Compact RCS Test Range Field Probing using a Shorted Antenna as Target

Gil Yemini, Stefano Sensani
ORBIT/FR Engineering Ltd. MVG,
24 Tsavei Hanahal St., PO Box 12096,
Emek Hefer Industrial Park, 3877701, Israel
{gil.yemini,stefano.sensani}@mvg-world.com

Andrea Giacomini, *Senior Member, AMTA,*
Lars J. Foged, *Fellow*, AMTA
Microwave Vision Italy SRL,
Via dei Castelli Romani 59, 00071, Pomezia, Italy
{andrea.giacomini,lars.foged}@mvg-world.com

Matan Kahanov, Maria Baskin, Ilan Kaplon
Center of Technology, Rafael
{matank,mariaba,ilankap}@rafael.co.il

Marcel Boumans, *Senior Member, AMTA,*
Antenna Measurement Experts GmbH
Ottobrunn, Germany
marcel.boumans@amxprts.de

***Abstract*— A new compact range for RCS measurements has been qualified. It has a quiet zone of 3m diameter, 3m length and operates from 0.7 to 50 GHz. The range is oriented for RCS measurements, whereas antenna measurements are not foreseen. All RF equipment is integrated close to the feeds with highly integrated pulsed Tx/Rx-modules. Therefore, classical field probing by moving a probe antenna along a linear slide would require significant modification of the RF system. If one measures the RCS of a target on the linear slide, it is difficult to distinguish the target down range reflection from the reflection of the linear slide structure. A long stand-off between target and slide is not practical for mechanical reasons in regard to accuracy requirements at 50 GHz. More important, simply measuring a reflective plate will not give any cross-polarization information. A more advanced target is created by using an antenna with a short circuit after an RF cable to locate the reflection of the short well behind the scanner in down range. In addition, the antenna receives only nominal quiet zone co-polarization, consequently, only reflects co-polarization from the short, and the feed receives the compact range induced cross-polarization at the feed (one-way). The method has shown to be extremely effective. More important, it uses the RF instrumentation and RCS measurement methods as designed for regular operation without any modification, thus is the most realistic system level quality representation of the quiet zone, can be repeated at any time without elaborate range reconfiguration requirements and can serve as part of the commissioned RF system performance qualification.**

The paper will present the quiet zone field probe test setup, a calculation of antenna and RF cable requirements, an analysis of the down range profile of scanner and reflective antenna and field probing results.

I. INTRODUCTION

Accepted practice for the qualification of the Quiet Zone (QZ) of a Compact Range (CR) is field probing, as stated in the IEEE Std 149 [1]. Qualitative indications are only given about the field probe scanner and about using an “appropriate antenna as a sensor”, where appropriate is not further defined.

Attention must be paid to the gain of the probe antenna, ideally the antenna should be isotropic to see all interference from any direction with equal weight. This is, however, not practical since the measured field would be heavily disturbed by reflections from the field probe scanner setup. If the probe antenna gain is higher than isotropic, the antenna sees wide angle interference with reduced weight. This is in most cases acceptable since the highest source of interference is the CR reflector edge diffraction, which is close to boresight (typically 8 to 12 deg). Chamber reflections are typically low, in particular for a serrated edge CR.

Common practice is to use NRL Standard Gain Horns (SGH) [2]. Sometimes also Open-Ended Wave Guide (OEWG) probes are used. Since SGHs and OEWGs have only a half octave bandwidth and a CR is usually very broadband, also wideband horns (e.g. ridged horns) are commonly used to reduce the number of probe antennas needed. For broadband antennas, the gain is lower at the low end of the frequency band (comparable to OEWG) and is higher at the high end, depending on up to which frequency the wideband horn is used. Except for low frequencies below 2.6 GHz, NRL horns can have too high gain to properly sample the ripple in the quiet zone. Good practice is to use antennas with a gain between 10 and 15 dBi.

In CR which are used for Radar Cross-Section (RCS) measurements field probing using a reflection target instead of an antenna has also been practiced [3]. Ranges with RF instrumentation for only RCS measurements would require significant effort to use a receiving antenna on the field probe since an RF path needs to be routed through the chamber just for the purpose of the field probe measurements. Obviously, a reflection measurement is the more “natural” way to qualify the QZ of a pure RCS range, since it uses the exact same instrumentation setup as used for any regular RCS measurement.

To be able to separate the target reflection from the scanner structure in down range, one needs to mount the target on a long stand-off, which is intrinsically sensitive to vibrations and putting a large bending moment on the scanner. Another drawback is the high effect of scanner planarity axes on the target peak reflection.

Common targets are flat plates, dihedrals, or spheres. With flat plates and dihedrals, it is crucial to pay attention to the equivalent gain resp. pattern beamwidth, which is quickly too high resp. too narrow for sampling the ripple properly. A sphere has too high interaction with the scanner structure like an isotropic antenna and is therefore not of practical use.

The method mentioned in [3] “where a small sphere is suspended by three or more strings and positioned over a planar or volumetric region” is considered too complex and impractical.

The reflection target proposed in this paper is a shorted antenna. By locating an RF cable between the antenna input connector and the short circuit, it is possible to “design” and postpone the down range reflection well behind the scanner structure reflections, avoiding the need of mounting the probe antenna on a long stand-off.

Shorted antennas have been measured with RCS measurement techniques for the purpose of acquiring antenna parameters [4], but the authors could not find in literature references where shorted antennas have been used to field probe and qualify RCS ranges QZ performance.

II. FIELD PROBING: ONE-WAY VERSUS TWO-WAYS

In this section, it is discussed how the results of the antenna probe method (one-way) and the reflection targets (two-way) differ. A simplified view of the CR plane wave and a single interference source (e.g. edge diffraction) is shown in Figure 1.

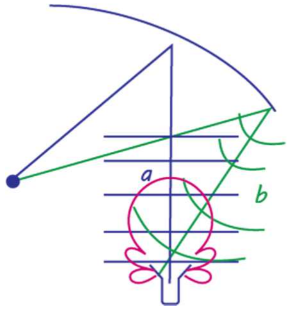

Figure 1. CR plane wave (a) and interference source (b) from the edge diffraction.

If the CR feed transmits a signal, the antenna probe receives the desired plane wave signal “a” and the undesired interference signal “b”. Note that in the following the use of the terms a and b are for the purpose of a qualitative discussion only, and do not represent an exact mathematical description of a physical model.

If the antenna is terminated with a short circuit, all of the received signal is re-transmitted, ignoring internal losses in first approximation. Since the setup is reciprocal, the transmission coefficient for the reflected signal from the antenna to the CR feed will be identical (s12 = s21).

Thus, the RCS of the antenna can be expressed as:

$$K\ (a+b)^2 = K\cdot(a^2+2a\cdot b+b^2) \qquad (1)$$

This is intuitive analyzing Figure 1. : the CR feed will receive the plane wave reflection of the shorted antenna (“a^2”), the contribution from the reradiated signal being diffracted from the reflector edge towards the CR feed (“a·b”), the signal from the feed diffracting from the reflector edge, received by the antenna and reradiated from the antenna in the CR propagation direction (“b·a”) and, finally, the signal from the CR feed diffracting from the edge, being retransmitted to the edge by the antenna and being diffracted to the CR feed (“b^2”). Note that “b^2” is much smaller than the other terms “a^2” and “a·b”.

Thus, a shorted antenna will square the field resp. the power in the QZ. Consequently, the one-way QZ field can be taken as the root of the signal probed with the shorted antenna. In dB this means that the signal is halved, consequently parameters like total variation, taper and ripple are halved.

Note that for n interference sources this discussion can be generalized as:

$$K\cdot(a+b_1+...+ b_n)^2 = K\cdot(a^2+2a\ (b_1+...+b_n)+\sum b_i\, b_j) \qquad (2)$$

where each term $b_i\, b_j$ is much smaller than the other terms.

Using a reflection target (plate or dihedral), there is a small difference in comparison to the shorted antenna, which is in most cases negligible as explained below.

If a plate of approximately the same surface area as the antenna aperture is considered, then if the plane wave hits the plate, the reflected field is comparable to the field in the transmitting antenna aperture. Thus, the reflected field as function of angle is comparable to the radiated field of the antenna. Consequently, the term “a^2” is comparable. Also, the amount of energy which hits the reflector edge is comparable, which means the term “a·b” is comparable and, because of reciprocity, also “b·a” is comparable. However, the path “b^2” is different: since the field from the diffraction source hitting the plate is inverted on the plate as a metallic reflection, the signal is specularly reflected away from the original diffraction source. Thus, the energy reflected back to the source (the reflector edge) is much less than in the shorted antenna case. The received signal can be symbolized as:

$$a^2+2a\cdot b+B^2 \qquad (3)$$

If a dihedral is considered, the principles for the reflections “a^2”, “a·b” and “b a” are similar as for the flat plate and thus comparable with the shorted antenna. The reflection “b^2”, however is again different: because of the double bounce the field is not inverted and is identical to the incoming field. Thus, all energy is reflected back to the diffraction source.

To think in the same way for the shorted antenna, the energy diffracted from the edge is “reflected” towards the reflector.

These differences in the field probing with different reflection targets are illustrated in Figure 2.

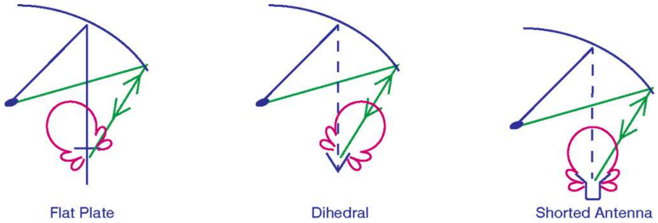
Flat Plate Dihedral Shorted Antenna

Figure 2. Field probing with Flat Plate, Dihedral or Shorted Antenna.

Thus, in the case of plate and dihedral the one-way fields are not exactly the square root of the two-way fields. But since the term “b^2” resp. “B^2” is much smaller than “a^2” or “$a \cdot b$”, it is in most cases a negligible difference.

III. CROSS-POLARIZATION

A relevant aspect of the CR performance is the polarization purity of the QZ, besides the amplitude and phase uniformity of the plane wave. Here interference resp. diffraction is secondary since cross-polarization in the QZ is mainly a Geometrical Optics (GO) effect.

The flat plate, as well as a sphere, reflects the incident field, which has a slightly rotated field vector, unchanged and, on the way back, the vector is counter rotated to its original orientation (reciprocity). This is illustrated in Figure 3.

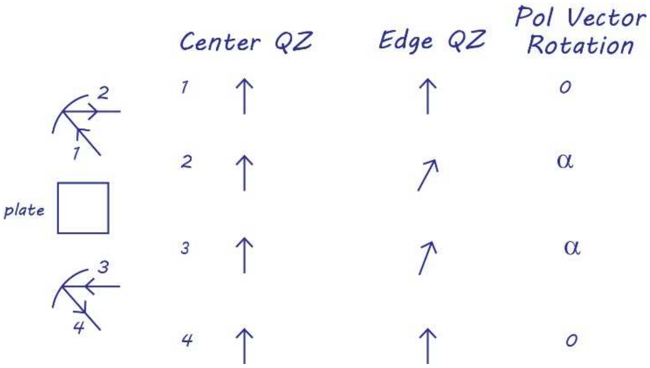

Figure 3. Cross-polar vector rotations measuring RCS of flat plate.

Consequently, cross-polarization cannot be characterized by measuring a flat plate or a sphere. It is indeed comparable to one-way measurements where the CR feed transmits and the SGH is aligned to the co-pol vector as seen in the QZ. If the SGH transmits in this same position, then the CR feed does not see any cross-polarization, though the SGH is misaligned with respect to the system polarization definition (typically horizontal or vertical).

With a dihedral, the linear polarization is “mirrored” along the connecting edge of the dihedral. On the way back the vector is counter rotated in relation to the incoming wave, but this is now in the same direction as the mirrored polarization. Thus, the polarization rotation is doubled, and compared to the one-way measurement the Cross-polar E-vector needs to be halved resp. the Cross-polar power reduced by 6 dB. This is illustrated in Figure 4.

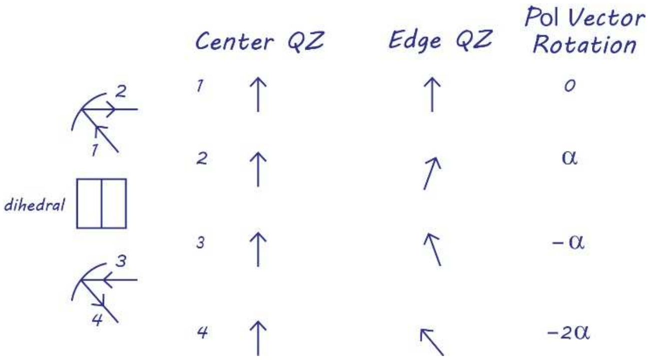

Figure 4. Cross-polar vector rotations measuring RCS of dihedral.

Now there is a fundamental difference with the shorted antenna. If the antenna is aligned according to the QZ nominal polarization definition (horizontal or vertical), then the received signal is only the co-polar part of what is received in the QZ. This signal is retransmitted as pure QZ co-polarization, and the CR feed receives the correct relation between co- and cross-polarization as in a one-way measurement.

IV. SENSITIVITY ANALYSIS

The sensitivity analysis allows to determine the dynamic range of the CR for field probing. The RCS of a short-circuited antenna is derived by comparing the radar equation with the Friis transmission equitation squared. The received power gets completely transmitted again and goes through the same path to be received by the radar.

The radar equation can be written as:

$$\frac{P_r}{P_t} = \frac{{G_r}^2 \sigma \lambda^2}{(4\pi)^3 R^4} \tag{4}$$

where:

- Pr and Pt are respectively received and transmitted power;
- Gr is the gain of the radar antenna (transmit and receive are equal);
- σ is the RCS of the target;
- λ is the wavelength;
- R is the equivalent range distance.

The Friis equation squared can be written as:

$$\frac{P_r}{P_t} = \frac{{G_r}^2 {G_p}^2 \lambda^4}{(4\pi R)^4} \tag{5}$$

where: Gp is the gain of the probe antenna.

By equating (4) and (5), the RCS of the target antenna can be easily derived:

$$\sigma = \frac{{G_p}^2 \lambda^2}{4\pi} \tag{6}$$

As a verification, the gain of the probe can be replaced by its effective aperture Ae:

$$G_p = \frac{4\pi A_e}{\lambda^2} \tag{7}$$

and the RCS becomes:

$$\sigma = \frac{4\pi {A_e}^2}{\lambda^2} \tag{8}$$

which can be easily identified as the RCS of a flat plate of surface Ae.

Considering the probe models used for the field probing and the sensitivity of the system, the resulting dynamic range facility is reported in Table I.

TABLE I. SENSITIVITY OF THE COMPACT RCS TEST RANGE.

Frequency (GHz)	Wavelength (mm)	Probe Model	Gain probe (dBi)	Gain (lin)	RCS (m^2)	RCS (dBsm)	Sensitivtity (dBsm)	Dyn. Range (dB)
0.7	428.6	SH400	6	3.98	0.2317	-6.4	-89.0	82.6
2	150.0	SH400	11.5	14.13	0.3573	-4.5	-86.0	81.5
4	75.0	SH400	11.5	14.13	0.0893	-10.5	-79.0	68.5
4	75.0	SH2000	6.5	4.47	0.0089	-20.5	-79.0	58.5
8	37.5	SH2000	9.5	8.91	0.0089	-20.5	-79.0	58.5
12	25.0	SH2000	11.2	13.18	0.0086	-20.6	-79.0	58.4
18	16.7	SH2000	13.2	20.89	0.0096	-20.2	-77.0	56.8
18	16.7	SH4000	10.3	10.72	0.0025	-26.0	-85.0	59.0
26	11.5	SH4000	11.7	14.79	0.0023	-26.3	-81.0	54.7

V. TEST SETUP

The Compact RCS Test Range described in this paper has a QZ of 3m diameter, 3m length and operates from 0.7 to 50 GHz. A 3D sketch drawing of the facility is shown in Figure 5.

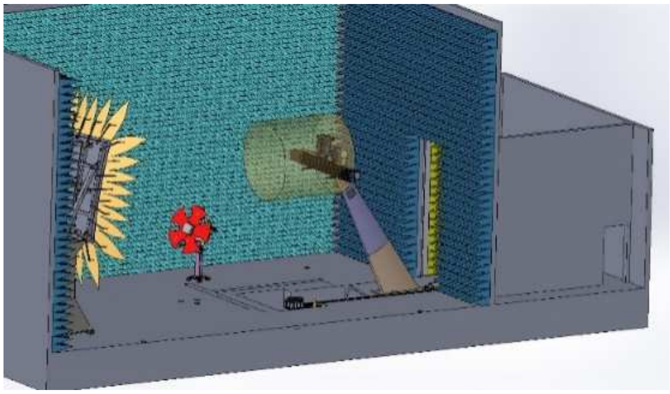

Figure 5. 3m QZ Compact RCS Test Range.

The range is only for RCS measurements, antenna measurements are not foreseen. All RF equipment is integrated close to the feeds with highly integrated pulsed Tx/Rx-modules. The operational frequency range is divided into three bands: 0.7-4 GHz, 4-18 GHz, and 18-50 GHz. The two lower bands employ a single antenna feed for both Tx and Rx channels (QH400 and QH2000 respectively), while the upper band uses separate antennas for Tx and Rx (QH18000) [5]. Stations using single feeds incorporate a short pulses Tx/Rx module that separates Tx from Rx by time. As a result, the two lower band are exploiting a true monostatic measurement, while the upper band measurement is quasi monostatic.

As previously explained, the QZ probing is carried out using a reflection target, and in particular a shorted antenna with a sufficiently long RF cable. A sketch of the field probe equipment in shown in Figure 6.

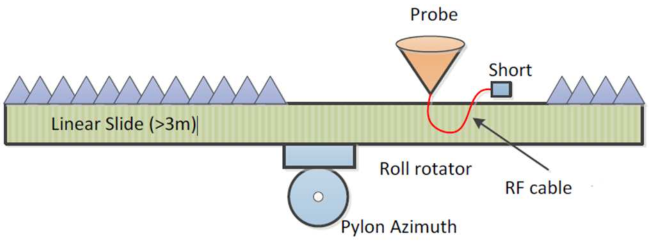

Figure 6. Field probe scanner with shorted antenna.

The purpose of this probing technique is to locate the down range reflection of the target well behind the field probe scanner. The down range RCS profile of the facility is shown in Figure 7. The contributors are identified in down range at different distances and the re-radiation from the short circuit is clearly identifiable. The RF cable length has been designed in such a way to isolate this contribution from the other unwanted signals, such as the probe structural scattering, the field probing equipment and the backwall of the chamber. Coherent background subtraction is also applied, showing a reduction of the echo of the different contributions, except for the probe antenna and its load.

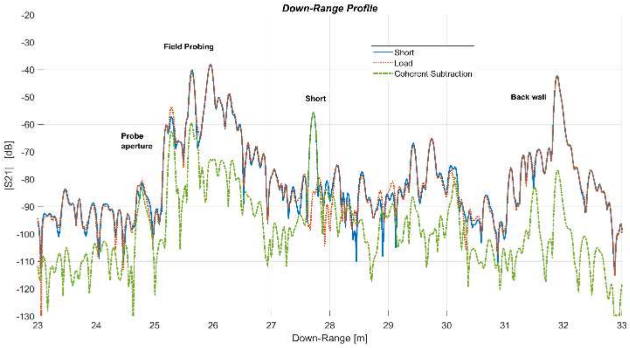

Figure 7. Down-range RCS profile of the faciltiy with the field probe scanner installed.

VI. TEST RESULTS

The test results collected from the field probing campaign are reported in this section. Cross-range plots in the QZ center showing the field uniformity in amplitude and phase at different frequencies are shown from Figure 8. to Figure 10. An outstanding agreement is found between the Physical Optics (PO) modeling of the as-built range (not considering absorber reflections) and the data measured with the probing technique based on the use of a shorted antenna.

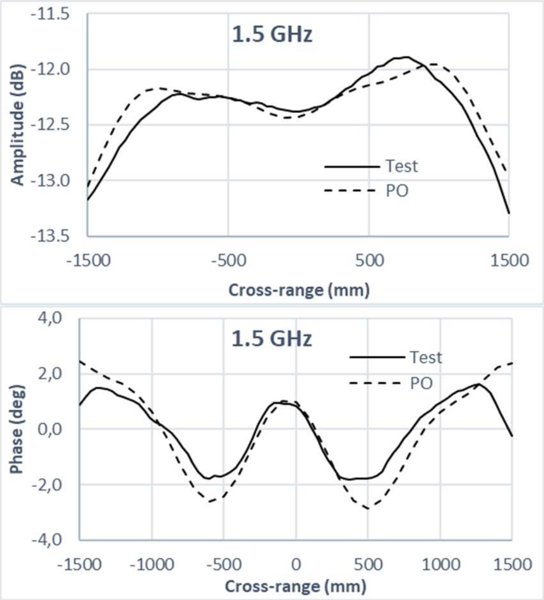

Figure 8. Cross-range QZ field at 1.5 GHz in amplitude (top) and phase (bottom), comparison between PO and probing data.

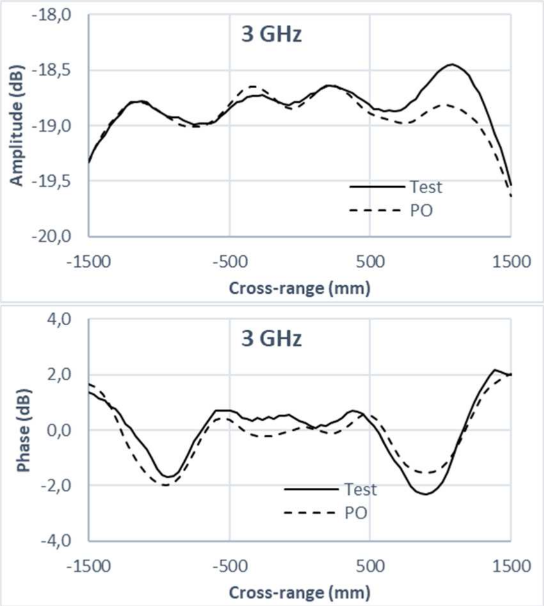

Figure 9. Cross-range QZ field at 3 GHz in amplitude (top) and phase (bottom), comparison between PO and probing data.

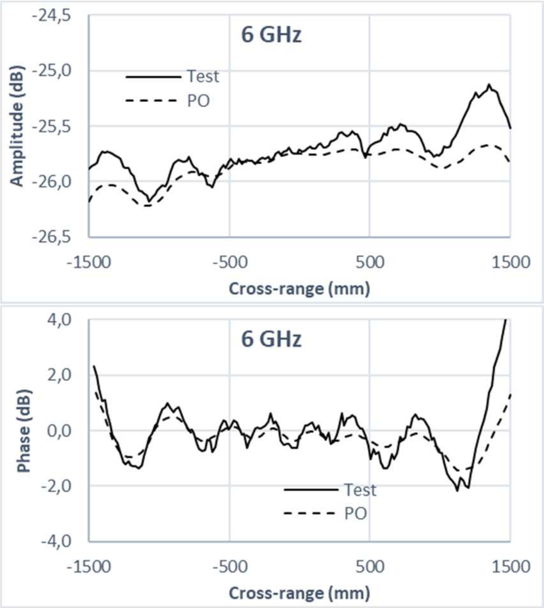

Figure 10. Cross-range QZ field at 6 GHz in amplitude (top) and phase (bottom), comparison between PO and probing data.

VII. CONCLUSIONS

It has been shown that field probing using a reflection target is most practical in an RCS range. Using a shorted antenna with RF cable between antenna input port and short circuit allows to get a clear down range separation of the target reflection and the scanner structure. Also, the shorted antenna allows us to measure cross-polarization with a reflection method. The one-way antenna field probing is exactly the square root of the two-way field probing method as far as Co-polarization is concerned. For Cross-polarization (more exactly XPD), the two methods deliver the same results. Comparison between PO simulations and field probe data have shown excellent agreement.

VIII. INTELLECTUAL PROPERTY STATEMENT

All work presented and related to this paper was solely the work of MVG Israel and did not include any support or consultation from the MVG OATI division located in the USA.

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