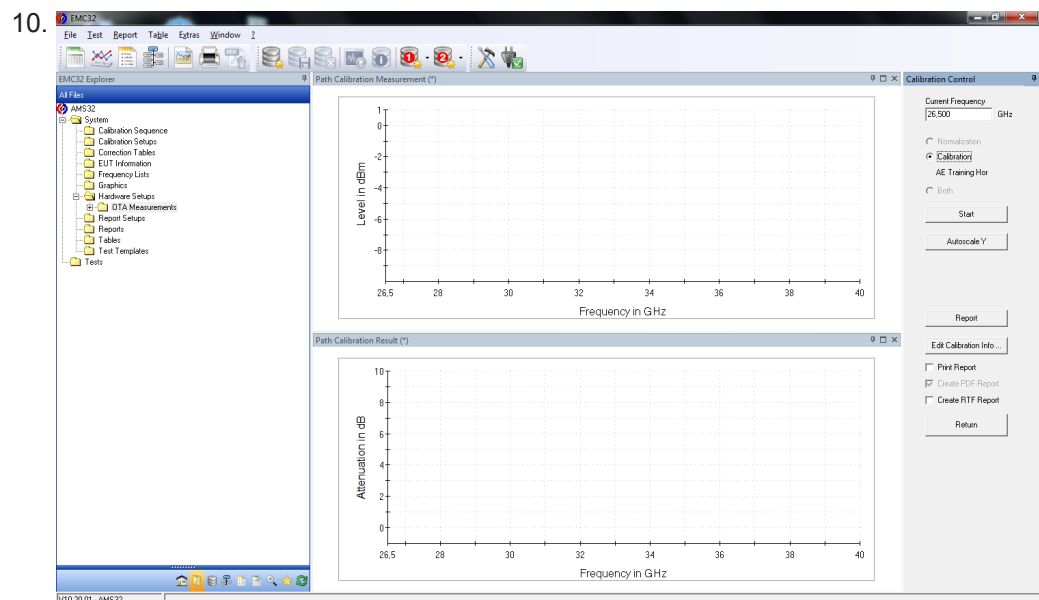


Figure 4-2: AMS32 Calibration View

Make sure, that the "Calibration" radio button is selected. Then, start the calibration process. AMS32 positions the reference antenna to the defined azimuth positions and measure the paths. If requested to overwrite the path tables, click "yes". When the calibration is finished, click "Return" and close the "Signal Path Calibration" and "Signal Path" windows.

With the calibration process finished, both horizontal and vertical paths are now successfully calibrated.

5 Measurement of a mm-Wave DUT


With a fully calibrated setup, accurate antenna pattern measurements can be performed.


Based on the hardware setup as defined in chapter [Chapter 3, "Virtual Hardware Setup in AMS32"](#), on page 8, a test template defines the test parameters.

1. Create a test template "OTA Auto Test": *File* → *Test Template open/new*.
2. Select "Radiated Power Passive Antenna" as "OTA Test Method".
3. In "General Settings", select the hardware setup created in chapter [Chapter 3, "Virtual Hardware Setup in AMS32"](#), on page 8.
4. In "Measurement Settings", define an appropriate "IF Bandwidth" (e.g. 1 kHz) and select phase measurement.
5. The "Loop Settings" define the actual test parameters like frequency, polarization, and azimuth and elevation range. For azimuth, continuous movement can be activated for a significantly increased measurement speed in the *stepped-continuous mode*.
6. Close the window by clicking "OK" and save the test template.

The created test template can be used for multiple tests with fixed parameters, e.g. to compare different DUTs or design iterations of the same DUT. The template can also be adjusted or duplicated for measurements with slightly different parameter sets.

For every test, the created test template is used as a starting point:

1. Create an "OTA Measurement" and select the test template from the menu bar *Test* → *Test (Sequence) open/new* or right-click the test template in the "AMS32 Explorer" under *Test Templates* → *OTA Auto Test* and select "New Test Direct".
2. In the test mode, start the measurement by clicking the "Play" button .

Note: Make sure that the required devices are in physical mode (connected) before starting a new test by clicking  or manually checking the device list.

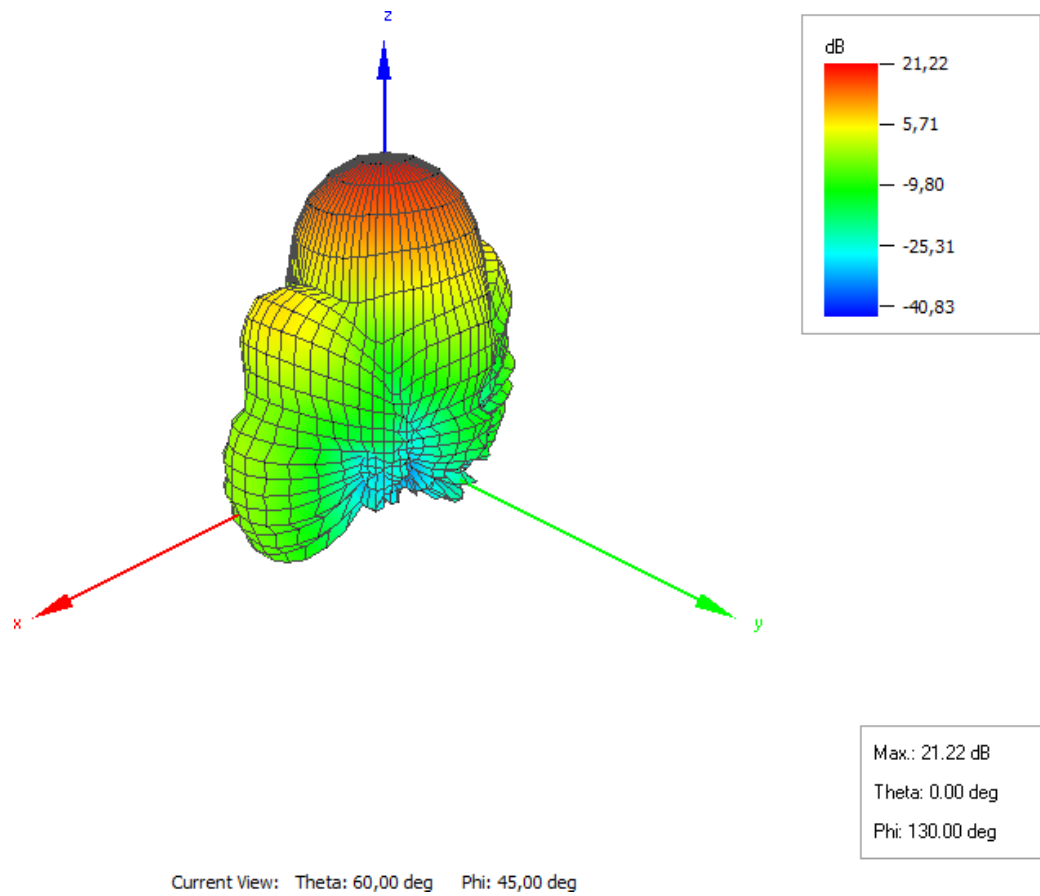


Figure 5-1: 3D Antenna Pattern in AMS32

When the measurement is finished, the recorded pattern is automatically opened in the 3D view, as shown in Figure [Figure 5-1](#). Under "Test" → "OTA Analysis", different analysis can be started based on the loaded test results. This includes different 3D and 2D pattern visualizations.

6 Near Field to Far Field Transformation in AMS32

6.1 Transforming the Measurement Data

If a test is open in AMS32, either by loading a saved test or by finishing a new measurement, OTA NF-FF evaluation can be accessed from the main menu entry *Test* → *OTA NF-FF Evaluation...* Depending on the installed NF-FF transformation algorithms and the activated options, a selection window for the algorithm to use are displayed.

1. In the "Near Field - Far Field Transformation" window (s.f. Figure [Figure 6-1](#)), some input data is required for the transformation algorithm. Depending on the algorithm, the required input parameters vary. The built-in AMS32 help can always be accessed using the **F1** shortcut on the keyboard for further information about the parameter. For all algorithms, define the size of the DUT, respectively the size of a primitive shape that completely surrounds the DUT. Also, define the angular step size of the transformed FF data.

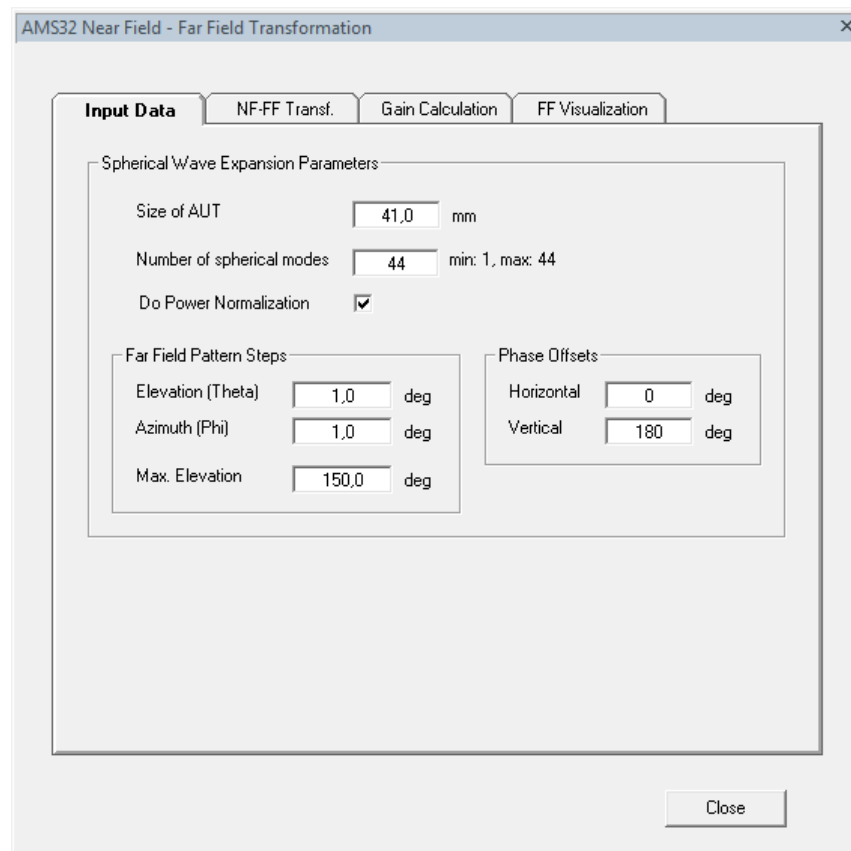


Figure 6-1: AMS32 Near Field - Far Field Transformation Window for Spherical Wave Expansion

2. In the "NF-FF Transf." tab, select the frequencies for which to transform the near field data to far field.

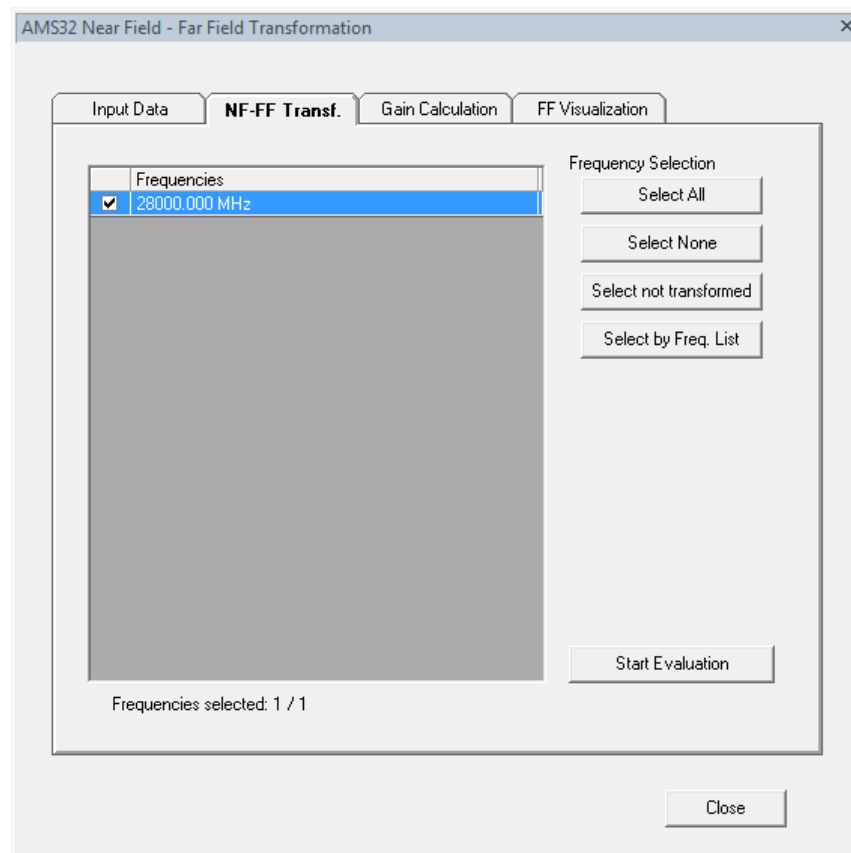


Figure 6-2: AMS32 frequency selection for NF-FF transformation

3. Start the transformation by clicking "Start Evaluation".
4. When the evaluation is finished, select the "FF Visualization" tab and select the transformed frequency.

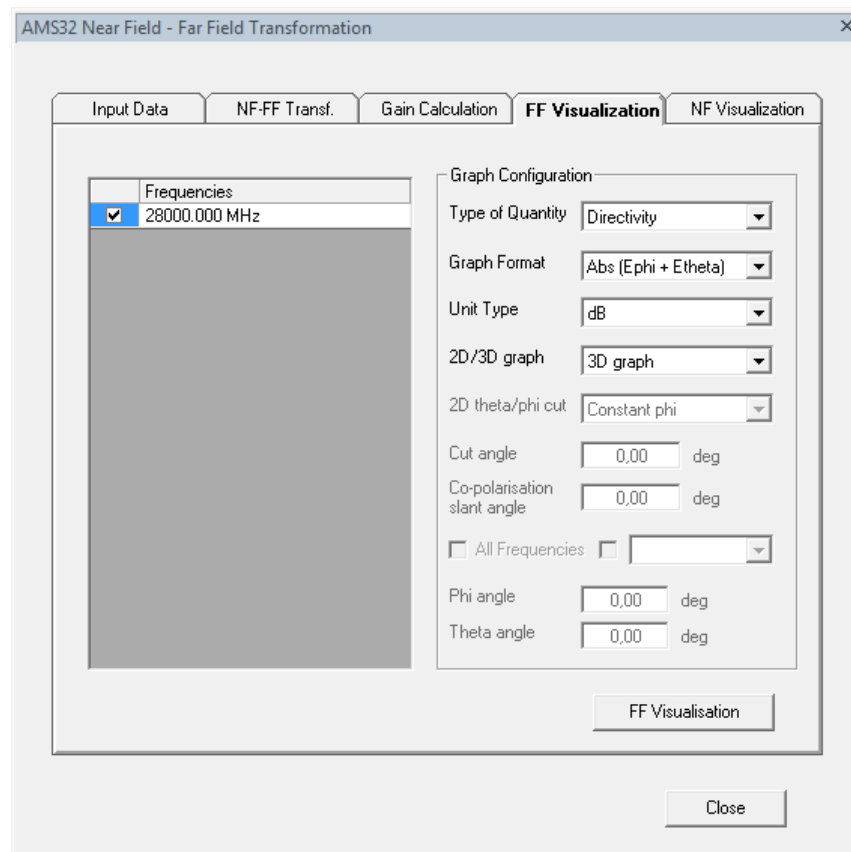


Figure 6-3: AMS32 far field visualization after NF-FF transformation

5. Set the "Graph Configuration" parameters as shown in Figure [Figure 6-3](#). Besides 3D
6. Click "FF Visualization".

The transformed data is visualized and can be used as any other graph in AMS32.

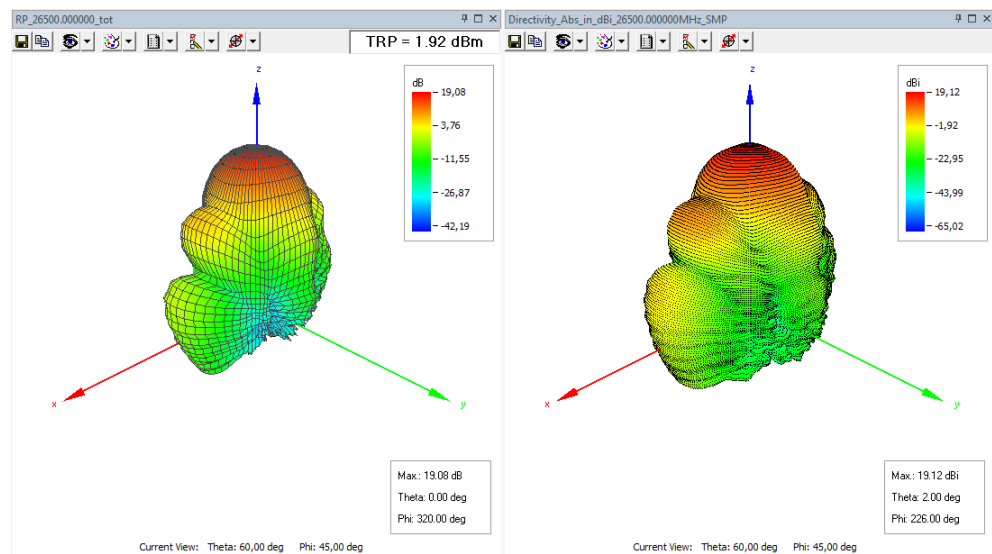


Figure 6-4: AMS32 near field and transformed far field pattern.

6.2 Gain Calculation

The output quantity of transformation is always the directivity in far field. Meaning, that absolute (path loss) calibration is not required for only near field measurements. To evaluate the far field gain, a gain calculation has to be performed. Using the gain calculation, the efficiency of the antenna is taken into account, either by directly supplying the efficiency information or by using the substitution technique with a reference antenna measurement. The "Gain Calculation" tab can be accessed in the "Near Field - Far Field Transformation" window.

To perform the gain calculation for a DUT, normally, the substitution technique with a reference antenna measurement is used.

1. Enable the "Gain Calculation" checkbox and select "Substitution Technique".
2. Select the reflection coefficient file for the DUT and the feeding cable from measurement instrument to DUT.
3. Select the folder, in which the reference antenna measurement test folder is located. Do not directly select the reference antenna test folder, but the parent folder in which multiple reference antenna tests can be stored, e.g. covering different frequency ranges.
4. Click "Do Gain Calculation" to start the process.
5. After successful gain calculation, the "Gain" measurement quantity after transformation can be selected for visualization.

7 Ordering Information

Designation	Type	Website
OTA Shielded Chamber	R&S®ATS1000	https://www.rohde-schwarz.com/product/ats1000
Network Analyzer	R&S®ZVA	https://www.rohde-schwarz.com/product/zva
Measurement Software	R&S®AMS32	https://www.rohde-schwarz.com/software/emc32/

8 Rohde & Schwarz

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

The electronics group ranks 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.

Sustainable product design

- Environmental compatibility and eco-footprint
- Energy efficiency and low emissions
- Longevity and optimized total cost of ownership



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