Quiet Zone Qualification of a Very Large, Wideband Rolled-Edge Reflector

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Abstract—Installing a large compact range reflector and electromagnetically qualifying the quiet zone is a major undertaking, especially for very large panelized reflectors. The approach taken to design the required rolled-edge reflector geometry for achieving a 5 meter quiet zone across a frequency range of 350 MHz to 40 GHz was previously presented [1]. The segmentation scheme, fabrication methodology, and intermediate qualification of panels using an NSI-MI developed microwave holography tool were also presented. This reflector has since been installed and the compact range qualified by direct measurement of the electromagnetic fields in the quiet zone using a large field probe.

This paper presents the comparison and correlation between the holography predictions and the field probe measurements of the quiet zone. Installation and alignment techniques used for the multiple panel reflector are presented. Available metrology tools have inherent accuracy limitations leading to residual misalignment between the panels. NSI-MI has overcome this limitation by using its holography tool along with existing metrology techniques to predict the field quality in the quiet zone based on surface measurements of the panels. The tool was used to establish go/no-go criteria for panel alignment accuracy achieved on site. Correlation of the holography predictions with actual field probe measurements of the installed reflector validates the application of the holography tool for performance prediction of large, multiple-panel, rolled-edge reflectors.

Keywords: Rolled-Edge Reflector, Compact Range, Field-Probing, Quiet Zone, Microwave Holography

I. INTRODUCTION

The defined theoretical surface geometry of any compact range reflector can never be perfectly realized. Machining inaccuracies and misalignment between multiple panels are the dominant sources of deviation from the ideal surface. A microwave holography tool previously developed and presented [1] was used during machining of the individual panels in order to determine an acceptable level of surface accuracy. The measured surface data of all panels measured individually were stitched together to simulate a “perfectly aligned panels” dataset and the RF performance was evaluated using the holography tool.

The reflector must be completely installed prior to RF characterization of the quiet zone with a field probe. This implies that all panels must be aligned to each other, the seams between the panels filled, and an electrically conductive path established across the seams. Since perfect mechanical alignment between panels cannot be achieved due to limitations of even the latest state-of-the-art metrology systems, a method for evaluating the quality of alignment achieved is required. The holography tool is used during the alignment of the panels to predict the quality of the quiet zone and to determine if the achieved level of alignment is sufficient or if further alignment is required.

The completely installed rolled-edge reflector in a compact range is shown in Figure 1. This reflector produces a cylindrical quiet zone that is 5 m in diameter and 5 m in length that operates in the frequency range 350 MHz to 40 GHz. The overall size of the reflector is 9.5 m x 9.5 m.

Figure 1 Compact Range with Rolled-Edge Reflector

The installation and alignment of the reflector panels are discussed briefly in the next section. The alignment is deemed complete based on the predictions of the holography tool. Measured data obtained from quiet zone field-probing is presented. Finally, comparison and correlation between the quality of the quiet zone predicted by the holography tool and actual field probe measurements are presented.
II. INSTALLATION AND ALIGNMENT OF A MULTI-PANEL ROLLED-EDGE REFLECTOR

This rolled-edge reflector is installed in a chamber that is 17 m x 17 m x 34 m long. The reflector design and description were presented in [1] and are provided below for context.

- Overall Size: 9.5 m x 9.5 m (31’x31’)
- Parabola in concave rim: 4.6 m x 4.6 m (15’x15’)
- Rolled-edge Size: 2.4 m (8’)
- Focal Length: 12.2 m (40’)
- QZ Size: 5 m x 5 m (diameter x length)
- QZ Illumination Angle: 22.6˚

The reflector is segmented into 21 panels with precision machined surfaces. The central lit region of 7.3 m x 6.4 m (24’ x 21’) in size is made of 9 main panels and the rolled-edge termination on the four sides is made as 12 separate panels as can be seen in Figure 4.

A. Installation of Panels

A laser tracker system is used to establish a reference coordinate system in the chamber to align the panels to the ideal surface geometry. The internal leveling feature of the laser tracker is used to establish the Y-axis. The Z-axis is measured by establishing a physical line along the length of the chamber floor in the center and measuring two points using the laser tracker. The reflector stand location is established and the anchor locations are marked for the stand. The installed reflector stand and the backup structure for the lower roll panels are shown in Figure 2.

Figure 2 Installed Reflector Stand

Figure 3 shows a panel being lifted with a mobile crane and installed on to the backup structure. The back of the panel consists of a bracket that interfaces with a three-point mount mechanism on the backup structure. The panels are adjusted during alignment by actuating the three-point interface.

Figure 3 Panel Being Installed

Figure 4 shows all the panels installed on the backup structure. It can be seen that the gaps adjacent to the roll panels are uneven and larger than the gaps among the center panels. This is because the center panels were coarsely aligned in the factory and the mounts for the roll panels were moved away from each other to make it easier to install with the mobile crane.

Figure 4 All Panels Installed

B. Alignment of Panels

After the physical installation of the panels is completed, the alignment process is implemented. A coherent laser radar (CLR) system [2] along with Spatial Analyzer (SA) metrology software [3] is used to align the panels to the ideal surface geometry located in the chamber coordinate system. Each panel has multiple fiducials or reference points that can be measured either with a laser tracker or a laser radar system. These fiducial points are established on the theoretical surface geometry during the machining and characterization of each panel and are referred to as nominals. The maximum coordinate measurement uncertainty of the fiducials using the CLR system is specified as follows:

- 0.3 m to 10 m range ± 100 microns (±0.004 inch)
- > 10 m range ± 10 ppm

The CLR system is as far as 18 m from some of the fiducials and measurement uncertainty could be as much as ±180 microns (±0.007 inch). Typically, the error is less than half this amount since the azimuth and elevation extent of the CLR is minimal and the range measurement of the CLR is considerably more accurate. As many as 9 fiducials are used per panel in order to improve alignment accuracy. During panel alignment, the
fiducials for each panel are measured and SA is used to compute the deviation of the measured fiducials from the nominals as well as to compute the adjustments required to the three point mount behind each panel in order to align the measurement fiducials to the nominals. After implementation of the adjustments, which are typically effected using precision jacking screws, the fiducials are measured again and the residual errors and further adjustments required are computed automatically by SA. Features such as auto measure point groups and relationships within SA are used extensively [3].

The CLR system is used to measure the surface of the panels automatically in a non-contact manner and the initial baseline after physical installation of the panels is shown in Figure 5. It can be seen that some of the panels are out of alignment by as much as an inch or more. Only about half the surface is within 0.05 inch from the nominal surface.

The panels are aligned to the nominal surface to less than 0.01 inch after a few adjustment iterations. Figure 6 shows that the majority of the central panels are within 0.003 inch from the nominal surface. The holography tool is used on this data to determine if further alignment is required. The results are discussed in the next section.

The final surface measurement data on the 9 center panels is shown in Figure 7. The rms of surface error was about 0.0013 inch. For the desired high frequency performance, the surface of the reflector must be extremely uniform only allowing small deviation from the required theoretical geometry [4]. The holography analysis is presented in the next section.
C. Evaluation of Surface Measurement 2

The panels were further tweaked to improve the alignment and the resulting surface as shown in Figure 7. The amplitude-ripple estimate and the phase-ripple estimate at 40 GHz are shown in Figure 10 and Figure 11, respectively. It can be seen that both the amplitude and phase across the quiet zone has improved.

In the contour plots, 98.1% of amplitude ripple and 99.9% of phase ripple are within specifications.

The amplitude and phase data for on-axis horizontal and vertical cuts are extracted from the contour plots and are presented in Figure 12 and Figure 13, respectively. It should be noted that amplitude ripple is estimated about the taper. In reality there will be amplitude taper due to the feed pattern.

The reflector panel alignment was deemed acceptable based on the presented data. The seams were subsequently filled.
using a specialized two-part epoxy that bonds chemically to the two adjacent panels. The seam surface was then finished with a conductive coating.

IV. FIELD-PROBING THE QUIET ZONE

The actual RF characteristics of the quiet zone were measured using a 5.2 m field probe. That is, the amplitude and phase variations within the quiet zone were quantified by direct measurement of the RF field. A picture of the field probe mounted to a large high-capacity antenna test positioner is shown in Figure 14. The field probe consists of two axes – a roll axis to set the polarization of the probing sensor, usually a standard gain horn, and a linear axis to transit the probing horn within the quiet zone. The entire probe can be rotated about the test positioners’ roll axis so that any arbitrary cut of the quiet zone can be probed.

Figure 14 Field probe Installed on Test Positioner

A horizontal cut across the center of the quiet zone is measured and the amplitude and phase variations are shown in Figure 15.

Figure 15 Amplitude and Phase Along a Horizontal Cut Through the Quiet Zone

The amplitude taper across the quiet zone due to the feed pattern is 0.6 dB and the amplitude ripple is within ±0.48 dB, with majority of the ripple less than half that amount. The phase variation is better than about 18° across the horizontal cut of the quiet zone.

A vertical cut through the center of the quiet zone is measured and the amplitude and phase variations are shown in Figure 16. It is seen that the amplitude taper is 0.54 dB and the amplitude ripple is less than ±0.32 dB. The maximum phase variation is about 14°. All measured data therefore fall within standard quiet zone specification at 40 GHz.

Figure 16 Amplitude and Phase Along a Vertical Cut Through the Quiet Zone

V. HOLOGRAPHY PREDICTIONS VERSUS FIELD PROBE MEASUREMENTS

The field probe measured amplitude ripple is about a 2nd order amplitude taper produced by the pattern of the compact range feed, whereas the holography predictions show the computed amplitude ripple without any taper. In order to compare the two sets, the taper is artificially removed from the field probe data. The amplitude ripple comparison between the holography predictions and field probe measurements for the horizontal cut through the quiet zone is shown in Figure 17.

Figure 17 Comparison of Amplitude Ripple Along a Horizontal Cut Through the Quiet Zone
It can be seen that the largest peak shown at a horizontal location of about 58 inches is exactly where predicted. There are several trends that correlate very well between predicted and measured data. It should be noted that the holography predictions take into account primarily the measured surface errors within the 9 central panels. Whereas, actual field probe measurements include other anomalies such as chamber scattering, reflector edge diffraction, polarization mismatch, direct coupling with feed, leakage, transmission line mismatches, etc. See [5] for a detailed discussion on these compact range error sources.

Figure 18 shows the comparison of the phase variation along a horizontal cut through the quiet zone. It is seen that the predictions correlate very well with measurements on most of the data. The differences in the phase are due to different quiet zone depths. The holography prediction is computed at the “perfect” center of the quiet zone, whereas the field probe measurement is made at the “approximate” center of the quiet zone. The straightness and alignment of the field probe to the wave front also causes variations in the measured phase.

Figure 19 Comparison of Amplitude Ripple Along a Vertical Cut Through the Quiet Zone

There are several peaks that line up between the two data sets. In general, both show that the amplitude response varies very randomly. However, the measured magnitude is less than about 0.32 dB. It can also be observed that the holography predicts a larger magnitude, which implies that the predictions are very conservative and hence can be safely used as a basis for in-process acceptance.

The comparison of predicted and measured phase variation along a vertical cut through the quiet zone is shown in Figure 20. There is excellent correlation between the two sets. In general, the trend of the phase variation along the cut is very similar between the two data sets. Quantitative comparison of the predicted and measured quiet zone metrics are shown in Table 1. Phase predictions are very accurate, while the amplitude predictions are conservative.

Table 1 Comparison of Quiet Zone Metrics

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<thead>
<tr>
<th></th>
<th>Horizontal Cut</th>
<th>Vertical Cut</th>
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<tbody>
<tr>
<td><strong>Phase</strong></td>
<td><strong>Amp</strong></td>
<td><strong>Phase</strong></td>
</tr>
<tr>
<td>Holography Prediction</td>
<td>±0.60</td>
<td>17.84</td>
</tr>
<tr>
<td>Field probe Measurement</td>
<td>±0.48</td>
<td>18.25</td>
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SUMMARY

Installation and alignment of a large, segmented rolled-edge reflector capable of producing a 5 m quiet zone was described. The use of the holography tool for predicting the RF performance within the quiet zone based on surface measurements including residual panel misalignment was presented. It was shown through field probing that the reflector performed well at frequencies as high as 40 GHz. Predicted data and the measured field probe data were also compared with good correlation, both qualitatively and quantitatively, despite the various error sources inherent in a compact range.

REFERENCES