Compact RCS Test Range Feed Carousel and Baffle House Design

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***Abstract*— A new compact range for RCS measurements has been installed and qualified by Orbit/FR Engineering Ltd. MVG. It has a Quiet Zone of 3m diameter, 3m length and operates from 0.7 to 50 GHz, with a feed carousel that allows for fully automated feed change. The RF design is not intended for antenna measurements in its current configuration, but mainly dedicated to RCS. The operational frequency band is split into three sub-bands: each of the lower two bands have a monostatic operated dual polarized feed, while the higher band has a quasi-monostatic operated feed configuration with two dual polarized feeds. Pulsed Tx/Rx modules are directly integrated into the feed assembly. Also, the RF band switching equipment, as well as the network analyzer, are integrated in the feed carousel, so that there are no flexing cables or any other relative movement of RF components when the relevant feed is moved into the focus. Together with tight temperature control, this leads to the best possible RF stability. Since all measurements are time gated, there is no need for an absorber baffle wall to prevent feed direct leakage into the quiet zone. Thus, all feeds are mounted on a clean absorber disk without any absorber blockage and unwanted primary pattern distortion down to a conical angle of 90deg. This allows to obtain an exceptionally good QZ performance even at the lowest frequencies, with an outstanding comparison with the predictions based on Physical Optics.**

The paper will describe the range design fundamentals, the feed carousel concept and the relevant RF instrumentation. The Quiet Zone performance evaluated by field probing with a Shorted Antenna located in the Quiet Zone will be extensively presented, demonstrating full compliance with the specifications.

I. INTRODUCTION

A Compact Test Range (CTR) for Radar Cross Section (RCS) measurements has been recently commissioned by Orbit/FR Engineering Ltd (MVG). The facility is oriented to RCS measurements and supports measurements in the operational frequency band from 0.7 GHz up to 50 GHz, with a cylindrical Quiet Zone (QZ) of 3-meter diameter and 3-meter length. The CTR consists of a tailored feed carousel, a corner fed metallic reflector and an interchangeable target support. The picture of the CTR seen from the reflector is shown in Figure 1.

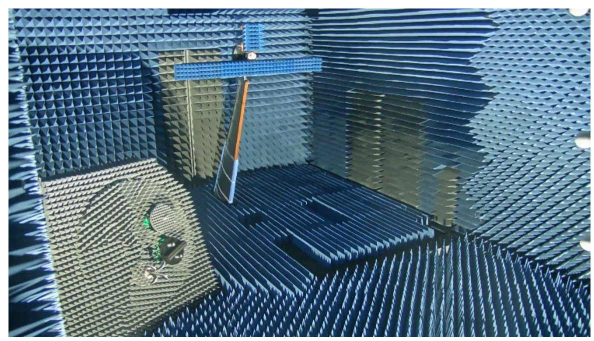

Figure 1. View of the Compact Test Range from the reflector area.

A detailed view of the Serrated Edge reflector seen from the target area is shown in Figure 2.

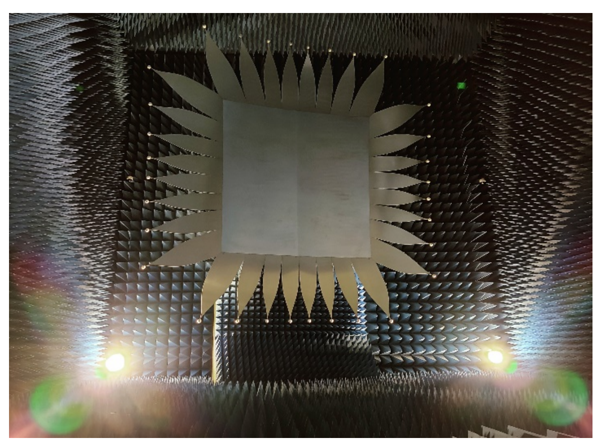

Figure 2. View of the 3m QZ Serrated Edge Reflector from the target area.

All CTR components were installed on a specially stiffened suspended floor, in order to eliminate external vibrational noise and maintain relative distances between them constant throughout the measurement campaigns. An anechoic chamber and an electromagnetic shielding were installed on the walls of the housing building to reject stray signals and reduce unwanted reflections. A temperature control system was designed and installed to keep environmental temperature as stable as 1°C (peak-to-peak) over time, once a working point was set. A detailed Computational Fluid Dynamics (CFD) analysis was performed to maintain and control the required temperature, humidity, and airflow parameters in the chamber, especially on the reflector surface and target region, as shown in Figure 3.

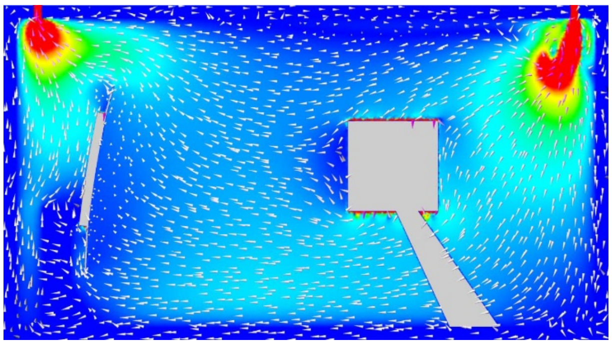

Figure 3. Computational Fluid Dynamics Analysis of the Compact Test Range.

Other supporting systems, such as cranes, lights, fire detection, cameras, etc., were designed and installed under careful electromagnetic considerations, to minimize stray signals and improve chamber clutter. Unwanted reflections from target supporting systems were reduced to the minimum. The design of the CTR was essentially based on a holistic approach, where all the interactions between the housing building and the CTR components were considered in the design process. Electromagnetic modeling and structural modeling based on Finite Elements Method (FEM) were extensively used at sub-system level in the detailed design of the system.

The CTR elements and its supporting systems were individually verified for proper functionality, before and after installation. When all sub-systems were considered ready, the CTR was characterized as a complete system.

II. MEASUREMENT PROCESS

The block diagram of the CTR electronic system is shown in Figure 4. The data acquisition computer, located in the control room, sends required measurement parameters to the electronic and the mechanical systems.

Once the Device Under Test (DUT) arrives at a desired position, a trigger signal is sent to the Vector Network Analyzers (VNA), that serve as an RF source, to start a frequency sweep. The RF signal from the VNA is routed using a band selector to the appropriate Transmit/Receive (TxRx) module. The RF signal is then amplified and transmitted to the CTR. The reflected signal from the DUT impinges the range feed antenna, amplified by a Low Noise Amplifier (LNA) and routes back to the VNA that serves as the RF receiver. The measurement data output from the VNA is sent back to the acquisition computer for further processing.

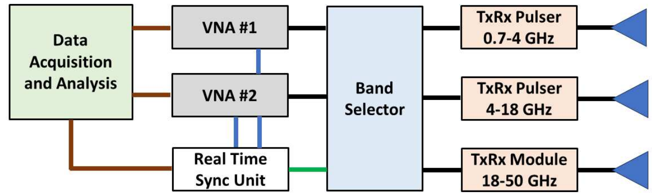

Figure 4. Block diagram of the RF system.

III. CTR FEED CAROUSEL

The design of the feed carousel enables using a single wide band RF source for all the measurements. Various frequency bands and polarizations are achieved using different routing. In the current system, two VNAs serve as sources in order to double the acquisition throughput.

During the design of the feed a special attention was given to usability and ease of maintenance:

- no relative movements along the RF gain chains during the system life time;
- enabling maintenance of the feed carousel with minimal effort, namely, making all the parts subject to periodic maintenance easily accessible.

The feed carousel, shown in Figure 5. , incorporates five possible feed stations, whereas three stations are equipped at present, two additional stations are available for future frequency upgrades. Once a band is selected, the carousel moves the selected feed to the focal point of the CTR and the RF band selector routes the RF signal to the appropriate antenna, as depicted in the RF diagram of Figure 4. Since the range is not intended for antenna measurements, all measurements are always time gated, so that no baffle house is required as part of the carousel design.

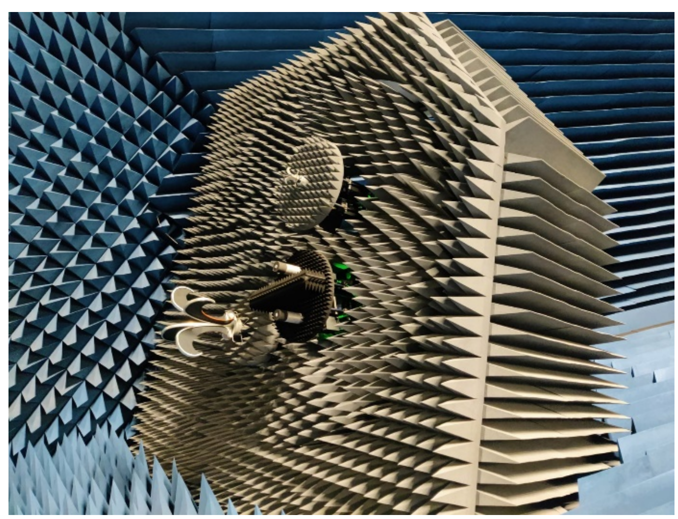

Figure 5. View of the Feed Carousel with five stations.

The RF source and the receiver are common to all frequency bands and move along with the carousel. Using this design, all RF cables are as short as possible and experience no movement during the system usage. The only moving cables are power and communication.

Feed stations design exploits the RCS usage of the facility. Namely Receive (Rx) and Transmit (Tx) functionalities are located in the feed carousel. Each station is designed to support all required elements and instruments for Tx and Rx in the active frequency band: Tx gain chain, T/R module, Rx gain chain and lastly the feed with its mechanical support.

The wide frequency range is divided into three sub-bands: 0.7-4 GHz, 4-18 GHz, and 18-50 GHz with sufficient overlap between the sub-bands. The two lower bands employ a single feed for both Tx and Rx channels, while the upper band uses separate feeds for Tx and Rx. Single antenna usage incorporates a pulsed T/R module that separates Tx from Rx by time, in order to prevent the receiver from saturation when the pulse is transmitted (Figure 6.). As a result, the two lower bands are exploiting a true monostatic measurement, while the upper band measurement is quasi monostatic.

Each frequency band is equipped with dual RF gain chain, different gain chain for each polarization. This design supports acquisition of two polarization at the same time. Moreover, the CTR supports performing measurement in all four possible linear polarizations simultaneously.

Using MVG MiDAS acquisition software, a fully automated measurement can be performed in all frequencies, polarizations, and possible target orientations.

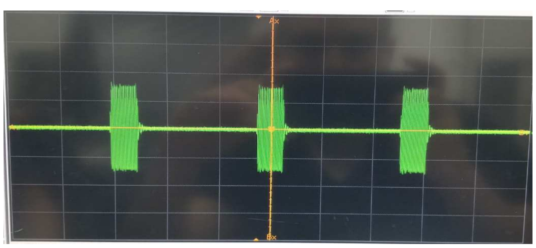

Figure 6. Tx/Rx Module Pulsing (carrier 700 MHz).

IV. ACQUISITION AND MEASUREMENT METHODS

All measurements are performed using stepped CW method. The frequency resolution is set to allow sufficient aliasing free range. The measured data is further processed using a software time gating. Therefore, direct leakage from the feed to the QZ is gated out. Moreover, bistatic reflection from the target back to the feed is also gated.

The measurement procedure and signal processing (i.e., gating) allows to relax some requirements in the feed design. No blockage or absorber baffle wall is needed to prevent direct leakage to the QZ, the feeds in the carousel are therefore located on a clean absorber disk. A field probing measurement was performed over the QZ main axes at a central plane to validate the QZ performance [1]-[2]. A special probing technique was considered, based on the use of a reflective target consisting of a Shorted Antenna located in QZ. Details and advantages of this probing technique can be found in [3].

Since both amplitude and phase of the E-field were measured, showing excellent correlation with design analyses based on Physical Optics (PO), an acquisition of a single plane in the QZ was deemed sufficient. Both H and V transmitted fields were characterized in their co- and cross-polarization characteristics to assess the polarization purity of the QZ.

As a result, a comprehensive characterization of the QZ properties was obtained. Some of the field probing results are presented in Figure 7. - Figure 9. , with the amplitude given in logarithmic scale (uncalibrated dB).

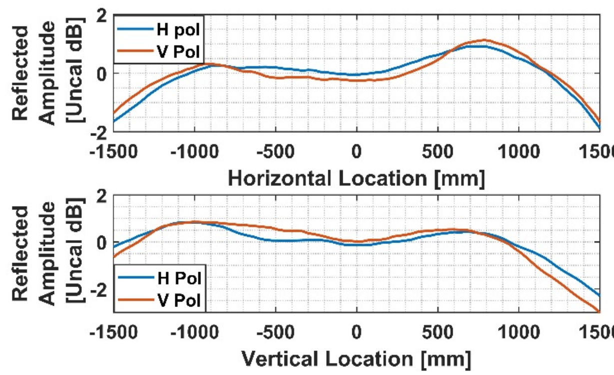

Figure 7. Typical Field Probing result at 1.5 GHz.

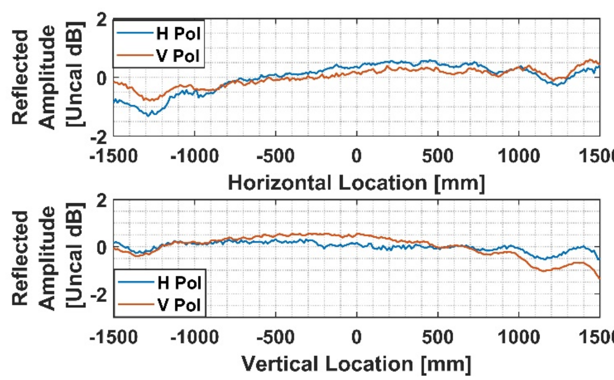

Figure 8. Typical Field Probing result at 10 GHz.

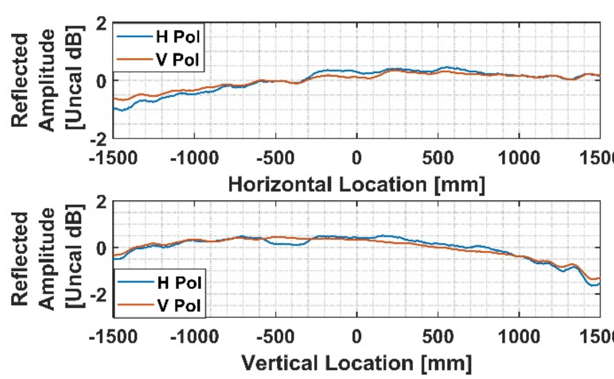

Figure 9. Typical Field Probing result at 34 GHz.

Each of the figures, show the impinging field amplitude variation vs. the Shorted Antenna location on the scanned axis. The figures shown are for the “two-way” field propagation: from the feed to the Shorted Antenna and back. It is worth mentioning that the field probe data (i.e. taper and ripple) should be divided by two in order to derive “one-way” data, which indeed corresponds to the standard specifications of a CTR [3]. Each of the figures includes two subfigures: the top subfigure shows the scanning along the horizontal axis, while the lower subfigure the scanning along the vertical axis of the QZ. Each of the sub-figures includes two traces, blue for the horizontal polarization and red for the vertical polarization.

Similar measurements were extensively performed for the complete frequency range of 0.7-50 GHz. During the field probing process, some pattern distortions were revealed. Investigations have shown that the lowest frequency band feed, which is protruding significantly from the absorber disk, was causing some distortions on the upper bands (i.e., signal bounce). Using a small absorber fence, the distortions were completely removed, and the corrective action was considered sufficient.

Generally, at the lowest frequencies, the QZ performance is influenced by the feed interaction with a baffle wall (i.e., prime pattern distortion, direct feed to QZ leakage, baffle wall blockage of the plane wave from the reflector to the QZ). Such effects are very difficult to elaborate with simulation, and often final baffle wall optimization needs to be done on site as part of range commissioning. Since this range has no baffle wall, and the absorbers surface behind the feeds is very clean, none of these effects are seen in measured field probing data. Performance indicators were extracted to evaluate the overall quality of the QZ. At lowest frequencies, the extracted parameters are amplitude and phase total variation (peak-to-peak). While at higher frequencies data was fitted to a parabola to extract the taper and ripple of the QZ in amplitude and phase. Extracted “one-way” field propagation data is summarized in Table I. As previously mentioned, this is obtained by dividing by two the “two-way” field probe data obtained from the measurements.

TABLE I. SUMMARY PERFORMANCE TABLE (ONE-WAY).

<table>
<tr><th>Frequency (GHz)</th><th>QZ scanning</th><th>Probe Polarization</th><th colspan="2">Amplitude total variation(dB)</th><th colspan="2">Phase total variation(deg)</th><th>Cross-pol relative to Co-pol (dB)</th></tr>
<tr><td rowspan="4">1.5</td><td rowspan="2">Horizontal</td><td>Vertical</td><td colspan="2">1.39</td><td colspan="2">11.1</td><td>-34 to -50</td></tr>
<tr><td>Horizontal</td><td colspan="2">1.4</td><td colspan="2">6.8</td><td>-28 to -60</td></tr>
<tr><td rowspan="2">Vertical</td><td>Vertical</td><td colspan="2">1.9</td><td colspan="2">9.3</td><td>-28 to -50</td></tr>
<tr><td>Horizontal</td><td colspan="2">1.56</td><td colspan="2">9.7</td><td>-30 to -50</td></tr>
<tr><th rowspan="2">Frequency (GHz)</th><th rowspan="2">QZ scanning</th><th rowspan="2">Probe Polarization</th><th colspan="2">Amplitude (dB)</th><th colspan="2">Phase (deg)</th><th rowspan="2">Cross-pol relative to Co-pol (dB)</th></tr>
<tr><th>Taper</th><th>Ripple</th><th>Taper</th><th>Ripple</th></tr>
<tr><td rowspan="4">10</td><td rowspan="2">Horizontal</td><td>Vertical</td><td>0.43</td><td>±0.14</td><td>-0.45</td><td>±0.8</td><td>-30 to -37</td></tr>
<tr><td>Horizontal</td><td>0.87</td><td>±0.15</td><td>-0.75</td><td>±0.8</td><td>-20 to -34</td></tr>
<tr><td rowspan="2">Vertical</td><td>Vertical</td><td>0.86</td><td>±0.13</td><td>-0.9</td><td>±1</td><td>-26 to-36</td></tr>
<tr><td>Horizontal</td><td>0.25</td><td>±0.13</td><td>-1</td><td>±1.2</td><td>-24 to -32</td></tr>
<tr><td rowspan="4">34</td><td rowspan="2">Horizontal</td><td>Vertical</td><td>0.45</td><td>±0.06</td><td>0.45</td><td>1.8</td><td>-30 to -40</td></tr>
<tr><td>Horizontal</td><td>0.7</td><td>±0.08</td><td>1.5</td><td>1.8</td><td>-26 to -35</td></tr>
<tr><td rowspan="2">Vertical</td><td>Vertical</td><td>0.8</td><td>±0.07</td><td>-0.9</td><td>1.8</td><td>-25 to -38</td></tr>
<tr><td>Horizontal</td><td>0.9</td><td>±0.14</td><td>-2.2</td><td>1.8</td><td>-25 to -40</td></tr>
</table>

The measured results have been compared to the QZ requirements, showing that the CTR meets and exceeds the specifications in most frequency bands. Compared to standard CTR specifications for banded antenna measurements, it is noticeable that the use of wide-band feeds, required for RCS applications, leads to a sacrifice in terms of amplitude taper at the high-end of the nominal feed bands and a slightly degraded cross-polar discrimination.

V. CONCLUSIONS

A Compact Test Range for Radar Cross Section measurements was constructed, installed, and commissioned by Orbit/FR Engineering Ltd. MVG. Since the measurements are time gated, the direct leakage from the feed to the QZ is intrinsically suppressed. This eliminates the need of a baffle house construction in the range, therefore the feed carousel can be designed with all feeds installed on a clean absorber disk, minimizing absorber blockage and unwanted primary pattern distortions.

The current CRT is a monostatic RCS range and therefore one may exploit the co-location of the transmit and receive functionalities to allow for time gating all measurements. Therefore, the direct reflection from the target to the feed is also gated out.

The measured Quiet Zone performance evaluated by field probing with a Shorted Antenna located in the target area has demonstrated the above assumptions. The experimental results match the simulated expectations based on Physical Optics simulations of the Quiet Zone, demonstrating full compliance with the specifications.

VI. 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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[1] "IEEE Recommended Practice for Antenna Measurements," in IEEE Std 149-2021 (Revision of IEEE Std 149-1977) , vol., no., pp.1-207, 18 Feb. 2022, doi: 10.1109/IEEESTD.2022.9714428.

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