Application Note

BASIC RADAR MEASUREMENTS WITH THE R&S®AREG800A

Configuring the R&S®AREG800A with mmWave frontends and the R&S®QAT100

Products:

- ► R&S®AREG800A
- ► R&S®AREG8-24/81/81W
- ► R&S®QAT100

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https://www.rohde-schwarz.com/appnote/1GP149

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Contents

1 Overview

The R&S®AREG800A is a powerful automotive radar echo generator. It is capable of over the air stimulation of automotive radar sensors with multiple static or dynamic radar objects. It can either be paired with R&S®AREG8 millimeter wave (mmWave) frontends for RF performance testing, or with the R&S®QAT100 antenna array for simulating ADAS scenarios.

This application note shows how to configure the R&S®AREG800A with either R&S®AREG8-24/81 remote millimeter wave frontends or the R&S®QAT100 advanced antenna array. It covers the instrument setup, connections, and configuration necessary to perform static object simulation using a basic setup.

This document is meant to provide a starting point for new users, showing how to perform the necessary steps to get going with radar object generation. After a brief introduction on the working principle of the R&S®AREG800A and its user interface, this application note runs through the configuration steps for the mmWave frontends to simulate static objects. Later, the configuration steps are extended to cover the R&S®QAT100 antenna array as well. Setups with more than one frontend or radar sensor, and dynamic object simulation are not covered by this document.

The abbreviation “AREG” in this application note refers to the automotive radar echo generator R&S®AREG800A. The abbreviation “QAT” refers to the advanced antenna array R&S®QAT100.

2 Introduction

A radar echo generator simulates artificial radar objects for a radar under test (RUT), making it possible to run tests using a compact lab setup instead of a large chamber or test range. It is a valuable tool to use during the whole development cycle of an automotive radar sensor and its associated systems. Rohde&Schwarz offers the R&S®AREG800A as a flexible and scalable solution to generate objects for both static and dynamic test scenarios.

The R&S®AREG800A is paired with either a millimeter wave (mmWave) frontend or the advanced antenna array R&S®QAT100. The frontend receives and converts the radar signal to a suitable intermediate frequency (IF). The AREG base unit then applies a signal delay, Doppler shift, and attenuation corresponding to the distance, radial velocity, and radar cross-section (RCS) of the simulated object (see Figure 1). The frontend upconverts the modified signal and radiates it back to the RUT. The QAT allows to transmit the signal back at a selectable angle, enabling the simulation of dynamic object azimuth.

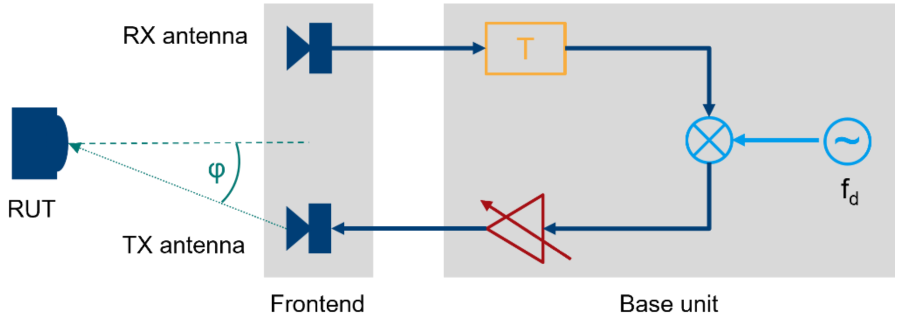

Figure 1: Operating principle of the radar echo generator, consisting of a frontend and the AREG800A base unit. The base unit generates an echo by applying a delay (yellow), Doppler shift (blue), and attenuation (red). The placement of the TX antenna with respect to the RUT determines the object azimuth φ.

In the AREG, the tasks of simulating the delay, Doppler, and RCS are managed by processing modules. A single AREG base unit can hold up to four modules, labeled A through D (see Figure 2). For bandwidths of 1 GHz and 2 GHz, each module provides two IF channels, e.g., module A can independently simulate objects on channels A1 and A2. Each channel consists of an RX input and a TX output. If the full 5 GHz bandwidth is needed, only the first IF channel of each module is available.

In total, the AREG supports up to eight IF channels, enabling the use of multiple frontends on a single AREG. This allows the stimulation of multiple sensors at once, or to realize a higher field-of-view (FOV) by using multiple QATs in front of a single sensor.

Figure 2 shows the back side of the AREG, with the four modules A through D marked. Each module has eight SMA connectors, providing an RX/TX pair for two IF channels, as well as auxiliary connectors to access the IF signal for use with external instruments.

Figure 2: Back side of the AREG800A, with modules A-D providing two IF channels each. Each IF channel consists of an RX input and a TX output. Auxiliary connectors provide access to the IF signals for connecting external instruments.

3 AREG800A GUI Concept

The following graphic illustrates the GUI concept of the AREG. The *System Config* tile at the bottom left is used to configure general instrument functions like network settings and remote access. The *Operation Setup* tile gives access to the different operating modes of the instrument. The *Measurement Setup* tile configures and maps the connected frontends to radar sensors. Once everything is set up, the required measurement is started in the top left *Radar Objects* tile.

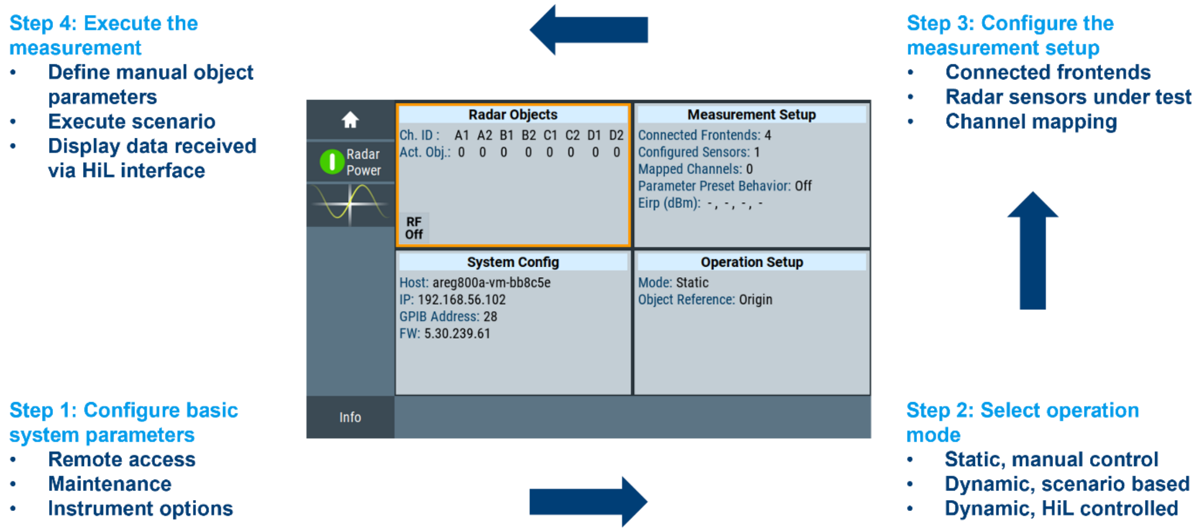

Figure 3: Overview of the AREG GUI concept showing the home screen and the associated configuration steps.

4 AREG800A with the AREG8-24/81 mmWave Frontend

The AREG8-24/81 mmWave frontends can simulate up to eight objects per frontend. The AREG supports up to four mmWave frontends simultaneously, with each frontend occupying one AREG IF channel.

There are three versions of the mmWave frontend: the AREG8-24 covers the 24 GHz to 24.25 GHz band (250 MHz instantaneous RF bandwidth). The AREG8-81 and AREG8-81W both cover the 76 GHz-81 GHz band. The AREG8-81 has 4 GHz instantaneous RF bandwidth, while the AREG8-81W supports 5 GHz of instantaneous RF bandwidth.

All mmWave frontends are available with either a monostatic antenna (S) or bistatic antenna (D) configuration. While the bistatic frontends offer better TX-RX isolation, they are not suitable for MIMO radars. If the RUT is a MIMO radar, a mmWave frontend with the “S” suffix indicating the monostatic version should be used.

The following sections are structured as a step-by-step guide on connecting and configuring a single mmWave frontend.

4.1 Connecting the Frontend

Each frontend is connected to the AREG via a control cable (connectors labeled *CTRL*) and two IF cables with SMA connectors. The frontends do not support hot plugging when the AREG is powered on.

To connect the frontend, plug the control cable into the *CTRL* connectors at the frontend and at the back of the AREG. Make sure the connectors are fully inserted and latched. The RX IF cable connects the *RX IF Out* connector of the frontend with the *RX IF In* connector at the back of the AREG. The *TX IF Out* of the AREG is connected to the *TX IF In* of the frontend.

Figure 4 shows a setup where the mmWave frontend is connected to the A1 IF channel of the AREG. All examples in this document will refer to this setup. Once all frontend connections are made, power on the AREG.

Figure 4: Diagram showing IF signal and control connections for a mmWave frontend connected to the AREG A1 IF channel.

4.2 Selecting the Radar Band

The radar band f_{RF} in which the AREG operates is determined by the frontend center frequency f_{FE} and the AREG system bandwidth B:

$$f_{\mathrm{RF}} = f_{\mathrm{FE}} - \frac{B}{2} \dots f_{\mathrm{FE}} + \frac{B}{2}$$

The frontend center frequency f_{FE} is set in the *Measurement Setup* >> *Configuration* >> *Frontend Config* tab shown in Figure 5.

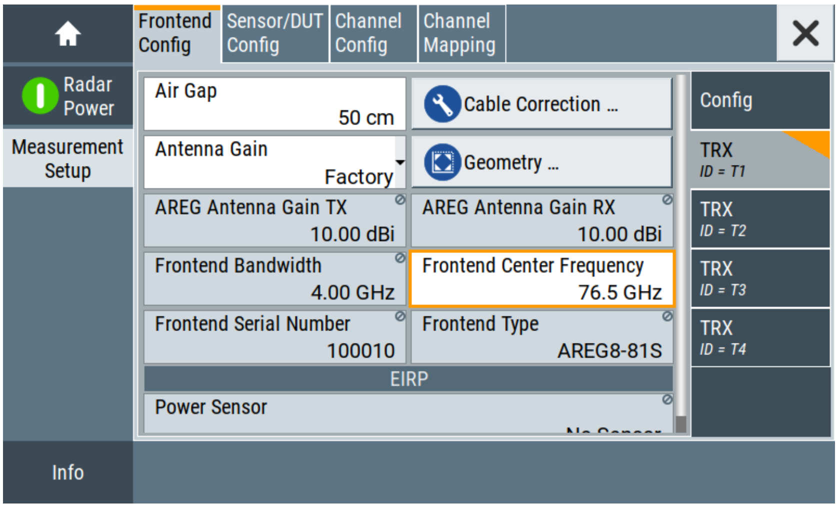

Figure 5: mmWave frontend configuration dialog of the AREG800A, with the frontend set to a center frequency of 76.5GHz.

The AREG system bandwidth B depends on the bandwidth setting of the AREG module that the frontend is connected to. The bandwidth of each AREG module can be individually set to 1 GHz, 2 GHz, or 5 GHz in the *Operation Setup* >> *Bandwidth Config* tab shown in Figure 6.

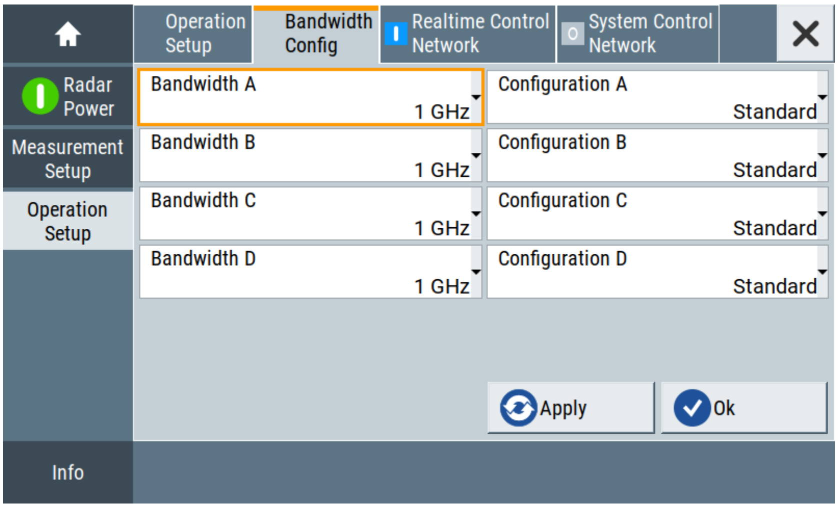

Figure 6: Bandwidth configuration dialog of the AREG800A, with all four AREG digital boards set to 1GHz bandwidth mode.

Only the AREG8-81W frontends support the full 5 GHz instantaneous bandwidth of the AREG module. With all other frontends, the maximum AREG system bandwidth B is limited to 4 GHz (AREG8-81) and 250 MHz (AREG8-24). The maximum instantaneous frontend bandwidth is shown in in the *Frontend Config* tab (see *Frontend Bandwidth* field in Figure 5).

In the *Bandwidth Config* dialog (Figure 6), choose a bandwidth setting that is equal or greater to the bandwidth that is used by the radar sensor. Lower bandwidths improve the RF performance of the instrument. The frontend center frequency f_{FE} does not have to correspond to the center frequency of the radar sensor itself. However, the signal of the radar sensor should fall within the selected radar band f_{RF}.

Example 1: A frontend center frequency of 76.5 GHz, and an AREG module bandwidth of 1 GHz is chosen as shown in Figure 5 and Figure 6. The AREG now operates in the 76-77 GHz radar band.

Example 2: A frontend center frequency of 79 GHz and an AREG module bandwidth of 5 GHz is chosen. However, the AREG8-81 frontend limits the AREG system bandwidth to 4 GHz. Therefore, the AREG operates in the 77-81 GHz radar band.

4.3 Configuring Setup Parameters

Two other important setup parameters are found in the frontend configuration dialog (Figure 5):

- Airgap: this is the distance between the frontend waveguide input (excluding the antenna) and the RUT. The airgap introduces additional signal delay and attenuation, which the AREG compensates internally. Therefore, the values for range and RCS defined in the user interface are the values the RUT will see.
- Cable correction: the IF cables also introduce additional delay and attenuation that needs to be compensated. The mmWave frontend comes with a set of factory supplied IF cables. The correction values for these cables are stored on the frontend and can be applied by selecting the *Factory* option in the cable correction dialog. If third party cables are used, custom delay and attenuation values for each cable can be set. Touchstone (s2p) files of the cables can also be imported.

4.4 Configuring Sensor Parameters

To calculate signal processing parameters, the AREG needs information about the RUT. These settings are independent from the radar band settings discussed in Section 4.2. As the AREG can stimulate multiple radar sensors at once, more than one sensor can be defined. Each sensor has its own settings. Figure 7 shows the sensor configuration tab for a single sensor.

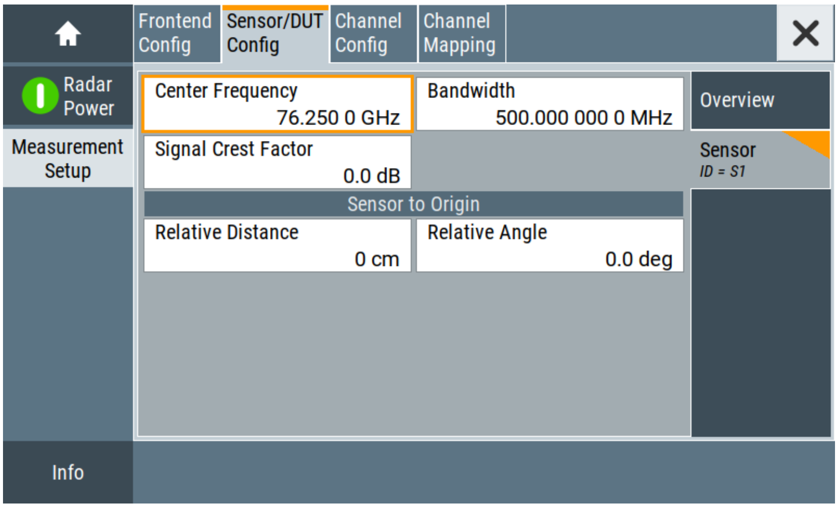

Figure 7: Sensor settings dialog of the AREG800A, showing the settings for a sensor signal with 76.25GHz center frequency and 500MHz bandwidth.

The following settings must be configured in the sensor settings dialog:

- Center Frequency: should be as close as possible to the actual center frequency of the RUT. It is used to calculate, e.g., Doppler shift for a given Doppler speed. It does not have to correspond to the frontend center frequency configured in 4.2.
- Sensor Bandwidth: bandwidth of the sensor signal. Used to calculate, e.g., instrument frequency response correction.

Example: The sensor uses a signal with a bandwidth of 500 MHz and center frequency of 76.25 GHz. The sensor settings should be set to these values (see Figure 7). However, we can keep the frontend settings as discussed in Section 4.2 (frontend center frequency of 76.5 GHz and AREG module bandwidth of 1 GHz), because the radar signal is within the 76-77 GHz radar band that the AREG covers with these settings.

4.5 Mapping the Frontend

Since there can be multiple frontends connected to the AREG, the instrument must be aware which frontend is connected to which AREG IF channel. Each frontend is also assigned to a RUT. The assignment is performed in the *Channel Mapping* tab shown in Figure 8.

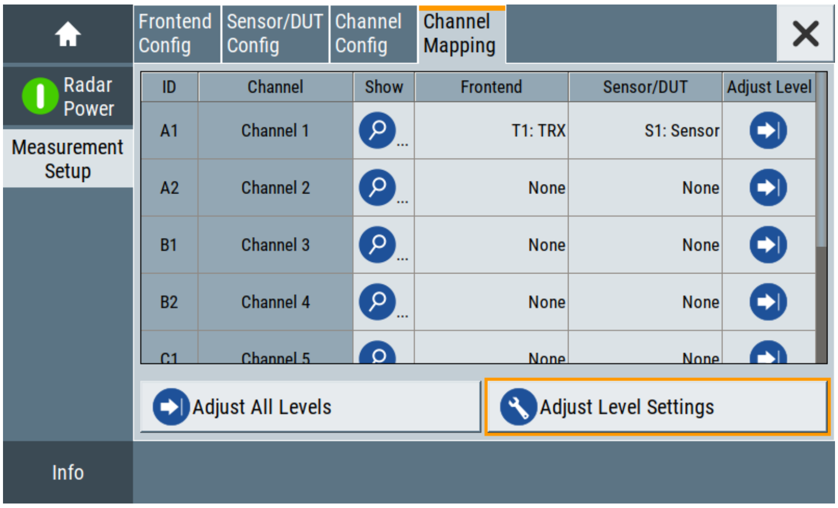

Figure 8: Channel mapping dialog of the AREG800A with a single mmWave frontend and radar sensor mapped to channel A1.

Each channel is identified by its *ID* (AREG module + channel number) and a user defined channel name. The mapping is performed by selecting one of the previously configured frontends and RUTs from the *Frontend* and *Sensor/DUT* fields.

In the earlier sections, we have configured a single mmWave frontend and RUT. Figure 8 shows them mapped to the IF channel A1 of the AREG.

As a last step, the adjust level function must be run while the radar sensor is transmitting. The adjust level function sets the RX input gain to a value that enables optimum dynamic range on the receive side of the AREG. Adjust level should be run when the RF settings on the AREG are changed, and every time the radar output power changes. If the adjustment results are unstable, increase the observation time in the adjust level settings.

After the adjust level procedure, a green radar power indicator on the left side of the AREG display should indicate an optimum input power level. If the indicator turns yellow or red, the input power level is either too low or too high. While this does not prevent the AREG from simulating an object, the quality of the simulated echo signal may be worse.

4.6 Enabling Static Objects

The instrument configuration is now complete, and objects can be enabled in the *Radar Objects >> Configuration* dialog shown in Figure 9. Each mmWave frontend supports up to eight objects with individual range, Doppler, and RCS settings. As the azimuth of the objects is determined by the position of the frontend antenna in relation to the radar sensor, all objects from a single frontend will have the same azimuth.

An object can be enabled by setting its state to *On*. All changes in range, Doppler speed and RCS are applied immediately.

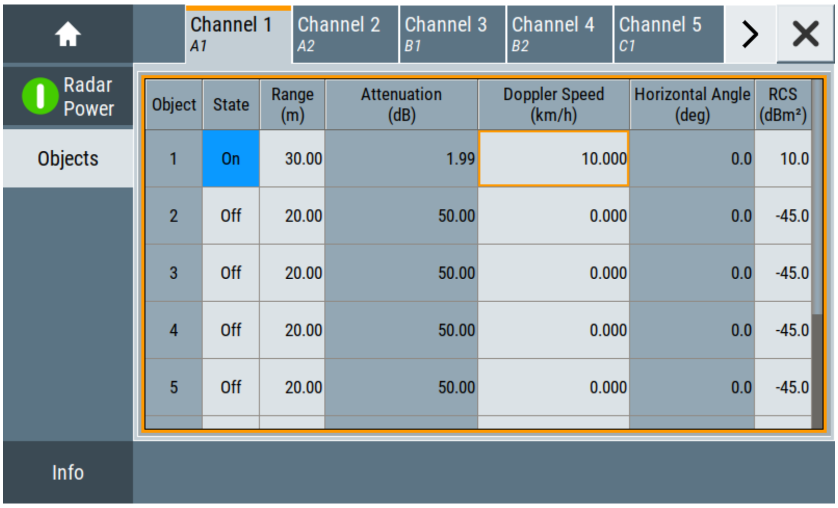

Figure 9: Object configuration dialog, with one enabled object at 30m distance, 10km/h radial velocity, 10dBsm RCS.

There are two modes for controlling the object signal power: Keeping the signal attenuation constant over range or keeping the RCS constant over range. This behavior can be changed in the unit dialog (*Measurement Setup* >> *Units* >> *Keep Constant*).

In the *Keep Constant* >> *Attenuation* mode, object attenuation will stay constant, regardless of object distance. Simulated objects will have the same power level regardless of range.

In the *Keep Constant* >> *RCS* constant mode, objects will have a fixed RCS, and the object attenuation is calculated according to the radar equation. This results in an object experiencing higher attenuation at longer distances.

5 AREG800A with the QAT100 Frontend

The R&S®QAT100 is an electronically switched antenna array. Compared to the mmWave frontends, the QAT allows the simulation of the object azimuth angle without mechanical movement of the frontend. This makes the frontend ideal for simulating dynamic scenarios. For azimuth simulation, it uses a row of ninety-six pairs of receive and transmit antennas. This row is divided into four equally long segments A through D (see Figure 10). Each segment is capable of simulating one object at a time, for a total of up to four objects per QAT. Each segment is connected to an individual AREG IF channel.

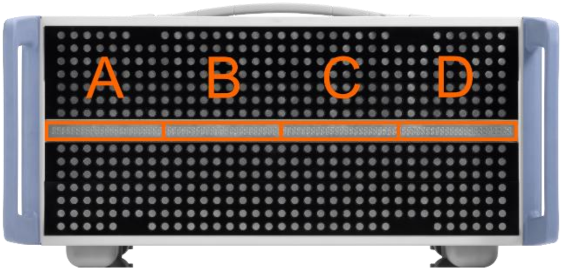

Figure 10: Front face of the QAT, with the four segments A-D marked along the antenna array.

The QAT supports two operating modes: line mode and segment mode. In line mode, a single object can be simulated across all four segments A through D. The IF signal is internally routed to the correct segment. Only one IF channel of the AREG is used. A single object can therefore be placed at any azimuth on the QAT. In segment mode, each of the four segments is connected to one IF channel of the AREG. Each channel can simulate a single object within the respective azimuth limits of the segment.

When simulating azimuth, the airgap determines the field of view (FOV) and angular resolution. The airgap is the distance between the face of the QAT and the RUT. The FOV α and angular resolution $\Delta\alpha$ can be calculated from the airgap distance d, the width of the antenna array (351 mm), and the distance between the individual antennas (3.7 mm):

$$\alpha = 2\tan^{-1}\left(\frac{351\text{mm}}{2d}\right)$$

$$\Delta\alpha = \tan^{-1}\left(\frac{3.7\text{mm}}{d}\right)$$

Table 1 shows typical airgap distances and the resulting FOV and angular resolution.

Airgap d	FOV α	Resolution $\Delta\alpha$
500mm	38.7°	0.42°
700mm	28.1°	0.30°
1000mm	19.9°	0.21°

Table 1: FOV and angular resolution for a single QAT at different airgap distances.

5.1 Connecting the Frontend

Depending on whether the QAT runs in line mode or segment mode, different IF connections are necessary. The line mode, which can simulate a single object, uses the *RX Select* output and the *TX Sum* input on the QAT. They need to be connected to a single AREG IF channel of choice. If the QAT is equipped with the QAT-B5 analog stepped delay line, use the *RX IF Out* and *TX IF In* connectors of the QAT-B5 module instead.

Figure 11 shows an exemplary QAT line mode connection to the AREG A1 IF channel, for both a QAT equipped with the QAT-B5 option (using *RX IF Out* and *TX IF In* connectors), as well as for a QAT without the QAT-B5 option (using *RX Select* and *TX Sum* connectors).

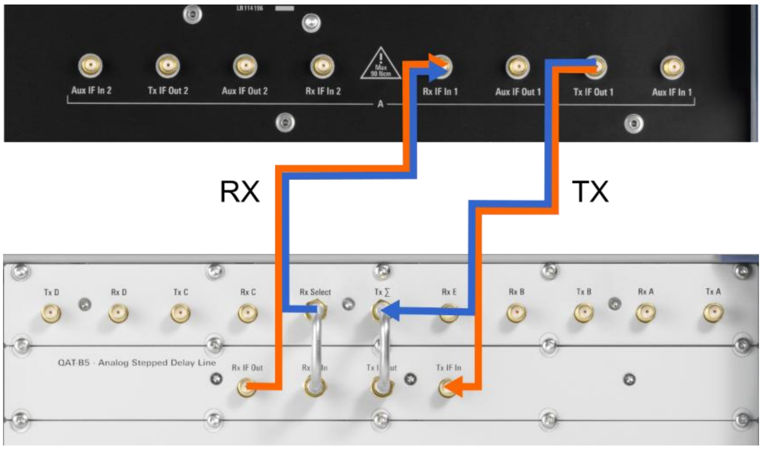

Figure 11: AREG IF channel A1 connected to a QAT in line mode. Orange connections for a QAT with QAT-B5 option, blue connections for a QAT without QAT-B5 option.

In segment mode, each segment is connected to an individual AREG IF channel. To simulate four objects, an AREG will need four IF channels. Two processing modules are necessary for such a setup.

Figure 12 shows an exemplary QAT segment mode connection of the AREG A1 IF channel to the QAT segment A. The remaining segments must be connected in the same fashion to other AREG IF channels.

Figure 12: AREG IF channel A1 connected to QAT segment A in segment mode.

Table 2 shows a complete example of all IF connections necessary for both line mode and segment mode. Different AREG IF channel/QAT segment combinations can be chosen as the connections are later set in the *Channel Mapping* dialog of the AREG by the user. Connections are always “RX to RX” and “TX to TX”.

Unused RX connectors at the back of the QAT should be terminated with 50 Ohm terminations.

Mode	Connections					
	RX Connections			TX Connections		
	QAT		AREG	QAT		AREG
Line mode (Single)	RX Select or RX IF Out	↔	Module A / RX IF In 1	TX ∑ or TX IF In	↔	Module A / TX IF Out 1
Segment mode (Multiple)	RX A	↔	Module A / RX IF In 1	TX A	↔	Module A / TX IF Out 1
	RX B	↔	Module A / RX IF In 2	TX B	↔	Module A / TX IF Out 2
	RX C	↔	Module B / RX IF In 1	TX C	↔	Module B / TX IF Out 1
	RX D	↔	Module B / RX IF In 2	TX D	↔	Module B / TX IF Out 2

Table 2: Exemplary IF connections between AREG and QAT for line mode (single segment) and segment mode (four segments).

5.2 Controlling the QAT100A

The QAT is controlled by the AREG via an Ethernet connection. There is no need for the user to make manual inputs on the QAT. The QAT must be connected to LAN port or the System Control port of the AREG.

Connecting the QAT to the System Control port directly improves latency and eliminates the need for a network switch if the LAN port of the AREG is used otherwise. To connect the QAT to the AREG via the System Control port, follow these steps:

1. Assign a manual IP address to the QAT. Use the arrow keys on the QAT to navigate to the *Network* settings. Press *Enter* to enter the network settings (see Figure 13). Press the *Enter* key to toggle DHCP off. Exit and enter the network menu again to see the updated (manual) IP address.

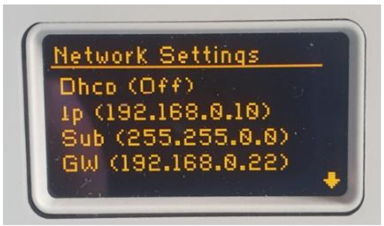

Figure 13: QAT display showing its network settings configured for a static IP address.

2. Configure a static IP address for the System Control port on the AREG. The IP address must match the subnet of the QAT address. The IP address is configured in *Operation Setup* >> *System Control* (Figure 14).

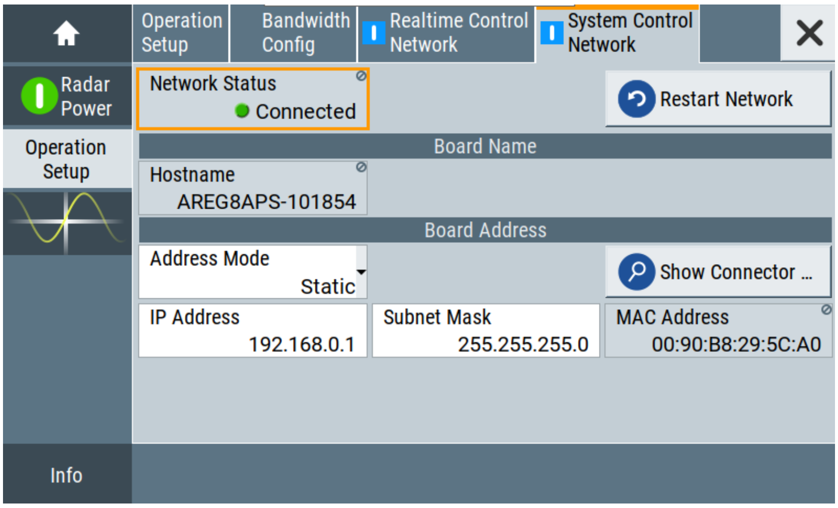

Figure 14: AREG system control port network settings with a static IP address configured.

3. In the *Measurement Setup* >> *Frontend Config* tab, add a QAT by pressing *Add* >> *QAT* (Figure 15).

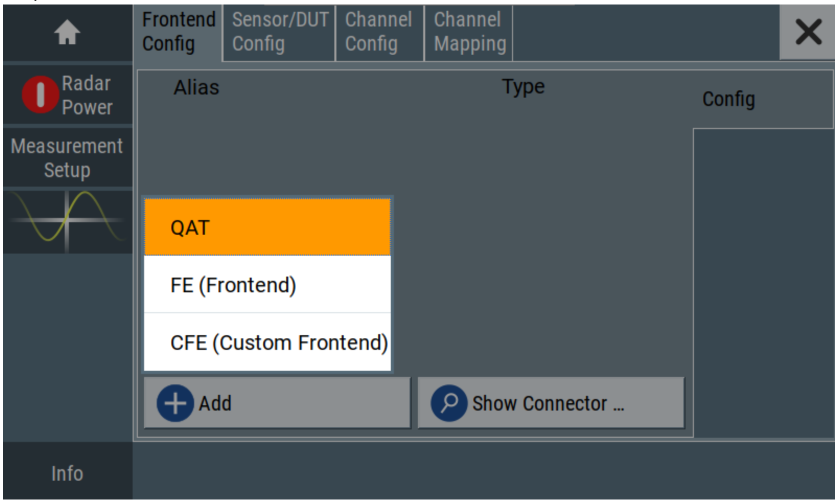

Figure 15: Types of frontends that can be manually added to the AREG.

4. Select the QAT tab on the right to enter the QAT settings (Figure 16). In the *QAT Hostname* field, enter the IP address of the QAT from step 1.

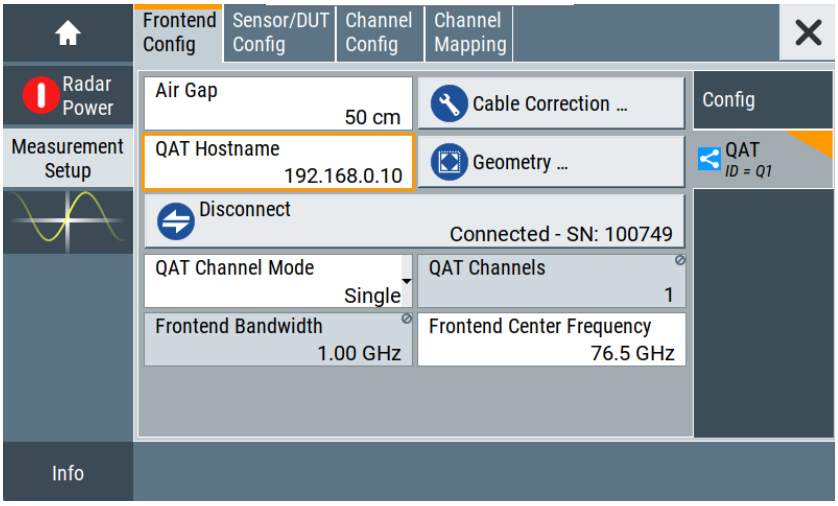

Figure 16: QAT frontend connection and settings dialog.

5. Click the *Connect* button. A blue connection icon in the right QAT tab shows a successful connection. The serial number of the QAT will also be displayed. Figure 16 shows a successful connection to a QAT.

Make sure that the LAN port, system control port, and real time interface are in separate IP subnets. Otherwise, the connection to the QAT will not work.

5.3 Configuring Setup Parameters

The configuration of the airgap and cable correction values is done in the frontend config dialog of the QAT (see *Airgap* field and *Cable Correction* button in Figure 16). The parameters are the same as described in Section 4.3. If the QAT is configured for segment mode, correction entries for all eight cables will be available. Unlike the mmWave frontend, the QAT does not come with factory cables, so no *Factory* correction option is available.

5.4 Selecting the Radar Band

The QAT has a single setting for its frontend center frequency. This setting has three discrete values and determines the radar band that the frontend operates in. The settings and the radar bands they cover are shown in Table 3.

QAT center frequency	Frontend bandwidth	Radar band
76.5 GHz	1 GHz	76-77 GHz
78.0 GHz	4 GHz	76-80 GHz
79.0 GHz	4 GHz	77-81 GHz

Table 3: Radar bands and associated center frequencies supported by the QAT100.

Regardless of the chosen bandwidth and center frequency, the bandwidth of the AREG module (set in *Operation Setup* >> *Bandwidth Config*) is always set to 1 GHz, since the QAT divides the signal by a factor of four internally.

5.5 Configuring Sensor Parameters

Sensor parameters should be configured as described in Section 4.4 above.

5.6 Mapping the Frontend

As with the mmWave frontends, the AREG must be aware which QAT segments are connected to which AREG IF channel. The user is free to choose any AREG IF channel to connect to any QAT segment.

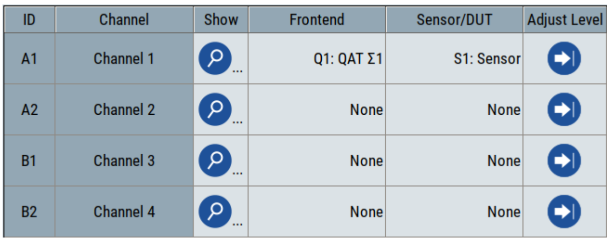

Figure 17: Channel mapping showing the QAT in line mode (QAT Sum) connected to the AREG A1 channel. This configuration corresponds to the line mode setup in Table 2.

When the QAT is in line mode, only the *QAT Sum* frontend needs to be mapped, as only one IF connection is required for the whole QAT (see example configuration in Figure 17). If the QAT is used in segment mode, each QAT segment *A/B/C/D* is mapped to an individual AREG channel (see example configuration in Figure 18).

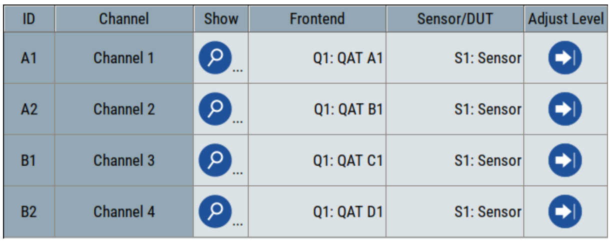

Figure 18: Channel mapping showing the individual QAT segments A, B, C, D connected to the first four AREG channels A1, A2, B1, B2. This configuration corresponds to the segment mode setup in Table 2.

After the mapping is complete, the *Adjust Level* function must be run while the radar is transmitting. The QAT then measures the output power of the radar to calculate the correct power level of the return signal. If multiple QAT segments are mapped, the *Adjust All Levels* button can be used to run the adjust level function for all mapped frontends consecutively.

5.7 Enabling Static Objects

Objects are enabled in the *Radar Objects* >> *Configuration* dialog, with individual range, Doppler, and RCS for each object. Additionally, an azimuth angle can be set. The input field for the azimuth angle shows the azimuth limits for the current segment (see Figure 19).

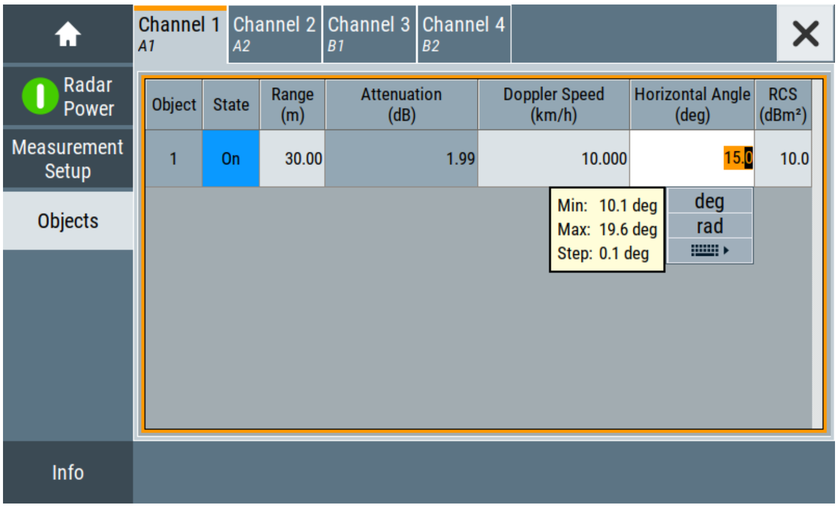

Figure 19: Object settings for a single QAT segment, with the azimuth limits of the segment shown in the input field.

Each of the AREG channels now only simulates one object, as the QAT is limited to one object per segment. In the case of line mode, this means one object per QAT. In the case of segment mode, there will be multiple channels, each with an individual object.

6 Ordering information

Designation	Type	Order No.
Automotive radar echo generator	R&S®AREG800A	1437.4400.02
Advanced antenna array, from 76 GHz to 81 GHz	R&S®QAT100	1341.0004.02
mmWave remote frontends		
76 GHz to 81 GHz, single antenna, 5 GHz RF bandwidth	R&S®AREG8-81WS	1437.9153K02
76 GHz to 81 GHz, two antennas, 5 GHz RF bandwidth	R&S®AREG8-81WD	1437.9160K02

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Data without tolerance limits is not binding | Subject to change

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