MISSION TO MARS - IN SEARCH OF ANTENNA PATTERN CRATERS

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ABSTRACT

Reflections in anechoic chambers can limit the performance and can often dominate all other error sources. NSI's MARS technique (Mathematical Absorber Reflection Suppression) has been demonstrated to be a useful tool in the fight against unwanted reflections. MARS is a post-processing technique that involves analysis of the measured data and a special mode filtering process to suppress the undesirable scattered signals.

The technique is a general technique that can be applied to any spherical near field or far-field range. It has also been applied to extend the useful frequency range of microwave absorber down to lower frequencies. This paper will show typical improvements in pattern performance, and will show results of the MARS technique using data measured on numerous antennas.

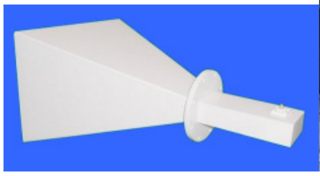
Keywords: NIST, 18-term, error evaluation, absorber, reflection, spherical near-field, suppression, MARS

1. Introduction

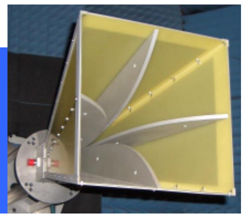
The NSI MARS processing technique has been in use by NSI and our customers since its introduction in 2005[1]. Validation of the MARS technique has been published in the 2005 paper and additional papers [2,3]. This paper will focus on additional description of the MARS technique over wide frequency bands and a number of antennas. Four antennas will be discussed here

1. WR-284 S-band Standard Gain Horn (SGH)
(used in some of the prior MARS studies)
2. Broadband dual polarized ridged guide horn which covers the band from 0.4 GHz to 6 GHz
3. Broadband horn which spans from 4 GHz to 40 GHz.
4. Omni-directional antenna that operates at 2.4 GHz.

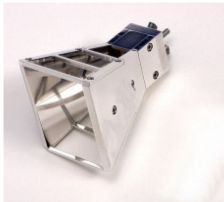
These 4 antennas are shown in Figure 1.



S-band SGH



0.5-6 GHz Horn



4-40 GHz Horn

Omni Antenna

Figure 1 – Several antennas used for MARS analysis

2. Spherical Near-Field Basics

Far-field results of Spherical near-field measurements are calculated by using a Spherical mode expansion technique developed by NIST and the Technical University of Denmark[4]. The basic idea is that near-field measurements in a Theta-Phi coordinate system can be uniquely described with a set of spherical mode coefficients. The spherical mode coefficients can be determined from the measured data in a very efficient manner. These coefficients are then corrected for the effects of the probe to determine the AUT mode coefficients. The same efficient processing is then used to produce far-field patterns, gain and polarization in a Theta-Phi coordinate system. The process is as follows:

1. Measure near-field data in a Theta-Phi coordinate system.
2. Determine spherical mode coefficients describing the near-field data.
3. Apply the probe correction to the spherical modes.
4. Expand the AUT coefficients into the far-field Theta-Phi coordinate system

The spherical mode coefficients are generated by the regular processing of the measured data. These coefficients are complex numbers that are functions of the polarization index s, the phi index m and the theta index n [4]. A plot of the amplitudes of the spherical modes for s = 1 for a typical measurement on the S-band SGH is shown in Figure 2.

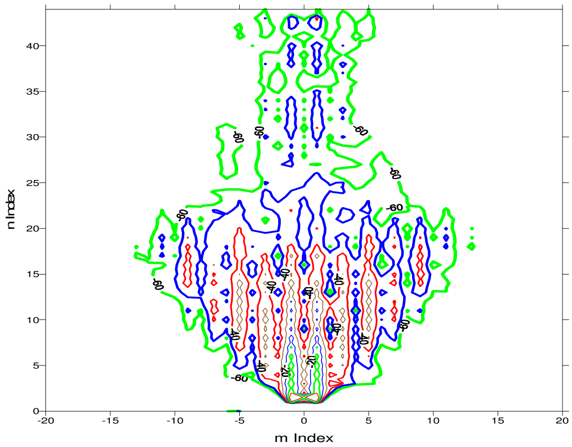


Figure 2 – Typical spherical mode amplitudes for the S-band SGH antenna.

3. Theory of the MARS Technique

We can obtain a more concise graphical display by selecting the m index for the maximum amplitude and plot a graph of the mode amplitude vs. the mode n number. Figure 3 shows a mode plot for the same data in Figure 2 for m = 1.

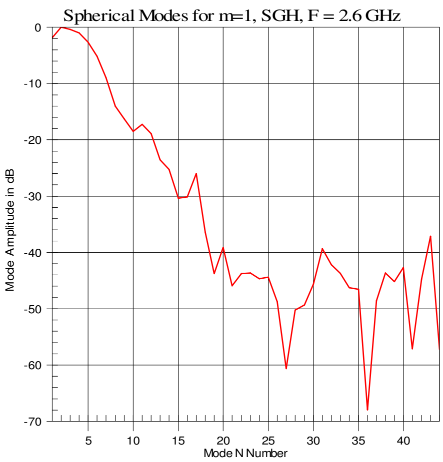


Figure 3 – Spherical Modes for SGH Antenna, m=1

The purpose of the MARS approach is to reduce the influence of scattering on far-field pattern results. We use a mathematical post processing technique that requires a minimum amount of information about the AUT, probe and antenna range geometry. The processing is applied during regular near-field to far-field transformation. The technique is general enough to apply to different types of spherical measurement geometries and to different antenna types. NSI has developed a mathematical operator that is applied to the measured data that helps to distinguish between the correct antenna properties and scattering. Best performance requires more measured data than for normal measurements. We typically use one half the spacing in theta and phi, compared to the value recommended by sampling criteria. This will usually require about double the test time, compared to normal measurements.

MARS uses the standard NIST Spherical Near-field to Far-Field Transformation Algorithm. As an inherent part of the far-field transform, the NIST algorithm uses a mode filtering technique. The mode cutoff is based on the fact that modes above a certain index number are exponentially attenuated and not detected by the probe. The mode cutoff is determined by the physical dimensions of the AUT.

The filtering is normally based on the aperture size of the antenna but may be increased for analysis purposes up to a limit determined by the near-field data point spacing. NSI's MARS technique applies a mathematical position shift to the AUT measured data during processing to optimize the way the spherical transform filtering is done.

A typical mode plot on the NSI-RF-SG284 Standard Gain Horn at 2.6 GHz is shown in Figure 4. In this figure, we have overlaid the measured mode plot, the shifted mode plot based on analytically translating the SGH phase center to the origin, and the filtering plot, showing where we have truncated the higher order modes.

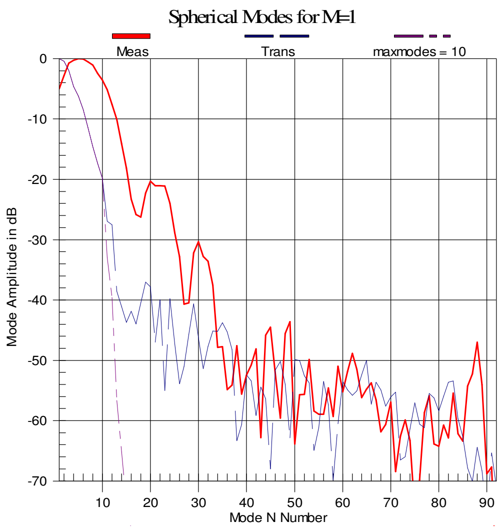


Figure 4 – Spherical Modes and MARS Filtering for SGH

The selection of which modes to filter out is made automatically by the MARS processing algorithm based on user inputs identifying the physical size MRE (Maximum Radial Extent) sphere which can contain the antenna. The user can also override the default filtering for evaluation during processing. In the SGH case, the minimum sphere which contains the translated antenna aperture causes the MARS processing to filter out all higher order modes above N=10 as these can not be part of the antenna's far-field radiation pattern.

4. MARS in Action

Prior papers by the authors have shown typical results with the MARS technique and validation of the technique on a number of antenna test cases [1,2,3] where the results have been compared to results from high quality ranges where scattering is minimal.

NSI's spherical systems can acquire near-field data over a sphere in three ways. The three options will be referred to "360 phi", "180 phi" and redundant data. The "360 phi" data set is taken with full 360° phi rotation of the AUT, but with only 0-180° motion in theta. In this mode, the AUT's main beam will only be looking at one side of the chamber during the measurement. The "180 phi" data set is taken with only 180° phi rotation, but a full 360° rotation in theta. In this mode, the AUT's main beam looks at all four of the side walls in the chamber. The redundant measurement uses a full 360º rotation in both theta and phi (see Figure 5), and the other two data sets can be extracted from the redundant measurement without additional measurements.

The three data sets can then be processed separately for comparisons. This double data set can reduce the effect of some scattering and also help reduce effects of the residual alignment errors in the system. This technique is further described in a 2004 paper by the authors[5], and we have used it as part of a simplified 18 term error evaluation process[3], adapted from the 1988 error analysis paper by Newell[6].

The redundant data was used for this study to develop an efficient way to estimate the improvement of the MARS processing. Comparisons with independent measurements from another facility are time consuming and not practical for routine measurements. Detailed comparisons of this type have been done and reported on with impressive results [1, 2, 3].

Full scattering analysis by moving the AUT and probe together in the measurement chamber is also not practical for most measurement systems and are time consuming. Confidence in the basic technique has been established since it is based on the same processing steps used in the usual near-to-far field spherical transformation with the addition of the translation of the far-field pattern to the origin. There is no approximation in this translation process, and the final mode filtering can be determined by the user. A tradeoff can then be made between filtering of unwanted scattering and retention of possible AUT higher order modes.

The recommended filter is based on the physical dimensions of the AUT, but the user can select a larger or smaller filter based on examination of the mode plots and past experience. The MARS process will reduce scattering errors in many measurements. It will not introduce additional errors if used properly. The following tests were developed to estimate the improvement for a given system and AUT combination with a reasonable amount of measurement and analysis.

Using the redundant data we have further evaluated the effectiveness of the MARS technique over a wider frequency band using available data on the S-band SGH and the other antennas. The basic approach is to establish a "best available truth model" of the antenna pattern as a reference. We use the redundant data set on the antenna with the best chamber absorber configuration with full MARS correction to create this "best available truth model". We then take a "180 phi" or "360 phi" non-redundant dataset measured on the antenna with the degraded absorber configuration and apply the MARS correction technique to derive the MARS improvement achieved which is defined as the reduction of the error level from comparison with the "truth model".

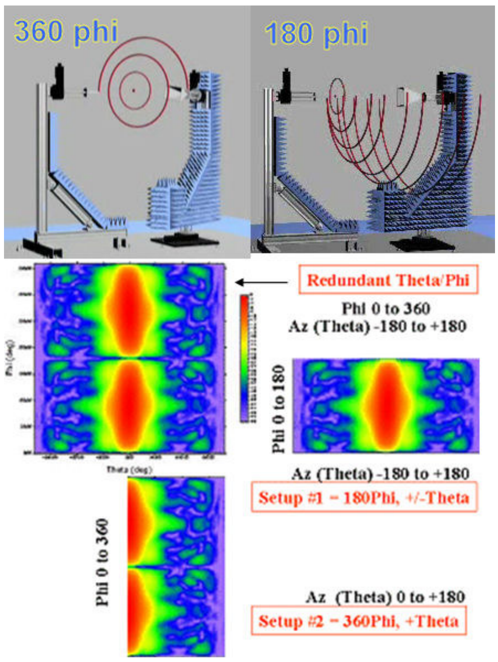


Figure 5 – Redundant data set through full rotation of theta and phi rotators, versus the two full spheres that can be derived for the "360 phi" or "180 phi" configurations

5. MARS on S-band SGH

The S-band SGH operates over the WR-284 band of 2.6 GHz to 3.95 GHz. The pattern comparison between 360 phi and 180 phi data with and without MARS and with and without the better absorber treatment was reported on in [2], and the key result is shown at 2.6 GHz in Figure 6.

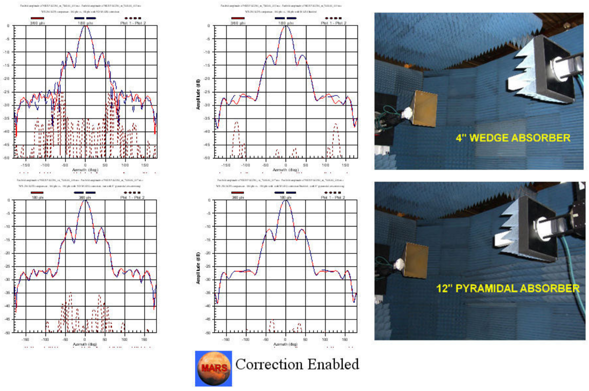


Figure 6 – The patterns on the right show the improvement achieved by using MARS. The upper patterns use the poor chamber with 4” wedge absorber, and the lower patterns use the better chamber with 12” pyramidal absorber

An extended analysis of that data has now been done over the full range of frequencies measured. Figure 7 shows the improvement in reflection level due to the MARS technique. The average improvement with the poor absorber is about 18 dB.

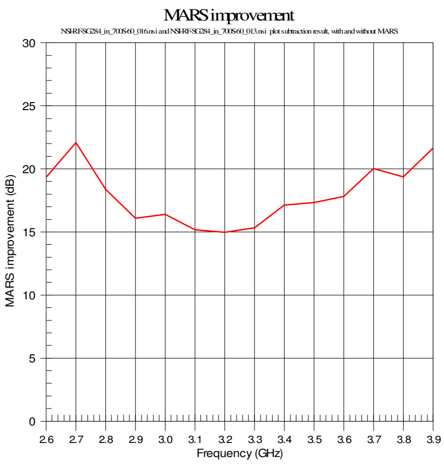


Figure 7 – MARS improvement over frequency band for SGH, chamber with poor 4 inch wedge absorber, using reference “truth model” data with 12 inch pyramidal absorber

6. MARS on 0.5 to 6 GHz Broadband Horn

We next tested a NSI-RF-DPH-10 Dual Polarized Broad-Band Horn Antenna over a wider frequency range of 0.5 to 6 GHz in the large NSI Spherical Chamber (Figure 8). This horn has a some flat-top type antenna patterns at certain frequencies and we were interested to demonstrate that the MARS processing does a good job on suppressing the chamber reflections and does not change the inherent radiation pattern.

Again we use a full redundant dataset with the good 12” absorber coverage to derive our “truth model” on the antenna for comparison. We then process the dataset with the poor 4” wedge absorber with and without MARS.

The pattern data shown in Figure 9 is at 5 GHz and you can clearly see the difference in the pattern in the left comparison, and how much better the match is when MARS is applied as shown on the right. You can also see the inherent pattern shape is retained while the reflections are suppressed. We ran this test over the 0.5 to 6 GHz band and plotted the MARS improvement versus frequency and the result is shown in Figure 10 - an average improvement of about 16 dB with MARS.

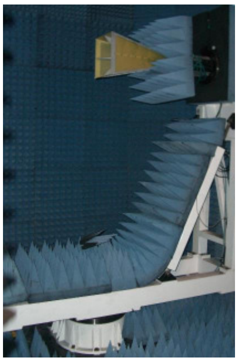
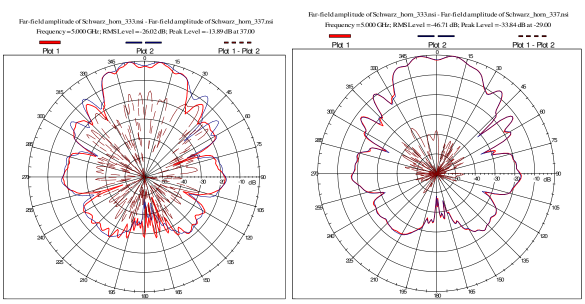


Figure 8 - NSI-700S-60 SNF scanner in anechoic chamber testing 0.5-6 GHz dual pol horn horn antenna



4” absorber no MARS   4” absorber with MARS

Figure 9 – 5 GHz dataset comparing data with 4” wedge absorber with and without MARS versus “truth model” with 12” absorber

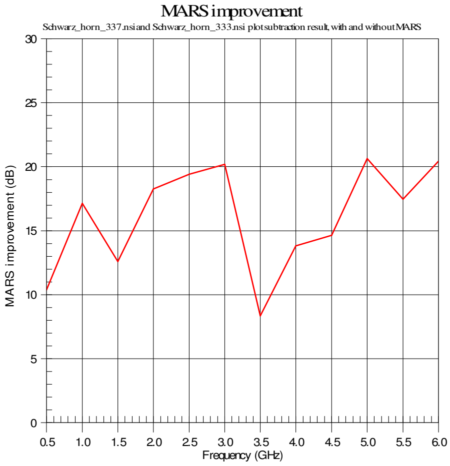


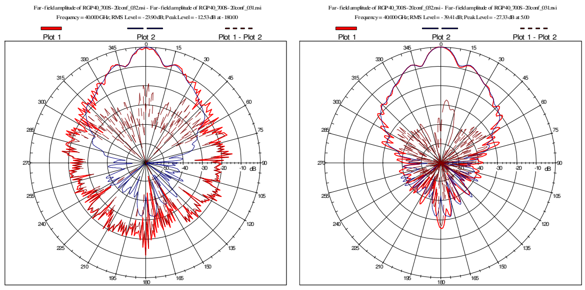
Figure 10 - MARS improvement for 0.5-6 GHz dual pol horn antenna in chamber when 4" wedge absorber was used

7. MARS on 4 to 40 GHz Broad-Band Horn

We tested a NSI-RF-RGP-40 Double Ridged Horn Probe Antenna, over the 4 - 40 GHz frequency range. This horn was tested on the small portable NSI-700S-20 Spherical Nearfield Test System. This system often travels to NSI trade shows for live exhibits but was located in the NSI conference room for the tests conducted here. This system has a metal panel located about 20" (0.5 m) off the range centerline that can be removed or covered with a flat absorber panel for MARS demonstrations and this capability was used for the results reported here. The system is shown in Figure 11 with the metal plate configuration (flat absorber panel stored at the lower left).

Figure 11 - NSI-700S-20 SNF scanner in NSI conference room with metal plate interference, testing 4-40 GHz ridged horn antenna

As you would expect, the reflections from the metal plate in close proximity are severe, and this is shown in Figure 12 along with the suppression achieved with MARS.



Metal plate no MARS   Metal plate with MARS

Figure 12 – 40 GHz dataset using metal plate versus "truth model" with 1" absorber panel covering metal plate

Figure 13 shows the improvement over the full frequency band with MARS – an average improvement of about 12 dB. MARS reduces the noise floor from about -15 dB to about -25 dB or -30 dB allowing quite reasonable antenna measurements to be made even in this 'hostile' environment!

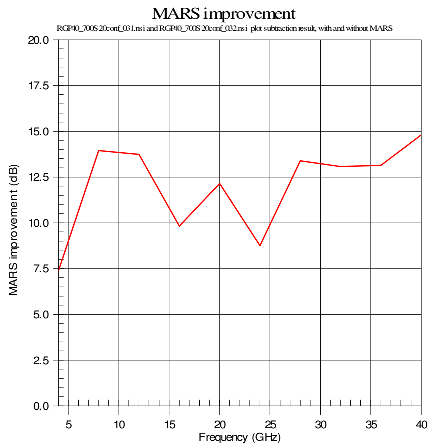


Figure 13 – MARS improvement achieved over 4-40 GHz band on wideband horn

8. MARS on Omni antenna

We tested a 2.4 GHz Omni directional antenna on our spherical Nearfield chamber. The antenna mounted to the positioner is shown in Figure 14. The pattern improvements with MARS are show in figure 15, and over a frequency range near 2.4 GHz are shown in figure 16. The average improvement is about 22 dB and we even see up to 30 dB improvement at one frequency.

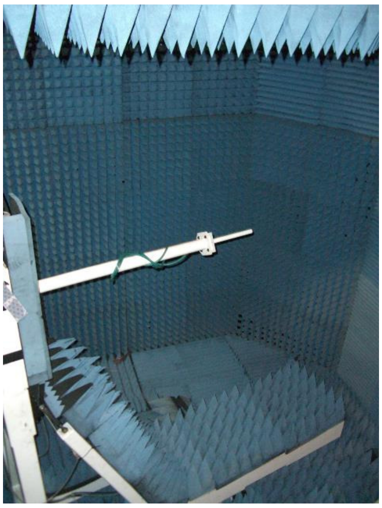
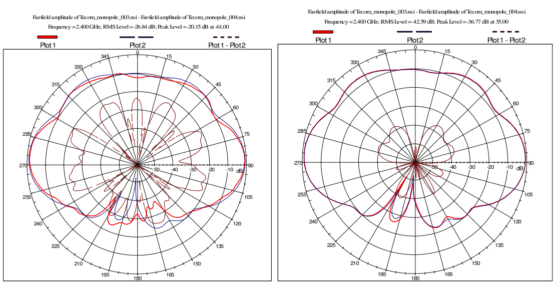


Figure 14 – Omni antenna on NSI-700S-60 SNF



4” absorber no MARS 4” absorber with MARS

Figure 15 – MARS improvement on Omni antenna at 2.4 GHz

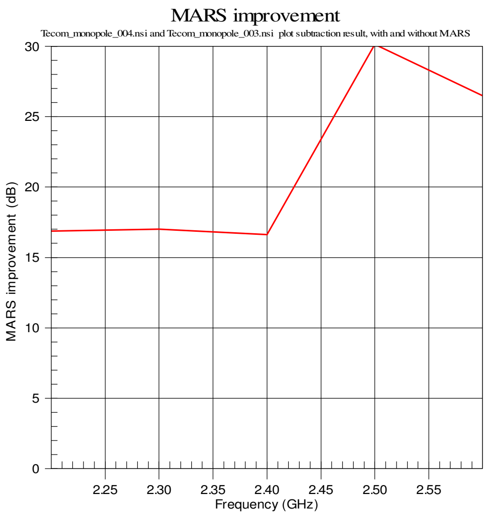


Figure 16 – MARS improvement on Omni antenna

Table 1 - Summary of the MARS improvements

Antenna	MARS improvement	Frequency	Antenna / Chamber configuration
1	18 dB	2.6-3.95 GHz	S-band SGH in poor chamber with 4” pyramidal absorber
2	16 dB	0.5 – 6 GHz	Dual-pol ridged horn in poor chamber with 4” pyramidal absorber
3	12 dB	4-40 GHz	Ridged horn on portable test system with metal plate corrupting result
4	22 dB	2.4 GHz	Monopole antenna in poor chamber with 4” pyramidal absorber

9. Summary

This paper describes an efficient measurement and analysis procedure that can be used to estimate the improvement in the MARS processing. It does not require extensive additional measurements and the analysis process is automated using scripts in the NSI software.

It has been applied to a number of antennas to demonstrate its usefulness over a wide frequency range and antenna types. Like the more extensive comparison measurements previously reported on, it demonstrates the improvement that can be achieved when scattered interference is a problem.

10. REFERENCES

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