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TECHNICAL SPECIFICATION

Short Range Devices (SRD) and Ultra Wide Band (UWB); Measurement techniques and specification for RX conformance tests with target simulator

Reference

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Foreword

This Technical Specification (TS) has been produced by ETSI Technical Committee Electromagnetic compatibility and Radio spectrum Matters (ERM).

Modal verbs terminology

In the present document "**shall**", "**shall not**", "**should**", "**should not**", "**may**", "**need not**", "**will**", "**will not**", "**can**" and "**cannot**" are to be interpreted as described in clause 3.2 of the ETSI Drafting Rules (Verbal forms for the expression of provisions).

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Executive summary

Automotive radars follow regulation for certification testing and the respective definition of limits for compliance. The present document describes new types of test equipment such as radar target generators, anechoic chambers and methods of measurements.

Introduction

Radars are increasingly taking a more important role in the evolving fusion of a variety of sensors to enhance Advanced Driver-Assistance Systems (ADAS) in the direction of Autonomous Driving (AD). Many of these functions go beyond driving convenience are related to safety, either reducing road accidents with all participants or ensuring pedestrian safety. Automotive radar regulations need to improve test coverage and the definition of compliance limits. The former requires a new type of test equipment, the radar echo generator or also called radar target simulator, which enables a radar to be functionally tested in a controlled laboratory environment as it would be operating on the road. The later requires new methods to achieve far-field measurement accuracy in much smaller distances.

With the out phasing of 24 GHz automotive radar implementations in some regions, the present document focusses on the high frequencies, namely 76 GHz to 81 GHz, without limiting measurement procedures and methods to these frequencies. Radars, operating in these frequency bands, require relatively large measurement distances, using the traditional far-field setups, resulting on costly and for some measurements impractical chamber dimensions to achieve reasonable test accuracies. Compact antenna test range concepts for over-the-air testing will go a long way in supporting regulators and the industry to establish the compliance limits required for the modern larger MIMO automotive radar sensors.

At higher frequencies, such as E-Band frequencies where automotive vehicle radar operates today, larger bandwidths, and MIMO Tx/Rx arrays implementations enable improved resolutions to create more sophisticated ADAS/AD functions. Higher integration and number of devices in combination with higher frequencies and larger bandwidths might also require to allow compliance limits to adopt the use of intermediate-frequency test strategies. MIMO technology demands the use of monostatic antennas to enhance the accuracy of angular measurement resolution and resolution.

1 Scope

The present document contains information on radar target simulators and their application for radar tests identified in ETSI EN 303 883-1 [i.1] and ETSI EN 303 883-2 [i.2].

The present document describes measurement setups and approaches for anechoic chambers both far-field and near field-to-far field transforming.

2 References

2.1 Normative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

Referenced documents which are not found to be publicly available in the expected location might be found at https://docbox.etsi.org/Reference/.

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The following referenced documents are necessary for the application of the present document.

Not applicable.

2.2 Informative references

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NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long term validity.

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

[i.1] ETSI EN 303 883-1 (V1.2.1) (02-2021): "Short Range Devices (SRD) and Ultra Wide Band (UWB); Part 1: Measurement techniques for transmitter requirements".

[i.2] ETSI EN 303 883-2 (V1.2.1) (02-2021): "Short Range Devices (SRD) and Ultra Wide Band (UWB); Part 2: Measurement techniques for receiver requirements".

[i.3] Federal Communications Commission § 15.253 (20.09.2022).

NOTE: Available at https://www.gpo.gov/fdsys/pkg/CFR-2013-title47-vol1/pdf/CFR-2013-title47-vol1-sec15-253.pdf.

3 Definition of terms, symbols and abbreviations

3.1 Terms

For the purposes of the present document, the following terms apply:

radar echo generator (REG), radar target simulator (RTS): Are both descriptions for the same type of equipment that can generate synthetic radar echo returns for testing of an actively transmitting radar sensor. This test instruments are specifically designed to test actively transmitting radar sensors according to ETSI EN harmonised standards.

3.2 Symbols

For the purposes of the present document, the following symbols apply:

A_{RTS}	Attenuation within the RTS/REG [in dB]
c_0	Speed of light [in m/s]
D_{Air}	the physical distance between RTS/REG frontend and EUT [in m]
f_c	Centre frequency of the Local Oscillator of the RTS/REG [in Hz]
f_D	Doppler frequency shift
G_{TX_Ant}	Antenna gain of the RTS/REG transmit antenna [in dB]
G_{RX_Ant}	Antenna gain of the RTS/REG receive antenna [in dB]
t_{proc}	RTS/REG processing time [in s]
t_{tof}	Time of flight [in s]
R	distance of the artificial object generated by the RTS/REG [in m]
R_{sim}	Simulated distance of a target [in m]
v_1	Speed of electromagnetic wave in medium 1 [in m/s]

3.3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

5G	Fifth-Generation
AD	Autonomous Driving
ADAS	Advanced Driver Assistance Systems
ADC	Analog Digital Converter
AWG	Arbitrary Waveform Generator
CATR	Compact Antenna Test Range
CW	Continuous Wave
DAC	Digital Analogue Converter
DRFM	Digital Radio Frequency Memory
EUT	Equipment Under Test
FCC	Federal Communications Commission
FF	Far Field
FFT	Fast Fourier Transformation
FMCW	Frequency Modulated Continuous Wave
FODL	Fiber Optical Delay Line
FOV	Field Of View
FSPL	Free Space Path Loss
GUI	Graphical User Interface
I/Q	Inphase/Quadrature phase
IF	Intermediate Frequency
LO	Local Oscillator
LRR	Long Range Radar
MIMO	Multiple Input Multiple Output
mmW	millimetre Wave
MRR	Mid Range Radar
OSI	Open Simulation Interface
RBR	Receiver Baseline Resilience

RBS	Receiver Baseline Sensitivity
RCS	Radar Cross Section
REG	Radar Echo Generator
RF	Radio Frequency
RTS	Radar Target Simulator
RX	Receive
SG	Signal Generator
SRR	Short Range Radar
TX	Transmit
US	United States

4 Overview

4.1 Info

The present document provides practical information and guidance on RTS/REG for compliance tests of Short Range devices such as automotive radars. The applicability of the procedures described in the present document is not limited to EUT covered.

5 Radar Target Simulator (Radar Echo Generators)

5.1 Types

5.1.1 General

There is a variety of Radar Target Simulator/Radar Echo Generator (RTS/REG) solutions available, that range from simple reflectors to complex digital test equipment. This clause describes several types of equipment.

5.1.2 Analog

Analog target simulators apply physical delay lines to delay the incoming electromagnetic wave from the radar and simulates an object in a certain range R_{sim} from the radar, formula (1). The simulated range is the sum of the speed of the electromagnetic wave in air/vacuum (speed of light c_0) multiplied by the time of flight t_{tof} divided by two and the speed in a certain medium (with speed v_1) multiplied by the time within the medium t_{proc} respectively. This includes the time for passing physical distance to the RTS/REG forth and back as well as the internal signal processing time.

$$R_{sim} = \frac{c_0 t_{tof}}{2} + v_1 t_{proc} \tag{1}$$

- R_{sim} Simulated distance of a target [in m]
- c_0 Speed of light [in m/s]
- t_{tof} Time of flight [in s]
- v_1 Speed of electromagnetic wave in medium 1 [in m/s]
- t_{proc} RTS/REG processing time [in s]

To delay the signal Fiber Optical Delay Lines (FODLs) are often used. FODLs are relatively flexible, phase coherent and can create small systems that convert the RF signal of the radar to optical and delay of a certain length. Often an Intermediate Frequency (IF) is used as low frequency signal handling is easier and creates less loss. After delay, the signal is then reconverted to RF and retransmitted to the radar. Some systems are also able to introduce Doppler frequency shift.

FODLs offer constant delay versus frequency, are immune to vibration, are largely resistant to electromagnetic interference, and fiber delays do not radiate energy. Repeatability of simulation, low system cost and time-savings are key advantages. FODLs cannot generate time-variant range-Doppler targets (a target which has a change in range and Doppler over time due to its own dynamics), nor do they offer continuous range settings or arbitrary signal attenuation and gain.

RCS can be simulated by attenuating the radar signal. After considering free space loss and antenna gain (EUT and RTS/REG) the attenuated signal indicates a target with a certain RCS.

Figure 1 shows a simplified sketch of the optical delay line system including Doppler frequency shift f_D.

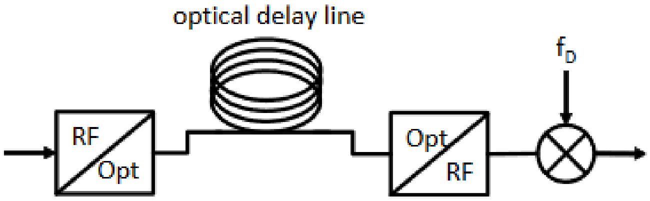

Figure 1: Optical delay line including Doppler frequency shift f_D

5.1.3 Digital

Digital target simulators rely on digital signal processing. The target generator receives an electromagnetic wave from the radar and modifies it digitally to picture the desired scenario. Adding delay on the signal simulates a distance to an object, frequency shift simulates a Doppler shift indicating the velocity of an object, and signal attenuation indicate a certain RCS. In addition, it is possible to add multiple delays, frequency shifts, and attenuation simulating multiple targets.

Often Digital Radio Frequency Memory (DRFM) is used to manipulate the radar signal digitally - down-converting, filtering and digitizing the received RF signal before storing and modifying it. Signals are then reconverted to analogue and mixed to RF frequency using the same Local Oscillator (LO) used for down-conversion. This is important to reduce phase noise. The minimum delay introduced by a DRFM is mainly limited by its ADC and DAC. In addition, signal processing adds a delay to the radar echo signal. Typical minimum range delays range from below 100 ns to below 1 µs. A further consideration is how the analogue RF signal is represented in the digital domain (amplitude, phase, I/Q) and the number of bits, because this is what mainly determines the DRFM's signal fidelity. Figure 2 shows a sketch of a digital representation of an RTS/REG where f_c denotes the carrier frequency of the down converting local oscillator.

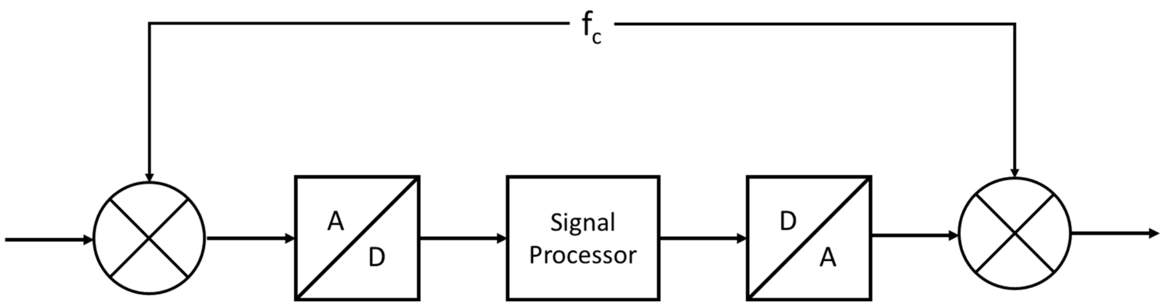

Figure 2: Digital representation of an RTS/REG

5.1.4 Hybrid

Hybrid target generators combine analogue and digital target simulator architectures and reduce the disadvantages of each individual approach. Usually, the analogue technique is used to simulate short distances which is more complex when using a digital target simulator since the required signal processing time limits the distance minimum that can be simulated.

On the other hand, the benefit of the high flexibility of digital target simulators can be used to simulate more complex schemes with multiple targets. Generating a scenario using analogue and digital simulation techniques requires precise synchronization and calibration between both modes.

5.1.5 Frontends

For different test needs, different form factors of target simulators exist. Integrated RF architecture combines the RF frontend as well as signal processing hardware/delay lines in one chassis.

A remote frontend has a separated RF frontend including mixers. Usually the connection to a base unit with delay line and controller is done using IF cables. Remote frontends offer more flexible use cases and easier integration into systems while an integrated RF target simulator eliminates possible problems with an accurate calibration of the flexible IF cables. All types of radar target simulators can be built as integrated RF or remote frontend type.

5.1.6 Differences

The analogue target simulator offers the possibility to simulate short distances while a longer signal processing delay in the digital units results in a greater minimum range to an object. On the other hand, the digital target simulator often offers more flexibility to simulate complex scenarios with multiple targets. Analog target simulators exist with one fixed distance, multiple fixed distances or variable distance using a switch matrix to toggle between different fiber-optic lengths. Faster switching of the distances can simulate a dynamic scenario of a target but phase jumps and attenuation. Depending on the update rate of the radar, the required phase coherence and RCS switching between different lengths back and forth could also simulate multiple targets.

The hybrid target simulator combines both approaches utilizing the fiber-optic cable of the analogue RTS/REG to simulating short distances and the flexibility of the digital RTS/REG for more distant and complex scenarios.

5.2 Parameters

5.2.1 General

There are many technical parameters of a RTS/REG that have to be defined before testing a radar sensor. This clause explains how to understand and interpret these parameters.

5.2.2 RCS

The relative size of an object detected by a radar sensor is defined as Radar Cross Section (RCS). Not only the RCS absolute value is important, but also the dynamic range of the RCS that can be simulated. As there can be targets in close range and far range with high and low RCS for example, the dynamic range is important. The dynamic range defines power values which can be simulated by the instrument.

In the following the effect on the RCS of different RTS/REG settings and measurement setup specific parameters are described.

The RCS calculation within a RTS/REG is done by the following formula (2).

$$RCS = -A_{RTS} + G_{TX_{Ant}} + G_{RX_{Ant}} + 20log\left(\frac{c_0}{f_c}\right) - 10log(4\pi) + 40log\left(\frac{D_{Air}+R}{D_{Air}}\right) \quad (2)$$

- RCS Resulting Radar Cross Section
- A_{RTS} Attenuation within the RTS/REG [in dB]
- G_{TX_Ant} Antenna gain of the RTS/REG transmit antenna [in dB]
- G_{RX_Ant} Antenna gain of the RTS/REG receive antenna [in dB]
- c_0 Speed of light [in m/s]
- f_c Centre frequency the RTS/REG is set to [in Hz]
- D_{Air} The physical distance between RTS/REG frontend and EUT [in m]
- R Distance of the artificial object generated by the RTS/REG [in m]; e.g. 150 m

In contrast to over the air measurements with corner reflectors, the RCS value is a function of the generated target distance as well as the physical distance between RTS/REG and radar under test. This leads to a "range dependent" RCS coverage which is exemplary shown in Figure 3. The figure shows the lower and upper RCS limits with an RX and TX antenna gain of 10 dBi, a carrier frequency of 79 GHz, an airgap to the radar under test of 1 m and a dynamic attenuation range of 70 dB (50 dB attenuation to 20 dB gain).

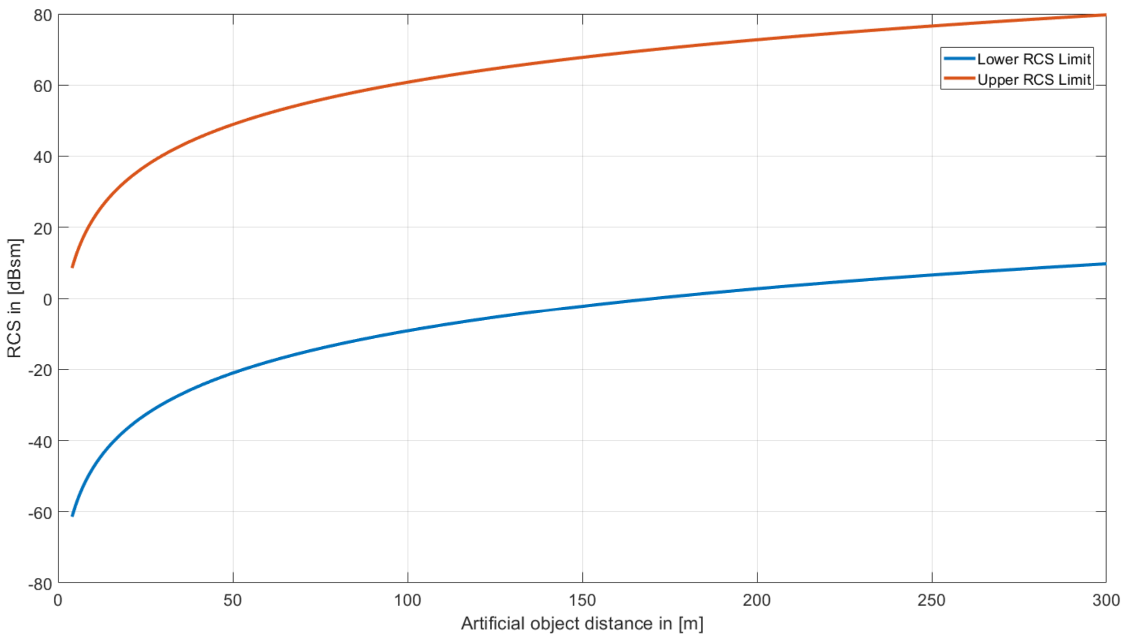

Figure 3: Lower and Upper Limit for an exemplary RTS/REG

The area between the two curves indicates the distance dependent RCS values that can be set with the RTS/REG.

Table 1: exemplary RCS values for 79 GHz radars according to IMIKO project

Car (strong reflection from target)	15 dBsm
Bicycle (medium reflection from target)	0 dBsm
Pedestrian (weak reflection from target)	-8 dBsm

When considering the exemplary RCS values for different object types from Table 1 and Figure 3 which shows the typical range dependent RCS coverage of a RTS/REG, the critical values when talking about the dynamic attenuation range are:

- Generating artificial objects with large radar cross sections in short distances (mainly defined by the maximum gain of the RTS/REG).
- Generation of artificial objects with small radar cross sections in large distances (mainly defined by the maximum attenuation of the RTS/REG).

When simulating driving scenarios, it is crucial to consider the RCS values and related distances. It directly influences which RTS/REG is capable to simulate the desired scenario, or not.

5.2.3 Radial velocity

Depending on the type of the used RTS/REG the artificial objects can be applied with a radial velocity in different manners. In common for all RTS/REG types is, that the radial velocity is mimicked by a Doppler offset applied to the originally received signal originating from the radar sensor under test. In analogue RTS/REG, it is typically realized using different local oscillators for down- and up-converting with a frequency offset between them equalling the desired Doppler frequency shift. In digital RTS/REG, the Doppler frequency shift is typically added in the digital domain. The advantage of digital RTS/REG is, that a common local oscillator can be used for the down- and up-conversion which results in a fully coherent frequency conversion. By maintaining the coherency less noise is introduced to the signal compared to analogue RTS/REG types.

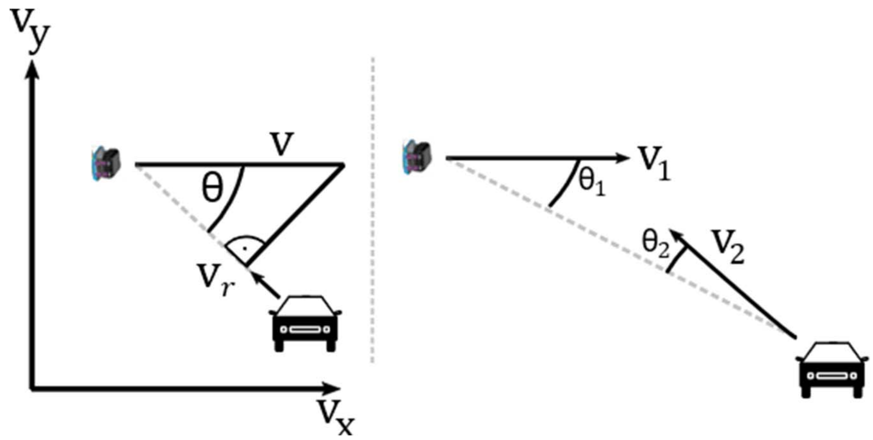

Figure 4: Example of a static radar sensor and an approaching target and a moving sensor with a moving target

If a moving target is travelling directly at the radar, the measured relative speed of the radar is its actual speed.

If the target is not directly moving towards or away from the radar, the measured relative speed v_r can be calculated as formula (3).

$$v_r = \sum_{i=1}^{2} v_i \times \cos\theta_i \qquad (3)$$

With v_i as velocities of the radar sensor and the target and θ_i as the angle between the line of sight and the actual direction of radar sensor and target.

A radial velocity setting range of ±500 km/h within the RTS/REG is sufficient to simulate automotive specific driving scenarios. With this setting range a scenario of two vehicles, each with a velocity of 250 km/h, driving towards each other can be simulated.

Micro Doppler and distributed objects are visible depending on the radars resolution in range and Doppler. For example a car has characteristic reflection points distributed at the car that reflect a certain "dimension" in range of a car. On the other hand, a pedestrian has characteristic Doppler effects of swinging arms and legs that become visible when measured with a radar that has high Doppler resolution. Often simulation of these signal characteristics are of interest during research and development of radar sensors and signal processing, but not in the scope of the present document at present.

5.2.4 Minimum range

The minimum range of the RTS/REG is defined by the distance of the EUT to the test equipment and internal processing time of the RTS/REG as described by formula (1). The time for the electromagnetic wave to pass through the RTS/REG depends for example on the internal circuitry/fiber optics/IF cables or signal processing delay.

5.2.5 Accuracy

The accuracy of the simulated targets relies on the performance of many internal components, the calibration and a proper setup.

Velocity shift accuracy is dependent on the attached CW source, some RTS/REG also allow the usage of an external source.

RCS accuracy depends for example on the accuracy of built in damping pads and dynamic range of the RF components, clipping effects, etc.

The simulated range depends on maintaining an exact physical distance between RTS/REG and EUT and the specified range resolution steps and sampling rates that are specified. RTS/REG with variable distance simulation offer a limited step size. Expected deviations from the specified range are declared in the calibration report.

To compensate additional losses and ensuring constant operation over the whole bandwidth of the instrument, the RTS/REG should be properly calibrated and offer enough flat amplitude, phase and frequency response.

5.2.6 Unwanted objects and crosstalk

Unwanted objects due limited isolation within the RTS/REG can occur when the RTS/REG has a limited isolation between RX and TX. Especially RTS/REG which have a single/combined RX and TX antenna are affected. Typically, waveguide circulators are used to achieve this antenna configuration. Those circulators only provide an isolation between 15 dB and 25 dB.

Large signals that should be retransmitted to the radar under test couple into the receive path of the RTS/REG again and do a "second round" through the RTS/REG. This is then visible/detectable for the radar under test as additional object at twice the artificial object distance of the wanted object.

5.2.7 Phase noise

Added phase noise to signal (depending on artificial object distance) can occur. With larger target distances (and therefore longer time passing between receive and transmit) the phase of the local oscillator decorrelates more compared to shorter delays. The target distance setting has therefore a tremendous impact in the measured phase noise.

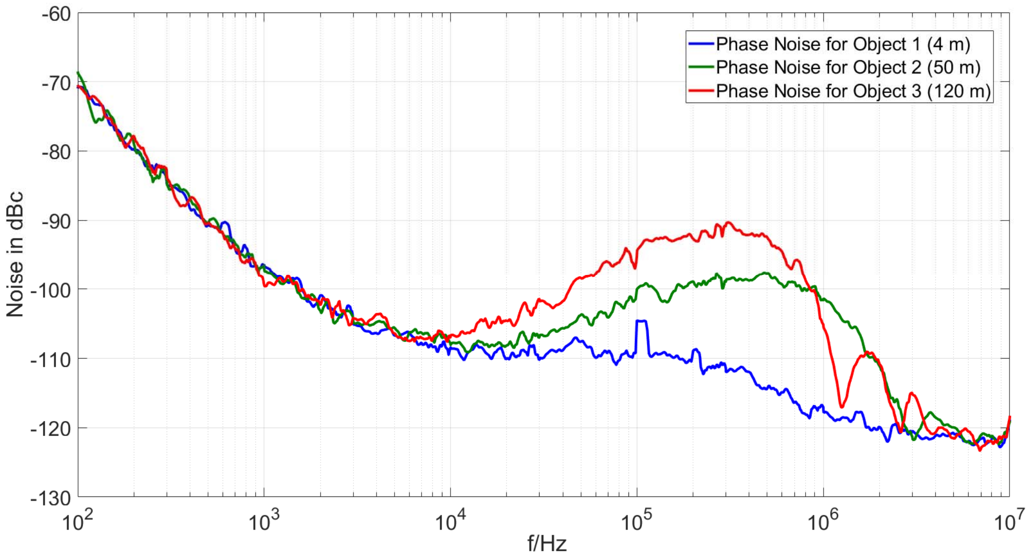

Figure 5: Exemplary phase noise curve for different distances

5.2.8 RF saturation

Similar to spectrum analysers where an optimal input level is desired, but even more important for RTS/REG, the radar signal power received through the RX port shall saturate the internal components like mixers and switches to operate the device at an optimal operation point.

RF signals with very low power can cause the radar echo signal to be more distorted. On the other hand, signals with too high power can be clipped.

Minimum and maximum input power at the waveguide flange are specified by the manufacturer.

5.2.9 Temperature effects

The temperature range of the RTS/REG is specified in its data sheet. Extreme temperatures/temperature changes can lead to a change of the behaviour of internal components or exceeding the calibration limits. Often RTS/REG have internal temperature calibration to compensate of such effects.

5.3 RTS/REG requirements - Parameter summary

The parameters that are proposed for ETSI testing are marked by *. All other parameters are recommendations for more complex radar sensor or ADAS function testing.

Table 2: Proposed parameter to be tested

Parameter	Application (Sensor Validation/ADAS Validation)	Value/Statement
General		
Modulation support*	Sensor Validation/ADAS Validation	RTS/REG shall be fully transparent, the output shall be a modified signal copy of the input.
MIMO radar sensor support*	Sensor Validation/ADAS Validation	A monostatic or bi-static antenna configuration can be used at the RTS/REG. The separation between the Tx and Rx antennas of bi-static antenna configuration should be as small as possible to minimize angle error. The angle error caused by antenna separation should not exceed radar angle accuracy (see explanation in clause 6.2).
RF Parameters		
RF frequency*	Sensor Validation/ADAS Validation	Depending on radar under test; for example for radars that are currently using the frequency bands: • 24 GHz to 24,25 GHz. • 76 GHz to 77 GHz. • 77 GHz to 81 GHz.
Instantaneous bandwidth*	Sensor Validation/ADAS Validation	Depending on radar under test; Instantaneous bandwidth for example for the radars mentioned above: • 250 MHz in the band 24 GHz to 24,25 GHz. • 1 GHz in the band 76 GHz to 77 GHz. • 4 GHz in the band 77 GHz to 81 GHz.
Amplitude flatness (maximum to minimum within frequency band with respect to mean value)*	Sensor Validation/ADAS Validation	±6 dB over 1 GHz.
Radar Cross Section accuracy/Output power accuracy for one single artificial object*	Sensor Validation	≤ 5 dB over the entire RF frequency.
Min supported e.i.r.p. interferer power level for in-band signal handling tests*	Sensor Validation	20 dBm e.i.r.p.
Artificial Objects		
Number of artificial objects* (simultaneously)	Sensor Validation*	≥ 1.
	ADAS Validation	Depending on simulated driving test scenario complexity, the RTS/REG has to support many individual artificial objects depending on the range resolution of the radar sensor (recommended are ≥ 4 objects within ±10° angle to generate a point cloud for object classification).
Artificial object radar cross sections*	Sensor Validation	For sensor validation dynamic range of the RTS/REG should be as high as possible, e.g. 60 dB for a single echo signal at a certain range. It shall be possible to simulate artificial objects with radar cross sections: • Car (+15 dBsm) up to 300 m. • Cyclist (0 dBsm) up to 150 m. • Pedestrian (-8 dBsm) up to 100 m. For further explanation see clause 5.2.2.

The following parameters are informative in case more complex sensor functions (e.g. range resolution) or even ADAS function validation is desired.

Table 3: Optional parameters of interest

Parameter	Application (Sensor Validation/ADAS Validation)	Value/Statement
General		
Test system modularity	Sensor Validation/ADAS Validation	Test system versatility by remote frontends - quick change between radar bands and antenna configurations should be possible.
Realtime interface	ADAS Validation	Dedicated Hardware-in-the-Loop interface with open standard support such as OSI.
Synchronization of multiple radar RTS/REG	ADAS Validation	Parallel test of several radar sensors; recommendation up to 8 synchronized test setups should be possible.
Artificial Objects		
Number of artificial objects* (simultaneously)	Sensor Validation*	≥ 1.
	ADAS Validation	Depending on simulated driving test scenario complexity, the RTS/REG has to support many individual artificial objects depending on the range resolution of the radar sensor (recommended are > 15 objects within ±10° angle to generate a point cloud for driving scenarios and even object classification).
Artificial object distances	Sensor Validation/ADAS Validation	For ADAS applications, distances in close and long range are of interest, e.g. up to 300 m (see clause 5.2.4).
Artificial object distance setting step size	Sensor Validation/ADAS Validation	The distance setting step size depends on the radar application. Recommended are 0,3 m for SRR, 0,6 m for MRR and 0,72 m for LRR. Distance settings in sub centimetre-range might be required depending on the radar resolution and tracking capabilities.
Artificial object distance accuracy	Sensor Validation/ADAS Validation	The object distance accuracy should be at least ±0,3 m, or better than the radar range accuracy declared by the manufacturer.
Angular resolution and FOV tests	Sensor Validation/ADAS Validation	FOV > ±10° (LRR) FOV > ±45° (MRR/SRR).
Angular resolution step size	Sensor Validation/ADAS Validation	< 3,6° for SRR in ±65° w. regard to EUT centre < 2,6° for MRR in ±45° w. regard to EUT centre < 1,3° for LRR in ±10° w. regard to EUT centre.
Radial velocity range	Sensor Validation/ADAS Validation	The radial velocity range should be ±500 km/h or cover the entire Doppler range of the radar under test as declared by the manufacturer.
Radial velocity step size	Sensor Validation/ADAS Validation	The radial velocity step size should be < 1,0 km/h, in case for micro Doppler testing < 0,05 km/h.
Miscellaneous		
IF input interface		IF input interface for connecting signal generators for interference testing; IF input interface has to support the full instantaneous bandwidth of the RTS/REG.
IF output interface		IF output interface for connecting signal and spectrum analysers and power sensors; IF output interface has to support the full instantaneous bandwidth of the RTS/REG.
Interferer signal robustness		The RTS/REG should be robust against the unwanted signals of RBR tests.

6 Measurement Setups

6.1 General Guidance

An anechoic chamber is mandatory for functional test of automotive radars using RTS/REG to provide a quiet RF environment, where the EUT only detects the objects being simulated and repetitive test results are possible.

Accurate and repeatable RF measurements require the so called Fraunhofer distance, the far-field distance, where plane wave propagation can be achieved. Typical amplitude taper's of less than 1,5 dB and phase taper of 22,5° are achieved within the quiet zone.

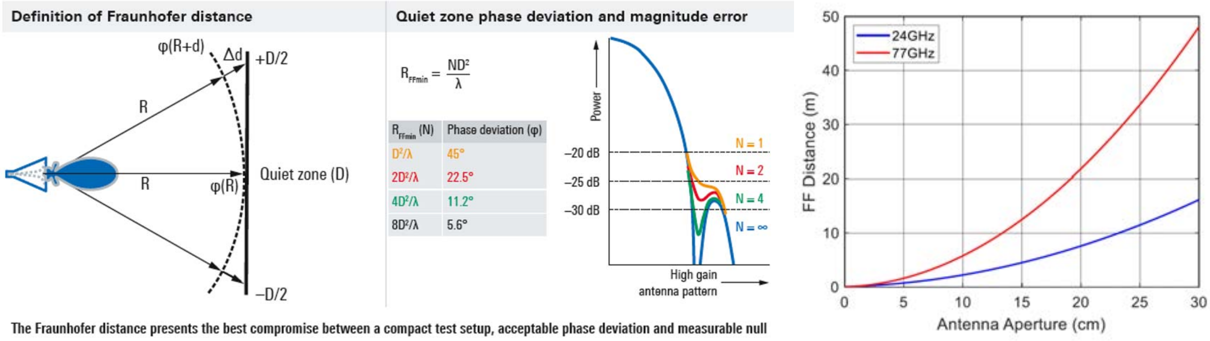

Figure 6: Definition of Fraunhofer distance and quiet zone in terms of wavelength and antenna aperture

The required higher angular resolution for radars is typically achieved through increased number of TX and RX antennas, which increases both the far-field distance and the required quiet zone for the measurements. For example, a far-field distance of more than 20 m is required for measurements of an EUT of 20 cm antenna aperture size at 77 GHz. Higher measurement distances lead to higher paths losses, decreased dynamic range for measurements and higher minimum distance of objects that can be simulated.

The test methods described in ETSI EN 303 883-1 [i.1] and ETSI EN 303 883-2 [i.2] based on traditional test equipment (power meter, spectrum analyser, signal generator) allow the use of reduced measurement distances. Depending on the radar itself (e.g. applying MIMO) the recommended far-field distance can become impractical even at millimetre waves for larger antenna apertures.

Nevertheless, for functional test of a radar using RTS/REG, depending on the type of signals and modulation used, the correct EUT measurement will not be possible, if they are done in the near-field range and they directly depend on the phase or amplitude measurement results. For example, range and radial velocity measurements are possible for linear FMCW radars in the near-field range of the RTS/REG, because they depend on the beat frequency between the transmit and receive signal. On the other hand, RCS measurements in the near-field is not possible, because RCS depends on the amplitude of the signals and the errors in the near-field are too high.

In summary, a complete functional test of a radar requires measurements to be done at a far-field distance. If this distance is too high for a certain EUT frequency and antenna aperture, then either methods to achieve near-field to far-field transformation in real-time, like a CATR setup, shall be applied, or some of the functional tests will not be possible.

6.2 Antennas

RTS/REG may support bi-static, mono-static or both antenna configurations.

A bi-static configuration describes independent antennas for RX- and TX-paths providing higher TX/RX isolation particularly important to handle very high receive power levels.

A monostatic configuration describes a single antenna with an integrated circulator providing superior performance to test MIMO radars, which target the best possible angular measurement resolution and accuracy, but the isolation between RX and TX is limited by circulator performance.

It is important that the RTS/REG provides a remote front-end module detached of the simulator base unit, so that the position of the antenna in the setup is more flexible and unwanted delays and path loss are minimized. (A "remote front-end module" is the RF part of the RTS/REG which can be detached from the main unit.)

6.3 Anechoic Chamber Setup

6.3.1 General

Generally, the same conditions as described in ETSI EN 303 883-1 [i.1], clause B.2 radiated measurements apply.

High performance shielding effectiveness (> 60 dB typical) and high-quality absorbers eliminating unwanted reflections ('ghost targets') due to chamber multipaths or indispensable installed equipment will improve the signal-to-noise ratio in the chamber and enable conclusive reliable EUT test results.

It may happen that some unwanted reflections in the chamber setup cannot be avoided and, in such cases, they are only acceptable if they can be eliminated by time gating or if their level is at least 20 dB below the level of the intended object being simulated throughout the EUT field of view.

6.3.2 Direct far-field setup

This method typically requires very large measurement distances compared to existing typical anechoic chamber sizes for functional test of automotive radars in combination with RTS/REG for the reasons explained in clause 6.1.

Direct far-field setups typically have smaller quiet zones than compact antenna test range setups.

Nevertheless, whenever other approaches are not technically possible, then either direct far-field testing with very large chamber or relaxed compliance limits with higher measurement uncertainties for practical measurement distances in near-field ranges will need to be employed. This is the case for the measurements of unwanted emissions in the out-of-band and spurious domains, which are difficult to be covered by other setups.

According to the far-field calculation formula (4) the minimum distance R_{min} is:

$$R_{min} = \frac{N\,D^2}{\lambda} \tag{4}$$

Where R_{min} is the minimum distance in meter and D is the antenna aperture in meter.

Table 4: R_{min} and resulting phase deviation

$R_{min}\,(N)$	Phase Deviation
$\frac{1\,D^2}{\lambda}$	45°
$\frac{2\,D^2}{\lambda}$	22,5°
$\frac{4\,D^2}{\lambda}$	11,2°

Using formula (4) with N = 2 the Far-Field (FF) distance can be plotted vs. antenna aperture size D for different radar frequencies.

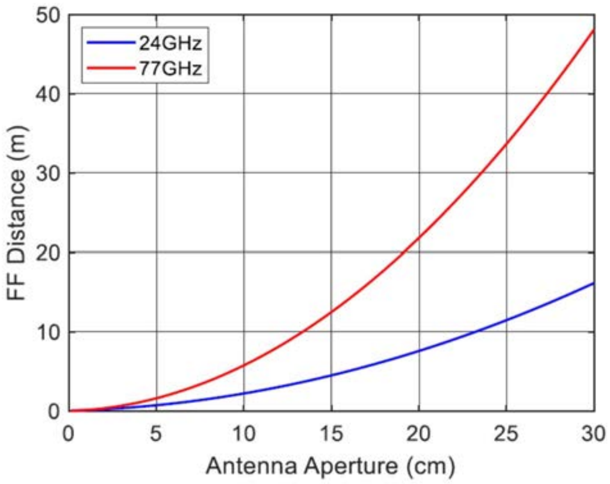

Figure 7: Required Far-Field (FF) distance

6.3.3 Near-field/far-field transforming setup

Compact Antenna Test Range (CATR chambers), sometimes described as indirect far-field method provide real-time near-field/far-field transformation on hardware without the need to post-processing (post-processing is impractical for functional testing).

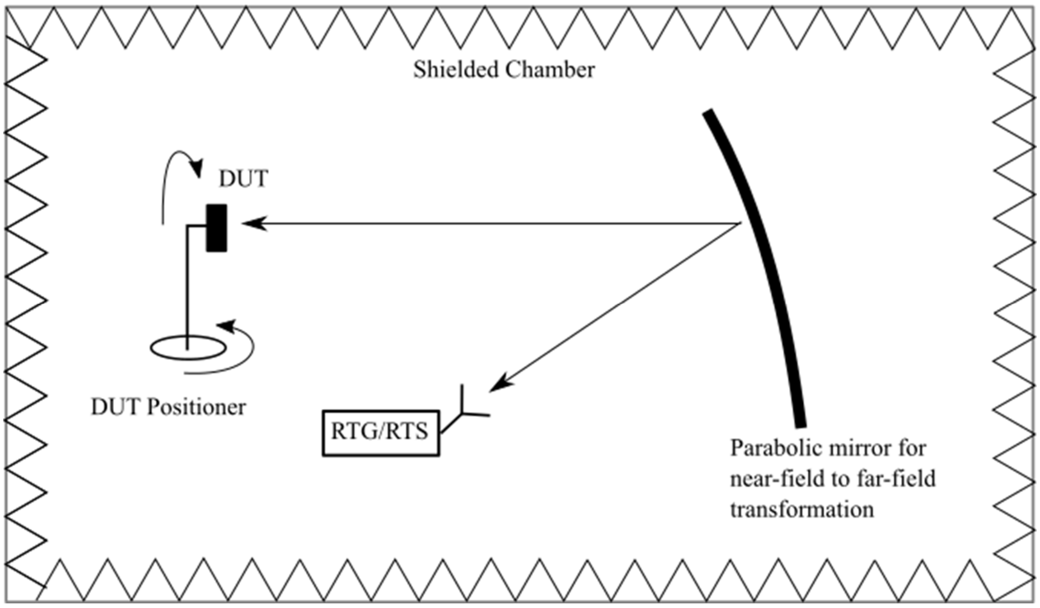

Figure 8: Example of a CATR chamber

A CATR system is a much smaller setup for precise bi-directional transmit and receive channels. The parabolic geometry of a mirror/reflector transforms near-field spherical waves into far-field plane waves in a short distance. Smaller setups lead to shorter cables lengths and smaller total path loss which is especially important for mmWave test setups.

It requires the antenna(s) of the RTS/REG to be positioned at the reflector focal point. Two critical reasons to employ monostatic antennas are: they enable higher accuracy angular measurement resolution important for MIMO architectures and they are also required for the principles behind the CATR real-time near-field/far-field transformation with single focal point to work.

The quiet zone of a CATR setup is cylindrical and there is close to zero path loss between the reflector and the EUT making the total Free Space Path Loss (FSPL) for the measurements lower and making the measurement accuracy of the system independent from the accuracy of EUT positioning in one of the axes, either vertical or horizontal axis (depending if it is a vertical or horizontal CATR setup).

The quiet zone size is typically 25 % to 70 % of the reflector size, the larger being achieved through higher quality reflector edge treatment and feeding arrangement.

As an example, at 40 GHz, a CATR setup for 5G testing can achieve 62 dB FSPL and 5 dB cable loss. A comparable direct far-field setup for similar measurement accuracy and smaller quiet zone has 92 dB FSPL and at least 10 dB cable loss. Such differences in automotive radar mmWave frequencies are much greater making the CATR setup by far the most favourable choice provided that the frequency ranges can be covered. A mmWave CATR setup typically covers the of 24, 77 and 81 GHz but not the complete frequency range up to 231 GHz as required by for example US FCC Part 15, section 15.253 [i.3].

6.4 Positioner

Most automotive radars are singular polarized and the positioners shall keep the EUT polarization alignment while having enough accuracy for the azimuth and elevation angular measurements. Accuracy of angular measurements requires that positioner movements keep the EUT always accurately and repeatedly positioned at the rotation centre. Today's image radar with MIMO aims for very high angular resolution. Positioners should have a higher angular resolution than the radar under test with an active feedback of the position. Typical high-performance positioners have an accuracy of 0,04°.

7 Radiated Measurements

7.1 Receiver Baseline Sensitivity

7.1.1 General

Receiver Baseline Sensitivity is the capability to receive a wanted signal at application related defined input signal levels while providing a pre-determined minimum acceptable level of technical performance.

To address the test case with the companion device as explained in ETSI EN 303 883-2 [i.2] for radar systems an RTS/REG can be used. In that case the companion device is the RTS/REG as shown in Figure 14 of ETSI EN 303 883-2 [i.2].

7.1.2 Radar Echo Generation/Target Simulation

This test assumes that data from the radar sensor under test can be displayed and recorded. Whether the display is in list format of range/Doppler/RCS or birds eye view or FFT view is up to the user. It has to be ensured that the data from the radar can be observed during this test.

Recommended measurement procedure:

1) Power on the RTS/REG and open the GUI to type in all desired parameters for an object to simulate.

2) The following RTS/REG parameter are common, some models may offer additional parameters for further characterization of the signal path or simulation of simulated objects:

   - Set frequency band/centre frequency:

     ▪ According to the application to be tested the assigned frequency band needs to be selected. The definitions of "RF frequency" in table 2 in clause 5.3 gives some examples. For more accurate object simulation, the centre frequency of the EUT is required. In case the radar under test is frequency agile, make sure that the bandwidth of the RTS/REG covers the entire bandwidth of the radar under test or limit the bandwidth of operation to fit the RTS/REG system bandwidth.

   - Chamber range/physical distance:

     ▪ The physical air gap between radar sensor and RTS/REG needs to be taken into the calculation for the signal path.

- RTS/REG antenna gain:
    - The gain of the RTS/REG antennas needs to be taken into the calculation for the signal path. For a bi-static device, RX and TX antenna gains are required. Some models assume the same gain for RX and TX antenna.
- Target range setup/simulated range:
    - The simulated range is the distance in which a radar sensor should detect the simulated object.
- Relative speed/simulated radial velocity:
    - The relative speed is the radial velocity of the simulated object at which the radar sensor should detect it.
- Object RCS (Radar Cross Section):
    - Sets the RCS for the simulated object.

Usually there is also a button in the GUI to apply all parameter changes and a possibility to switch on and off the RF performance.

Make sure the radar sensor is switched on and is transmitting and receiving radar signals.

7.1.3 Receiver Sensitivity

To test the receiver sensitivity a radar target has to be generated at the desired range of test. By reducing the power output of the RTS/REG the sensitivity level of the radar can be found once the radar does not detect the simulated target anymore.

To perform this test one should prevent receiver saturation of the RTS/REG. Typical input power levels at the receiver port are in the domain of -20 dBm (where the RX antenna gain is not taken into account). Also take a look at the datasheet of the corresponding RTS/REG and the input recommended power levels.

The RTS/REG provides at least 60 dB of dynamic range control (e.g. -50 dB to +10 dB attenuation/gain) for simulating the desired RCS.

Depending on the antenna configuration, a limited isolation between TX and RX path may apply, high input power and settings for a target with a high RCS might generate multiple unwanted objects (loopback of signal).

However low input powers up to -70 dBm can be handled by a RTS/REG. Depending on the parameters of the simulated object, transmissions of an even lower TX signals (e.g. -120 dBm) can be simulated to test the receiver sensitivity level.

7.2 Receiver Baseline Resilience

7.2.1 General

Receiver Baseline Resilience (RBR) is defined as the capability to maintain a pre-determined minimum acceptable level of performance in the presence of unwanted signals in the frequency band of operation, applicable adjacent and remote frequency bands.

An RTS/REG is able to generate the required reference object, operate as a companion device for the EUT and can also be used as interfering source by injecting and transmitting unwanted signals towards the EUT.

7.2.2 Interference Signal Generation

7.2.2.1 General

To test interference signal handing, RTS/REG also can be used to transmit interference signals towards the radar under test. In addition to the simulated radar echo signal the RTS/REG can generate any other RF signal.

Depending on the required test there are several test and measurement setups possible.

7.2.2.2 Interference signal injection through separated mmW remote header (setup 1)

This setup is the most flexible in terms of testing capabilities, but also the most complex and expensive one. The maximum output power of the target and interferer is defined by the remote head.

Recommendation

The setup is recommended in case the interference signal shall be originating from another angle than the radar echo signal. It is also recommended for generating unwanted signals that are out-of-band.

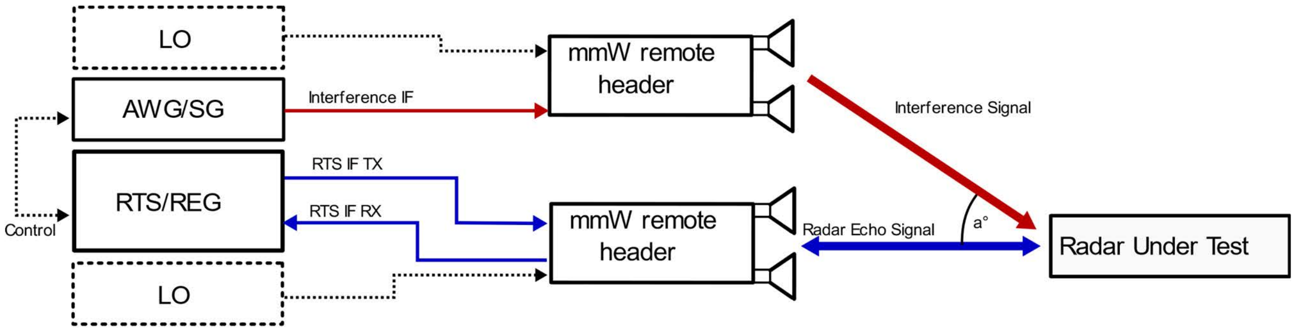

Figure 9: Interference signal injection through separated mmW remote header

Table 5: Advantages RBR setup 1

Advantages	Disadvantages
Supports in-band/out-of-band interference (60 GHz to 90 GHz)	Cost
Interference signal injection at the various angle positions from the RTS/REG	High frequency LO signal for the remote head has also to be supplied
Higher radiated power with independent remote head possible	
Interference signal can be generated with independent of RTS/REG	
There will be no intermodulation products	

7.2.2.3 Interference signal injection through combiner with single mmW remote header (setup 2)

Instead of the a second remote head, an RF combiner (IF level) can be used. Since the IF is typically in the domain of some hundred MHz to low GHz, many RF combiners are commercially available and easy to handle. The maximum output power of the target and interferer is defined by the remote head.

Recommendation

The setup is recommended in case the interference signal shall be originating from the same angle than the radar echo signal. It is also recommended for generating unwanted signals that are out-of-band (one needs to take care of the mmW remove head specification).

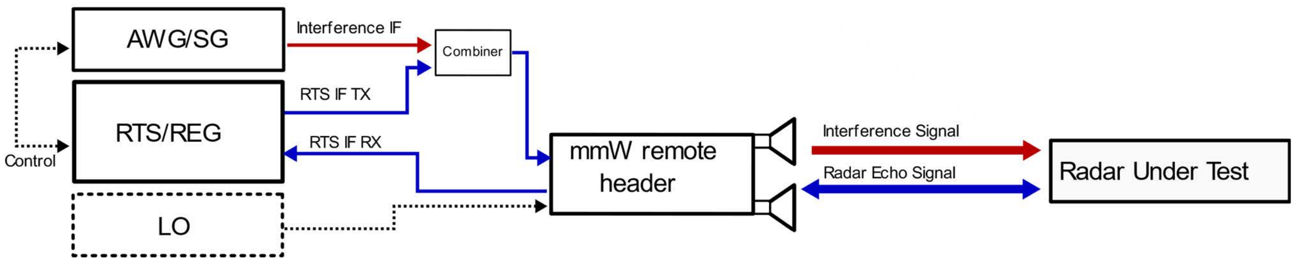

Figure 10: Interference signal injection with single mmW remote head and RF combiner

Table 6: Advantages RBS setup 2

Advantages	Disadvantages
Less RF components and less pricy compared to setup 1	Single direction of target and interference signal only
Interference signal injection at the various angle positions from the RTS/REG	High frequency LO signal for the remote head has also to be supplied

7.2.2.4 Interference signal injection with IF path of RTS/REG (setup 3)

The most convenient setup is to use the IF path of the RTS/REG and a low frequency signal generator (AWG, SG). The maximum output power of the target and interferer is defined by the RTS/REG IF path gain and mmWave remote head.

Recommendation

The setup is recommended in case the interference signal shall be originating from the same angle than the radar echo signal. It is also recommended for generating unwanted signals that are in-band.

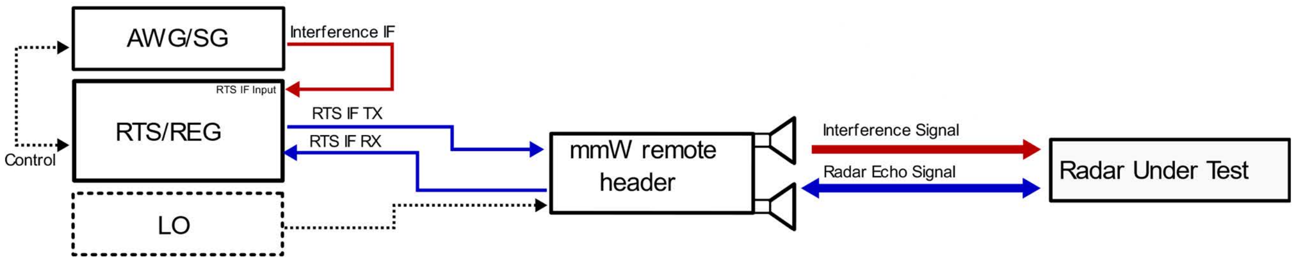

Figure 11: Interference signal injection through RTS mmW remote header or RTS Tx Path

Table 7: Advantages RBS setup 3

Advantages	Disadvantages
Low cost (one remote head is handing both echo signal and interference signal)	Supports only in-band interference
Low frequency signal generator (IF of RTS/REG typically < 6 GHz)	

7.3 Temperature Testing

Automotive radar sensors are part of the car's components most exposed to environmental influences. Testing over a certain temperature range is required.

RTS/REG equipment is specified to operate at a certain temperature range. This temperature range is typically much smaller than the temperature range of the test.

The RTS/REG operating temperature is 0 °C to +55 °C. However to have RTS/REG operate in the optimum performance and best accuracy to meet the requirements in clause 5.3, it is recommended to have the RTS/REG to operate in 25 °C ± 5 °C (20 °C to 30 °C).

The test setup shall be in such a way, that the device under test is decoupled from the RTS/REG e.g. using isolating, but RF transparent material.

If no other conformance test for the receiver requirement assessment over the environmental profile of the EUT is provided in the related standard, then the measurement setup as given in ETSI EN 303 883-1 [i.1], clause A.5.3.2.3 shall be used.

Annex A (informative): Change History

Date	Version	Information about changes
August 2022	1.1.1	First version

History

Document history		
V1.1.1	September 2022	Publication