Application Note

# E-Band VNA for Automotive Market: Bumper and Emblem Measurements

## Purpose

This application note, developed in conjunction with vendors in the automotive market, will present a configuration used to test and measure the transmission and reflection characteristics of materials (emblems and bumpers) placed in front of automotive radars. The configuration explained below will make it possible to provide clear and accurate measurements for companies working in the automobile market. These will be precise and repeatable measurements given in dBs for transmission and reflection characteristics.

## Introduction

A radar placed behind an emblem or bumper of a car must transmit its signal with minimal interference. Specifications of the materials are required by the car manufacturers to ensure the proper operation of the radars. To test the emblem or the bumper, a ShockLine MS46522B vector network analyzer (VNA) with option 83 (5 meter E-band) is used to provide the necessary frequency range coverage, measure all S-parameters ($S_{11}$, $S_{12}$, $S_{21}$, and $S_{22}$), and characterize the behavior of the material. In this case, instead of using a conducted setup, where the signals are transmitted through a transmission line like a coaxial cable, two antennas are attached to both ports of the ShockLine MS46522B-083 VNA to transmit and receive the signals. The model of antenna used must be defined according to the test configuration, always considering a plane wave must be present in the surface to be measured (working in the E-band [60 to 90 GHz], this should not be an issue). Specific antennas with lens or dielectric will be chosen to form the wave.

For this test, the shape of the material under test (MUT) is something that must also be considered as it can affect the results depending on the width, paint, manufacturing process, etc. Another question that arises is whether it is better to use a single, large beam on the whole surface to be tested or a smaller beam and to do it in two or three tests.

It is important to note that during these tests the radiation environment was not ideal to characterize a MUT and that some care had to be taken. The most important issue is reflections. In the open environment used, reflections could happen and ruin the measurements. To avoid reflections there are two options that could be used that are not exclusive of each other. The first requires placing an absorbent material all around the room, however, this can complicate the setup even more. The second is the use of the gating process in the ShockLine VNA. In this case, a gate is defined around the test distance range to exclude any external interference.

The test results were quite precise and consistent, getting measurement accuracies in the order of a few hundredths of a dB. When conducting these measurements, the ShockLine VNA did not seem to be the most critical element affecting the accuracy of the measurement, rather it was the actual position of the tested sample for the reflection measurement. This measurement was influenced by the angle between the direction of the transmission and the plane of the sample. A small longitudinal displacement of the sample has little affect on the transmission measurement and for the reflection it is on the order of ± 0.2 dB for ± 1 mm.

The measurements on the bumpers gave values around 0.7 dB for the transmission and –9 dB for the reflection. These values, of course, being affected by the thickness and paint used.

Although traditional E-band measurement systems, which are much larger and more expensive, can yield sufficiently accurate results, we must also consider how those systems would fair in a production environment. The lower cost and smaller “plug-and-play” form factor of the ShockLine MS46522B model is perfectly suited for this type of production use.

Today, radars used by automotive manufacturers are critical elements in their safety systems. In the future, these systems will be considered even more critical for the autonomous car. At the output of the production line, all bumpers and emblems must be measured to ensure that they comply with safety standards and the results will be saved to maintain traceability. One must be able to leverage a quick and easy-to-use VNA system that can be placed in a production plant environment.

## Basic Setup

The following basic configuration was created to conduct the material measurement tests. The space between the antennas had to be: 1) wide enough to allow a bumper to be placed in between them, and 2) able to reach the far field conditions for the wave to be a plane at the sample. Precision mechanics must also be used to maintain the MUT alignment between the two antennas. In this configuration, two dielectric antennas are used but this could be changed depending on the requirements. To avoid multiple reflections, absorbent material was used to improve the configuration. Some samples and bumpers were measured and the results correlated with previous measurements.

## VNA Setup

Complex configurations are not necessary for radar characterization measurements. The information needed by bumper manufacturers is usually transmission and reflection parameters in the form of S-parameters in logarithmic scale (plus phase). Thus, 4 traces are configured showing $S_{11}$, $S_{22}$, $S_{12,}$ and $S_{21}$ in log scale.

- **Frequency range:** the configured frequency range will be decided by the customer, depending on their particular requirements (typically between 75-80 GHz)
- **Number of points:** 201
- **Power:** 0 dBm
- **IFBW:** 10 kHz

## Calibration Setup

As with most uses of a VNA, this application requires the instrument to be configured and calibrated to get accurate results. The calibration method used for these radiated measurements is the Line, Reflect, and Match (LRM) algorithm, in which a reflection plane is used for reflective calibration, a line for transmission calibration, and a perfect match.

The calibration kit consists of a simple metallic plate with a known thickness so it can be considered in the calibration process. The plate should be as conductive as possible, and with a flat response in the entire frequency range of interest (a reflection response has been seen in which some anomalies appeared in the higher frequency band).

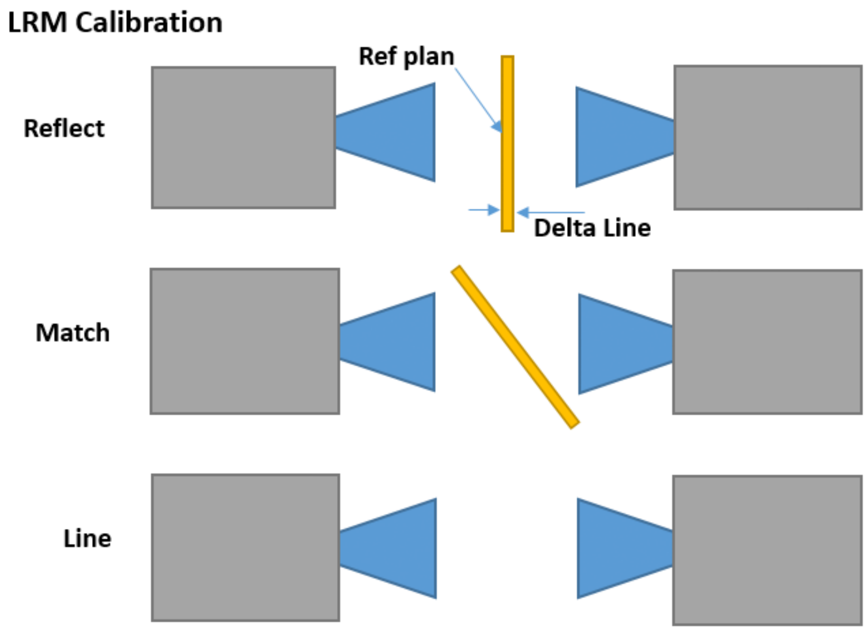



*Figure 1. LRM setup used with metal plate and antennas*

For the LRM algorithm, the Reflect for both ports will be done with a metal plate placed perpendicular to both antennas, while the Line will be done without the plate. Finally, for the Match, the metal plate placed at a 45° incline will give no reflection back to any of the ports and achieve the same behavior of a perfect match. In this case, the use of an absorbent material placed to both sides of the metal plate can improve calibration (Figure 1).

In our case, the distance between both antennas is 310 mm, a distance large enough to have some room to place the samples or bumper parts and to be in the far field conditions of the antennas. The metal plate, with a width of 2 mm, is placed in the middle.

## LRM Menu for the ShockLine MS46522B VNA

In the ShockLine MS46522B VNA calibration setup (Figure 2), note that the line length configured is 0 mm (A). When a 0 line length is used, the system is being told that the "ports" are at the sample plane.  In that case, the reflect offsets are also 0.  In this setup, the calibration standards entries are self-consistent and the calibration is legitimate.

Also, in the LRM setup, the reflection is configured to be short-like (B), and the reference plane to be situated in the middle of line 1. Also, a Match must be configured as Cal Device Y (B), which could also be a second line if we use LRL calibration algorithm.

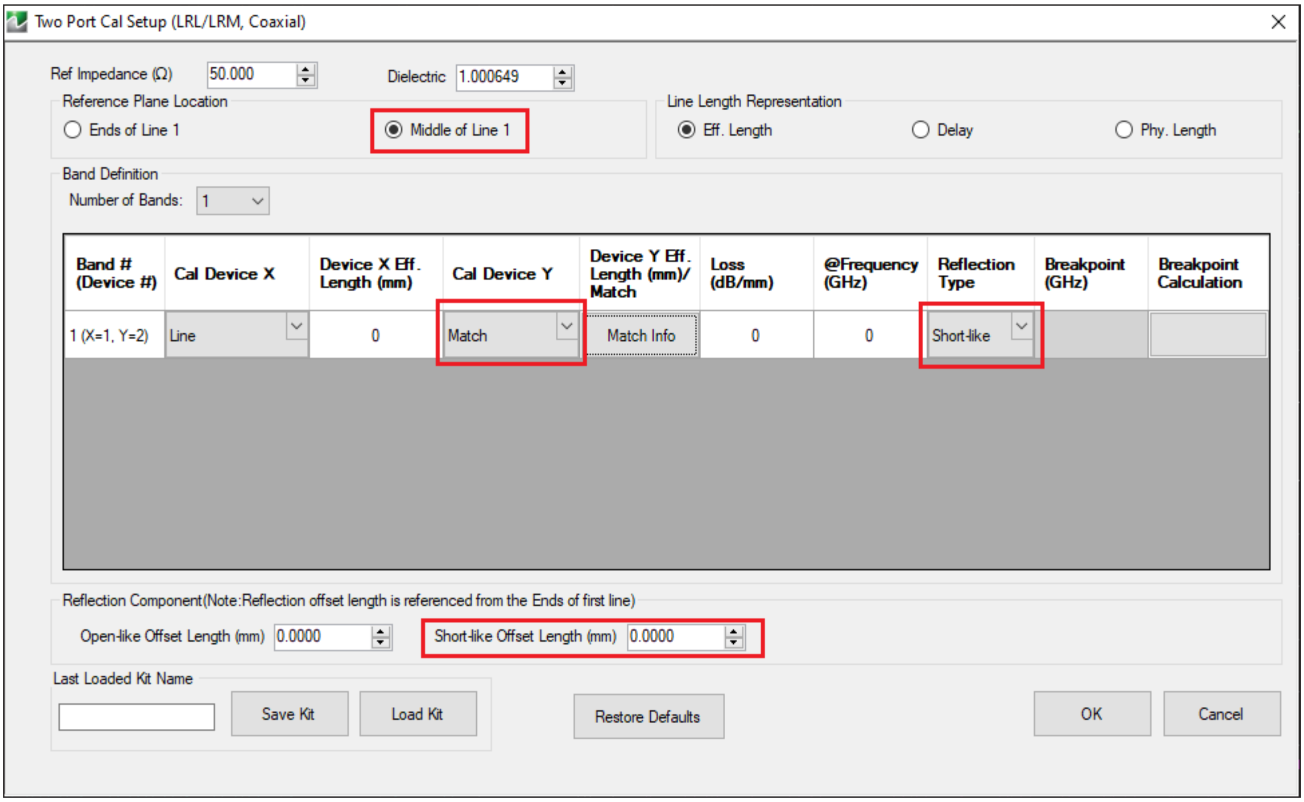



*Figure 2. LRM calibration setup*

Once the system is calibrated, the measurement of the “Line” (no metal plate or plastic sample in the middle of the setup) would give the flat trace of both magnitude and phase. Figure 3 shows an example the results achieved after a good calibration procedure.


*Figure 3. Transmission response after calibration*

It is expected to have a magnitude ripple of less than ±0.25 dB and a phase ripple of less than ±0.2°, as shown in Figure 4. The calibration process, however, could be affected by different parameters, like position of the metal plate, external reflections, etc. Special care should be taken when performing the calibration process to obtain best results.

## Test Configuration

The bumper (or material sample) will be set at the reference plane, which is the middle point between the antennas (in the case of measuring bumper parts, mechanical positioners play an important role to place the bumper in the precise position to be measured).

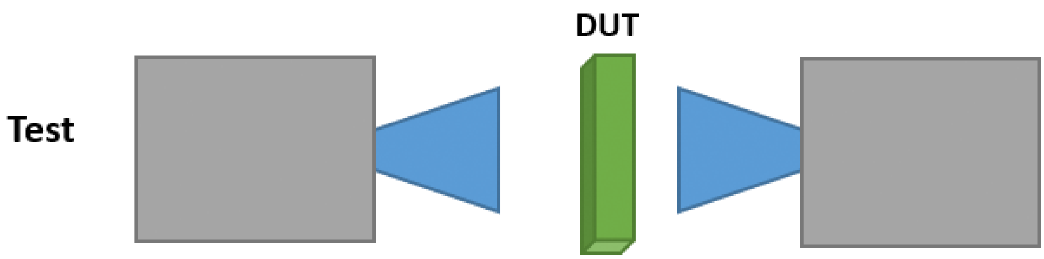
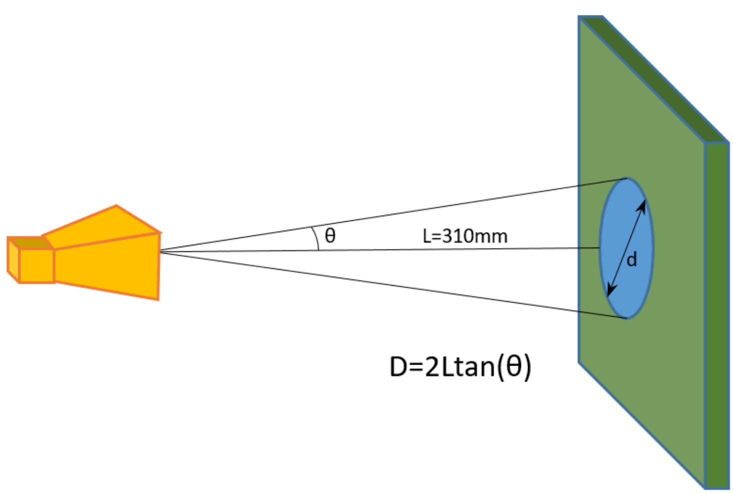



*Figure 4. Measurement setup*

The distance between the antennas is dependent on the test requirements. Far field conditions need to be met, which is easy in this frequency range (supposing far field is ten times the wavelength, these conditions are met when the antennas are set apart by 5 cm or more). It is also important that the radiation spot on the sample not exceed or even be similar to the sample size to avoid dispersion. Figure 5 illustrates the situation if a dielectric antenna and horn antenna are used (radiation pattern for both can be found at the end of this document):




| Dielectric Antennas | |
|---|---|
| 3 dB Beam width (deg) | 5 degrees |
| 10 dB Beam width (deg) | 9 degrees |
| Distance (L) | 310 mm |
| Diam 3 dB | 27.06978 mm |
| Diam 10 dB | 48.79506 mm |
| | |
| **Horn Antenna** | |
| 3 dB Beam width (deg) | 10.5 degrees |
| Distance | 310 mm |
| Diam 3 dB | 56.97 mm |

*Figure 5. Radiation spot on the sample*

Using dielectric antennas with a distance of 31 cm between them, the radiation spot (diameter) is less than 3 cm for a 3 dB attenuation (less than 5 cm for a 10 dB att). Similar calculations with the horn antennas shows a spot of 57 mm in diameter. This means that having a sample of 15x15 cm provides enough margin to be sure the spot will fall entirely in the sample.

In the case in which absorbent material is not available, a gate can be configured to improve the measurement and avoid external reflections (these external reflections can appear in the trace as additional ripple). Thus far the material position has been established as the reference plane, which is the zero position. The gating should now be configured around the zero position. This can be seen in Figure 6 that shows the time domain response (in bandpass mode) of the $S_{21}$.

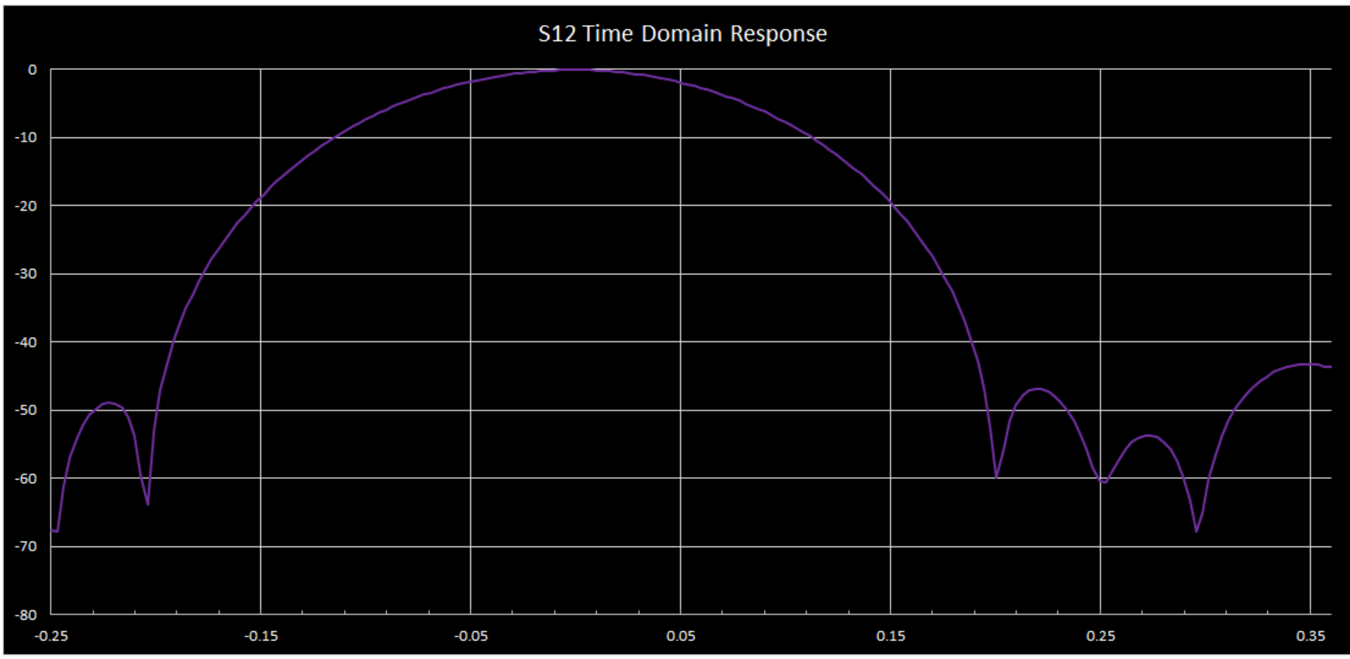



*Figure 6. Time domain response of the transmission response*

Then, what needs to be discovered is the width of the window to use in the setup to try to improve the results. This will depend on the frequency span being used in the measurement (the higher the frequency span, the shorter the window size needed). Table 1 shows the relationship between the configured frequency span and the window size (these values state the window size for reflection measurements; for transmission measurements the window size must be doubled):

| **Window Type** | **LP main lobe width (null-null)** | **BP main lobe width (null-null)** |
|---|---|---|
| Rectangular | .5/BW | 1/BW |
| Nominal | 1/BW | 2/BW |
| Low side lobe | 1.5/BW | 3/BW |
| Minimum side lobe | 2/BW | 4/BW |
| Kaiser (parameter β) | $\left(\frac{0.5}{BW}\right)\frac{\sqrt{\pi^2+\beta^2}}{\pi}$ | $\left(\frac{1}{BW}\right)\frac{\sqrt{\pi^2+\beta^2}}{\pi}$ |
| Chebyshev (parameter α dB) | $\left(\frac{0.5}{\pi \cdot BW}\right)\sqrt{\left(\frac{\pi}{2}\right)^2+\left(\cosh^{-1}\left(10^{\alpha/20}\right)\right)^2}$ | $\left(\frac{1}{\pi \cdot BW}\right)\sqrt{\left(\frac{\pi}{2}\right)^2+\left(\cosh^{-1}\left(10^{\alpha/20}\right)\right)^2}$ |

*Table 1. Gate size as a function of the frequency span*

As an example, using a nominal window with a frequency span of 3 GHz we should use a 2/3 ns gate for transmission, what is equivalent to, if we consider a propagation velocity of Vp= $3.10^8$ m/s, a 20 cm gate for reflection measurements, and, consequently, to a 40 cm gate for transmission measurements. In the trace shown in Figure 7 (using a nominal window with a frequency span of 3 GHz, a 20 cm gate for reflection measurements, and a 40 cm gate for transmission measurements), we can see the gate around the time domain response in transmission.

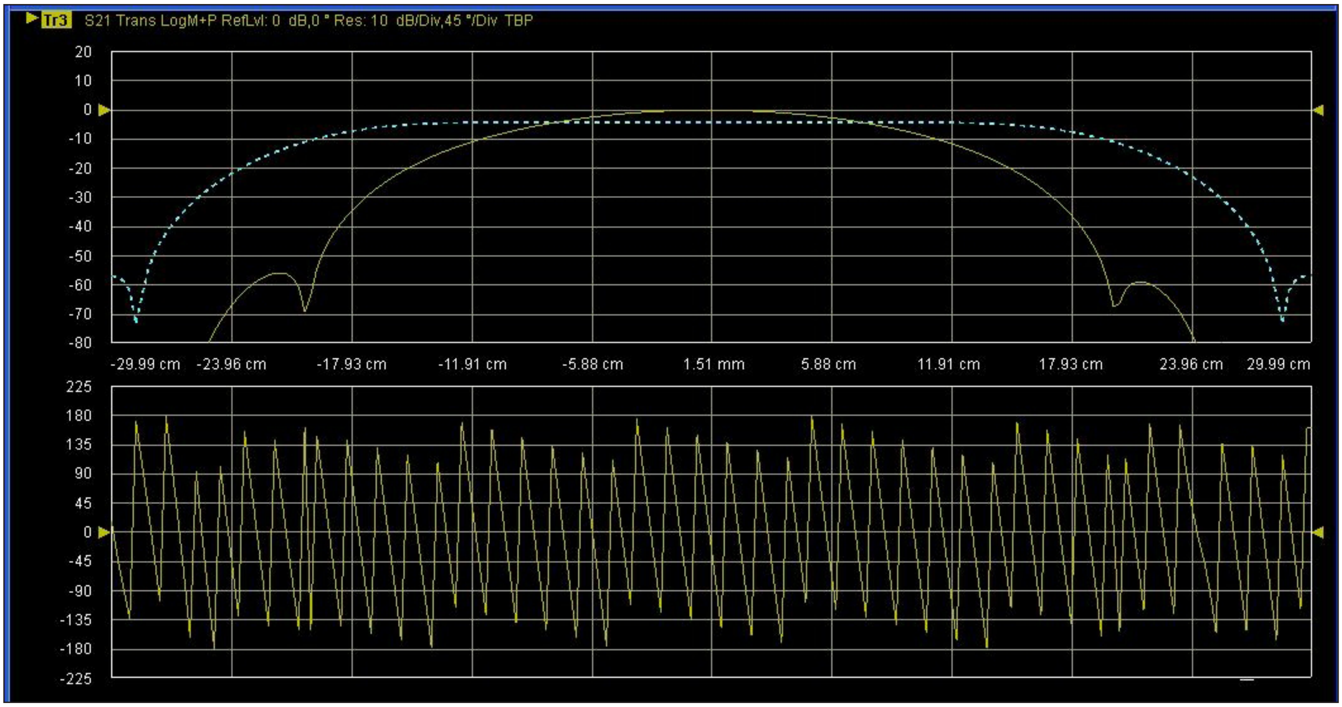



*Figure 7. 40 cm nominal gate applied to TD transmission response*

We can also see how the gate affects the time domain (TD) response. Of course, window type can be changed and the size modified, which will slightly vary the response. Then we can move to displaying the "Frequency Response with Time Gate" to see the result after applying the gating to our measurements. In the following trace we can see the transmission and reflection response of the thru with and without gate (Figure 8). We can clearly see the fading of the ripple in both traces, but also some effect on the trace itself. Not a big difference in transmission trace, which can be degraded by 0.02 dB, but a significant variation in reflection. Still, reflection values are still very good numbers (almost less than –40 dB), and it could be worth trying with different window sizes and types to enhance the results.

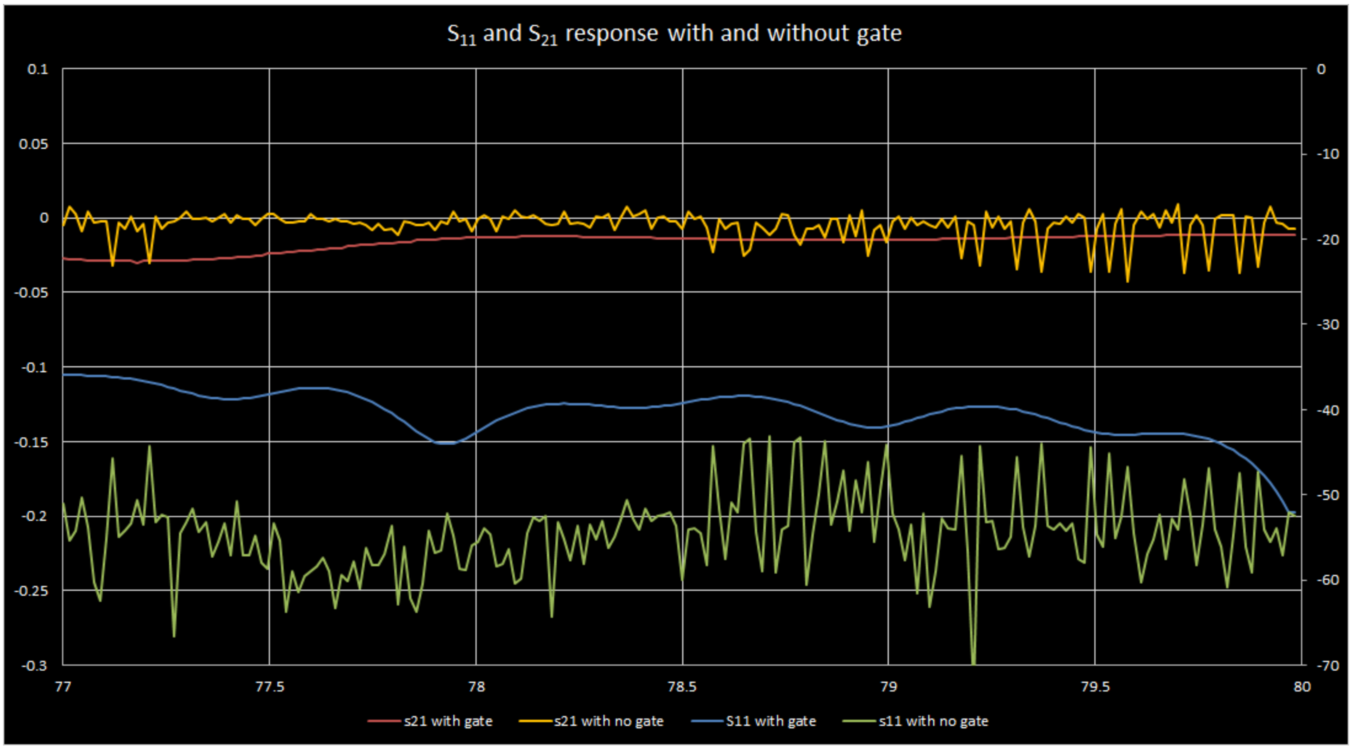



*Figure 8. Transmission and reflection response with and without gate*

Another point to be considered with these results is the fact that the setup of the system was not fully optimized (precision mechanical positioners for the MUT or extender heads and antennas were not used). It is important to reiterate that in this setup, the precise placement of the MUT, extender heads, and antennas will play a big role in the results to be obtained. Later in this document, some pictures of the setup in some customers will be shown.

## Test Results

For traceability, storage of the results is important, and, for this purpose, the data and images can be saved. Care must be taken when saving the data if the format is in .s2p because, by default, the gating will not be taken into account. The results can be saved in a .csv or .txt format, or the ShockLine MS46522B system can be setup to save the .s2p file with the applied gating in the system menu as shown in Figure 9 **(System → Setup → Misc. Setup → SnP Files Setup)**. In the SnP Setup popup window, select Save Gated Data to keep the gating in the .s2p file.

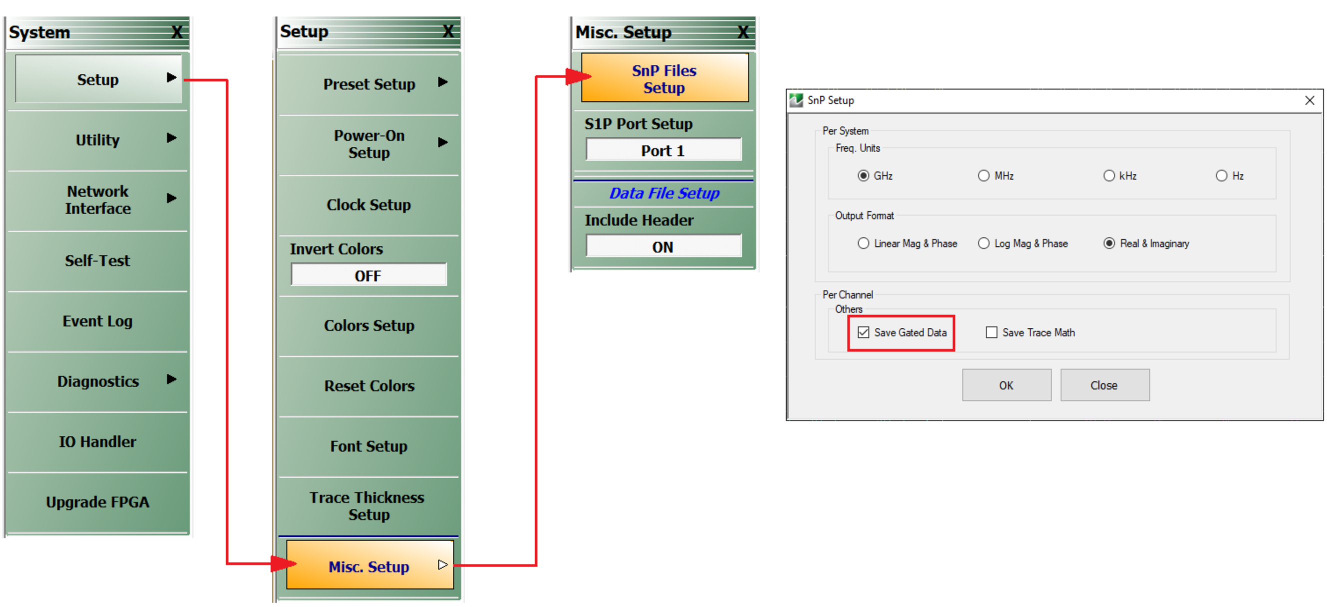



*Figure 9. Procedure to change the s2p file data*

## Some Examples

Recently, great interest has developed within the European automotive industry around characterizing materials used in bumper manufacturing that could affect radar transmissions. The big automobile manufacturers are pushing their contractors to measure the material characteristics in the E-band frequency range on all related components used in radars. Different materials, paint coatings, plastic injection methods, and material widths must be tested many times in a production environment to accurately characterize their behavior. To accomplish this, simplicity and ease-of-use of the VNA system is usually what customers require. The ShockLine MS46522B E-band system and this particular setup for material characterization appears to be the best solution to fit those needs. A VNA that is almost plug-and-play, a calibration method that barely takes a couple of minutes to be done, and a measurement method that is repeatable and easy to perform constitutes the best setup for making these measurements.

Of course, and in order to obtain consistent results, precise positioning of the setup is required. This is usually not a problem at all for these type of customers, but it is something to be considered when approaching this setup.

One customer was a contractor working on bumpers for a major European automobile manufacturer. In this case, they were able to manufacture a structure to hold both the VNA extender heads with the antennas and the sample to be measured. They also built the metal plate for calibration (Figure 10).

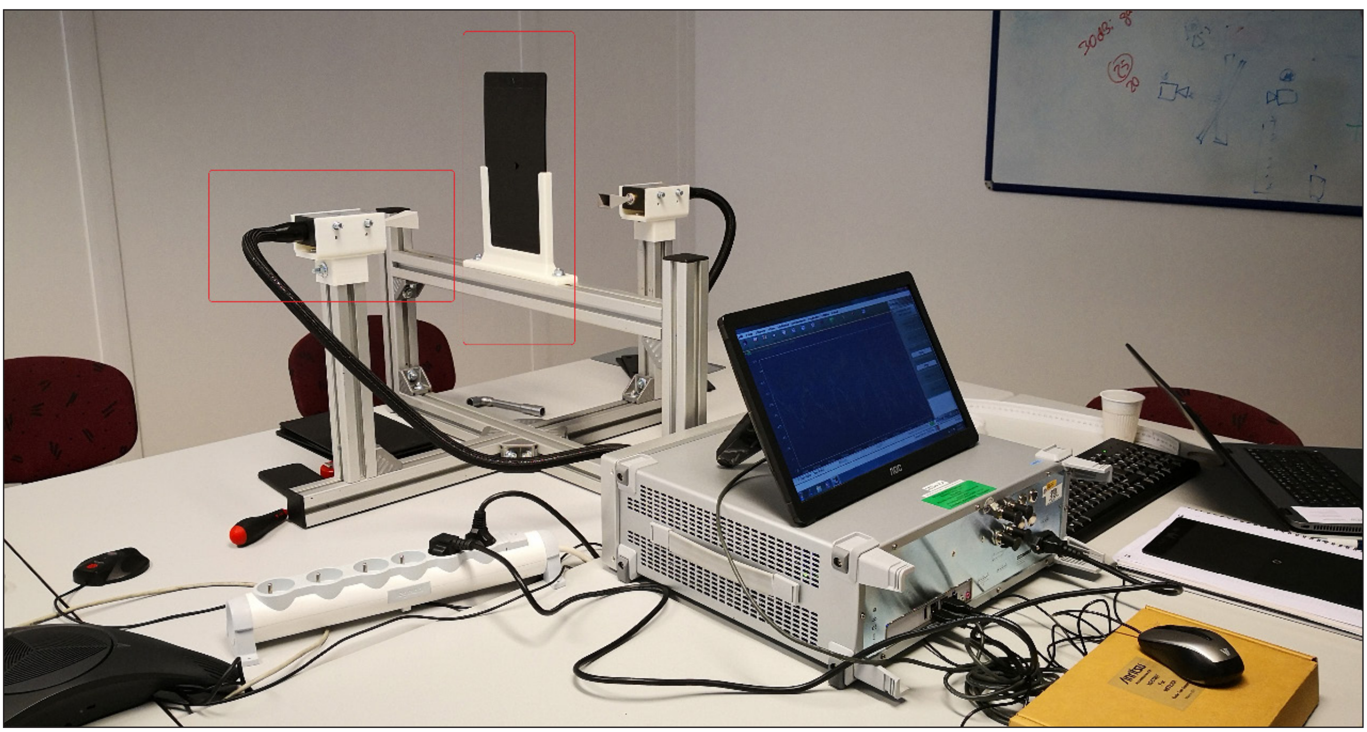


*Figure 10. System setup for the measurements with customer*

In the picture we can see the structure to hold the parts of the system and all of them are movable so we can adjust the length between the antennas, the position of the sample, etc. One important point to mention is the holder of the extender head. They were 3D printed in plastic, which turned out to be a good solution as in a second demo for a different customer this holder was manufactured in metal and was the cause of several reflections.

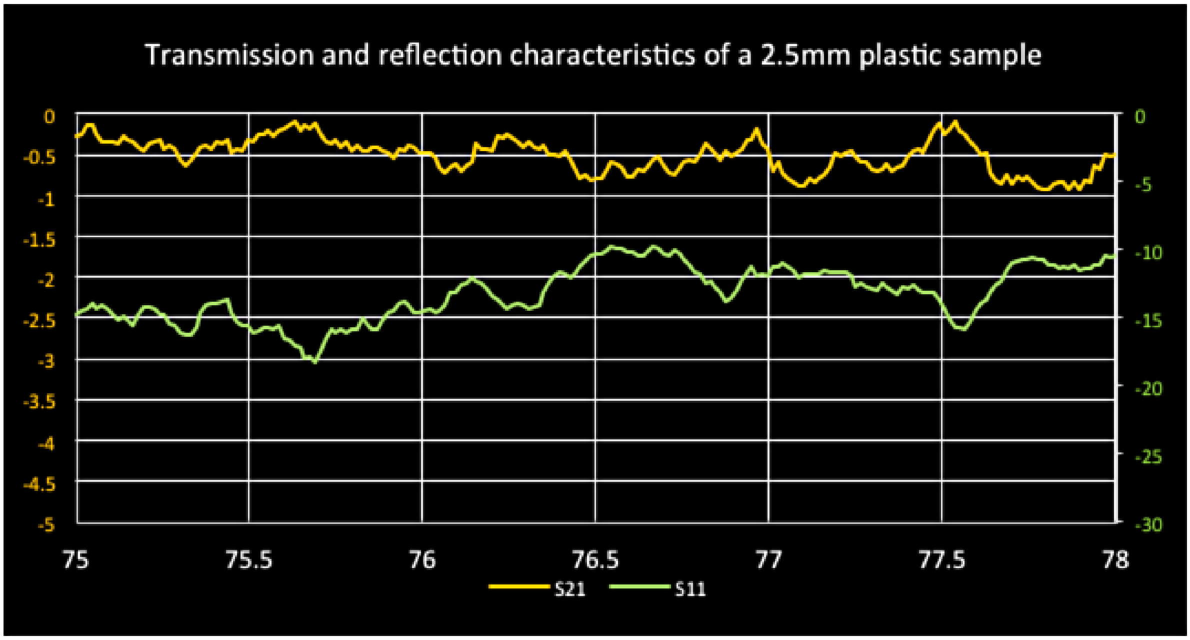



*Figure 11. Transmission and reflection behavior of a plastic sample*

In Figure 11 we can see the trace with the reflection and transmission characteristic and behavioir of one of their plastic samples.

The possibility of adjusting the vertical position of the sample gives us the flexibility to play with different sample sizes.

A second customer visited was a contractor working in this case for PSA group. Here the mechanical setup was a bit more complex, as they wanted to characterize not just samples but entire bumper parts (however once again, they took care of manufacturing everything to setup the system). The results were very similar to what we measured with the other customer, with the exception of some ripple obtained in transmission due to the extender head holders manufactured in metal in this case. One lesson learned is that it is better to have the parts in plastic if possible, to avoid possible reflections affecting our measurements.

## Summary

The ShockLine MS46522B E-band system enables a very simple and intuitive setup to conduct material characterization. The most appreciated feature is the simplicity of the setup and configuration, as well as the repeatability of the measurements compared to other systems.

The equipment required can be summarized in the following:

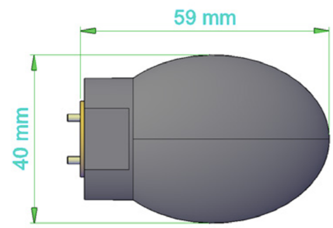
- ShockLine MS46522B-082 (1 meter E-band option.  Alternatively, option 083 with 5 meter test cables could be needed in case of testing whole bumpers)
  - Option 002 Time Domain
- Two antennas (WR-12)
- Calibration kit (a metallic plate)
- Mechanical setup to hold the samples and the extender heads

The antennas to be used can vary depending on the requirements of the customer, as we have previously shown. One should always consider how big the spot is that we want to illuminate in the sample to select the antenna we want to use. Following we can see different antennas that can be used in this setup:

- **Anritsu dielectric antenna:** this high-gain dielectric antenna offers very high performance and narrow beam width. It comes in WR-12 interface to be attached to the WG interface in the extender head.
- **Anritsu horn antenna:** this antenna has a lower gain and, thus, wider beam width, but still performs properly for these setups.

**Dielectric Resonator Antenna**

| | |
|---|---|
| Frequency Range: | 60-95 GHz |
| Input Power: | Max. 5 W |
| Gain: | 28-32 dBi |
| Return Loss: | < - 16dB |
| Connector type: | WR 12 |
| Connector flange: | UG387U |
| Polarization: | Linear |
| 3 dB HPBW Theta: | ~5° |
| 3 dB HPBW Phi: | ~5° |
| Weight: | 120 g |
| Length: | 50 mm |
| Diameter: | 40 mm |



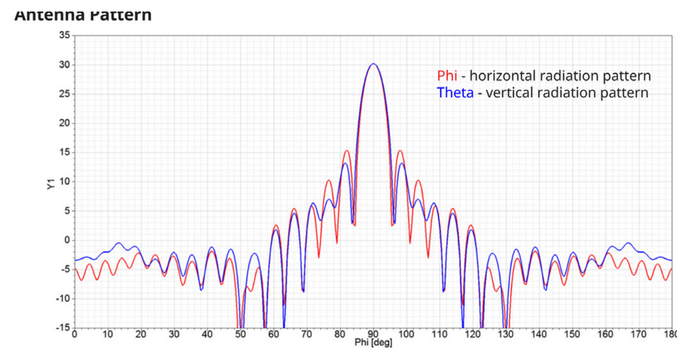



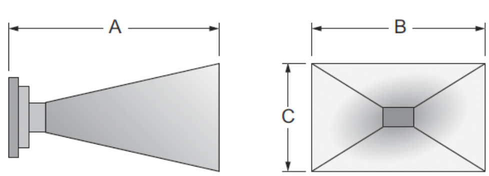

*Figure 12. Dielectric antenna performance data*

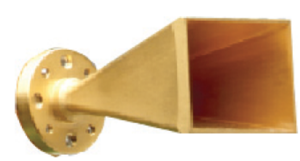
The interface is WR-12 and the size of the antenna is reduced, doing this appropriate for this kind of setups. For more information please refer to the Antenna and Antenna Kits Technical Data Sheet located on anritsu.com.

- **Anteral:** another lens antenna with typically more than 30 dB gain and a narrow beam (typically less than 5°) width for small radiation spots. To learn more visit Anteral's website.

**Horn Antennas** Directional horn antennas are RoHS compliant and feature a standard one year warranty.

| Frequency Range (GHz) | Gain (dBi) | VSWR (max) | Flange | Dimensions A x B x C (mm) | Designator | Anritsu Part Number |
|---|---|---|---|---|---|---|
| 60.5 to 92.0 | 25 | 1.2 | UG-387/U | 134.00 x 28.00 x 21.00 | WG26 WR12 R740 | 2000-1872-R |



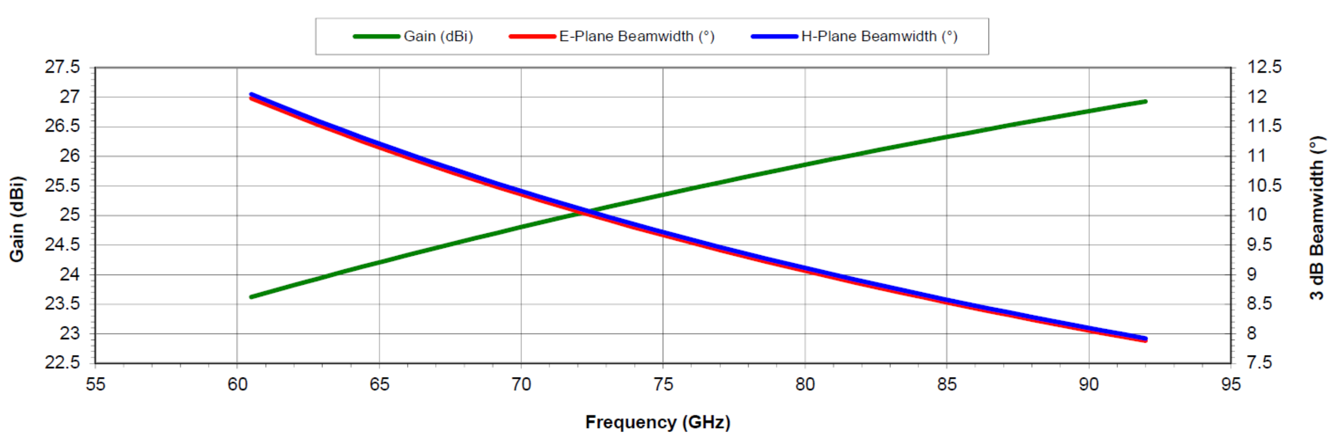
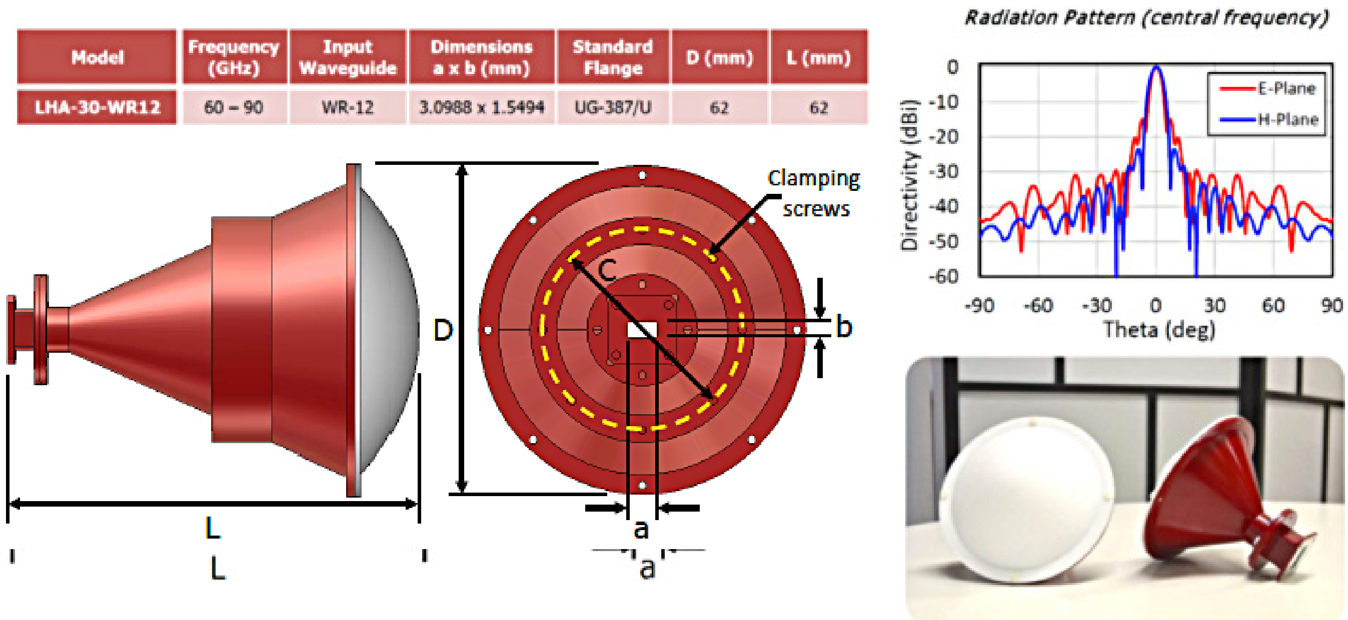



*Figure 13. Horn antenna performance data*



| Model | Frequency (GHz) | Input Waveguide | Dimensions a x b (mm) | Standard Flange | D (mm) | L (mm) |
|---|---|---|---|---|---|---|
| LHA-30-WR12 | 60 – 90 | WR-12 | 3.0988 x 1.5494 | UG-387/U | 62 | 62 |



*Figure 14. Anteral lens antenna performance data*

## Radar Configuration on the Car

Here is a sample configuration of the radar on the car. This information comes from one car manufacturer (data can vary significantly between different manufacturers). The radar is relatively close to the bumper. It is not mandatory that the radar is positioned perpendicular to the bumpers, so sometimes it is positioned at an angle (in this example, 7°) between the radar and the plane of the bumper where the beam is transmitted. Different angles can be measured to characterize the effect of this deviation in the position of the radar device.

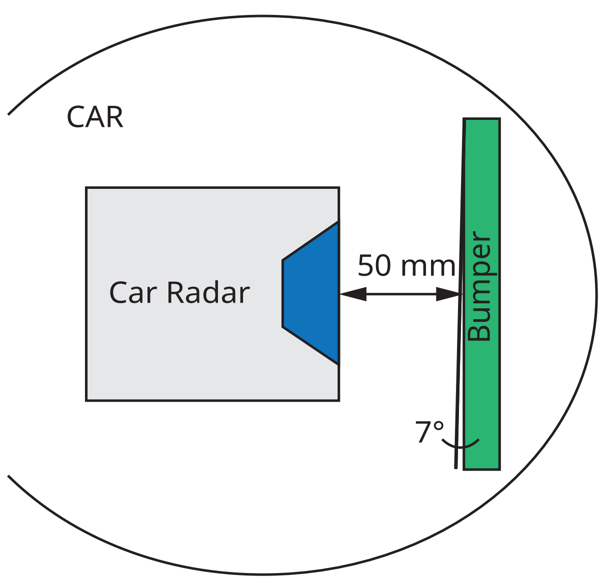




*Figure 15. Diagram of radar positioning regarding the bumper*

## Note

This document was initially created by J.P. Guillemet in co-working with J. Martens, JB Soeiro, and G. Denis, as a result coming from some tests with cars and bumpers manufacturers. This is an update coming from the last tests done, mainly with the bumper manufacturers with additional tests performed and feedback documented and received.

Anritsu envision : ensure

Specifications are subject to change without notice.


• **United States**
**Anritsu Company**
450 Century Parkway, Suite 190, Allen,
TX 75013 U.S.A.
Phone: +1-800-Anritsu (1-800-267-4878)

• **Canada**
**Anritsu Electronics Ltd.**
700 Silver Seven Road, Suite 120,
Kanata, Ontario K2V 1C3, Canada
Phone: +1-613-591-2003
Fax: +1-613-591-1006

• **Brazil**
**Anritsu Electrônica Ltda.**
Praça Amadeu Amaral, 27 - 1 Andar
01327-010 - Bela Vista - Sao Paulo - SP - Brazil
Phone: +55-11-3283-2511
Fax: +55-11-3288-6940

• **Mexico**
**Anritsu Company, S.A. de C.V.**
Blvd Miguel de Cervantes Saavedra #169 Piso 1, Col. Granada
Mexico, Ciudad de Mexico, 11520, MEXICO
Phone: +52-55-4169-7104

• **United Kingdom**
**Anritsu EMEA Ltd.**
200 Capability Green, Luton, Bedfordshire LU1 3LU, U.K.
Phone: +44-1582-433200
Fax: +44-1582-731303

• **France**
**Anritsu S.A.**
12 avenue du Québec, Batiment Iris 1-Silic 612,
91140 VILLEBON-SUR-YETTE, France
Phone: +33-1-60-92-15-50
Fax: +33-1-64-46-10-65

• **Germany**
**Anritsu GmbH**
Nemetschek Haus, Konrad-Zuse-Platz 1
81829 München, Germany
Phone: +49-89-442308-0
Fax: +49-89-442308-55

• **Italy**
**Anritsu S.r.l.**
Via Elio Vittorini 129, 00144 Roma Italy
Phone: +39-06-509-9711
Fax: +39-6-502-2425

• **Sweden**
**Anritsu AB**
Isafjordsgatan 32C, 164 40 KISTA, Sweden
Phone: +46-8-534-707-00

• **Finland**
**Anritsu AB**
Teknobulevardi 3-5, FI-01530 VANTAA, Finland
Phone: +358-20-741-8100
Fax: +358-20-741-8111

• **Denmark**
**Anritsu A/S**
Torveporten 2, 2500 Valby, Denmark
Phone: +45-7211-2200
Fax: +45-7211-2210

• **Russia**
**Anritsu EMEA Ltd.**
**Representation Office in Russia**
Tverskaya str. 16/2, bld. 1, 7th floor.
Moscow, 125009, Russia
Phone: +7-495-363-1694
Fax: +7-495-935-8962

• **Spain**
**Anritsu EMEA Ltd.**
**Representation Office in Spain**
Edificio Cuzco IV, Po. de la Castellana, 141, Pta. 5
28046, Madrid, Spain
Phone: +34-915-726-761
Fax: +34-915-726-621

• **United Arab Emirates**
**Anritsu EMEA Ltd.**
**Dubai Liaison Office**
902, Aurora Tower,
P O Box: 500311- Dubai Internet City
Dubai, United Arab Emirates
Phone: +971-4-3758479
Fax: +971-4-4249036

• **India**
**Anritsu India Pvt Ltd.**
6th Floor, Indiqube ETA, No.38/4, Adjacent to EMC2,
Doddanekundi, Outer Ring Road, Bengaluru – 560048, India
Phone: +91-80-6728-1300
Fax: +91-80-6728-1301

• **Singapore**
**Anritsu Pte. Ltd.**
11 Chang Charn Road, #04-01, Shriro House
Singapore 159640
Phone: +65-6282-2400
Fax: +65-6282-2533

• **P. R. China (Shanghai)**
**Anritsu (China) Co., Ltd.**
Room 2701-2705, Tower A,
New Caohejing International Business Center
No. 391 Gui Ping Road Shanghai, 200233, P.R. China
Phone: +86-21-6237-0898
Fax: +86-21-6237-0899

• **P. R. China (Hong Kong)**
**Anritsu Company Ltd.**
Unit 1006-7, 10/F., Greenfield Tower, Concordia Plaza,
No. 1 Science Museum Road, Tsim Sha Tsui East,
Kowloon, Hong Kong, P. R. China
Phone: +852-2301-4980
Fax: +852-2301-3545

• **Japan**
**Anritsu Corporation**
8-5, Tamura-cho, Atsugi-shi, Kanagawa, 243-0016 Japan
Phone: +81-46-296-6509
Fax: +81-46-225-8352

• **Korea**
**Anritsu Corporation, Ltd.**
5FL, 235 Pangyoyeok-ro, Bundang-gu, Seongnam-si,
Gyeonggi-do, 13494 Korea
Phone: +82-31-696-7750
Fax: +82-31-696-7751

• **Australia**
**Anritsu Pty Ltd.**
Unit 20, 21-35 Ricketts Road,
Mount Waverley, Victoria 3149, Australia
Phone: +61-3-9558-8177
Fax: +61-3-9558-8255

• **Taiwan**
**Anritsu Company Inc.**
7F, No. 316, Sec. 1, NeiHu Rd., Taipei 114, Taiwan
Phone: +886-2-8751-1816
Fax: +886-2-8751-1817


nqa ISO 9001 Registered



11410-01181, Rev. B Printed in United States 2020-03