Reducing Measurement Uncertainty In EMC Test Laboratories

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Introduction

Calculating measurement uncertainty has been the subject of many technical articles and presentations recently. There has been a lot of confusion about how to calculate a realistic, and meaningful, measurement uncertainty quantity. There is even more confusion about how to handle this uncertainty quantity.

A realistic consideration is how well a measurement can correlate between two different test laboratories. Radiated emissions tests for commercial EMC standards are notorious for their poor correlation between laboratories. While some test facilities claim +/- 2 dB, once everything is taken into account, the real number is more likely to be about +/- 4 to greater than +/-7dB! Such a large correlation deviation can easily cause one test facility to pass a given product, while another test facility will fail the same product. Clearly, this is undesirable, especially when a given product is likely to be tested in different facilities, and at multiple times as various options are added.

It is necessary to develop a means of ensuring both, that all sites are within tolerances acceptable for compliance testing, and that data can be correlated from one site to another. To do this, additional correction factors must be introduced. While these are not (yet) acceptable for the preparation of data to show compliance, they do provide a high degree of confidence that all sites are operating properly and providing a quality service.

Sources of Deviation

Deviations are caused by a number of different sources. The quality of the test environment (OATS or Anechioc room), the test process, and the accuracy of the measurement equipment all contribute to this deviation. Some of these issues are technical in nature, that is, better calibration can reduce the deviation, while others are not technical and are more difficult to control.

The quality of the test environment is made by comparison to an ideal open area environment with an infinite metal ground plane. Reflections from the edge of the metal ground plane, reflections from walls (and anechoic materials), as well as reflections from other objects all contribute to the imperfection of the test environment. The site attenuation measurement serves to quantify the amount of ‘error’ across the frequency range.

The site attenuation measurements serve to show that the site is within the acceptable limits for the specific type of test being performed. However, regulatory agencies do not accept data, which has been corrected for these variations when submitting data for compliance. A deviation of +3dB at one site could be –3.5 dB at another. The uncertainty of the site is based on the accuracy of all the measurement equipment as well as the site itself.

Site deviations caused by the test process come from a number of factors, but mostly from the process used to optimize the emissions. Once a signal is under suspicion, then the cables and peripherals are moved manually to find the combination which produces the highest emissions. Optimization is done in many different ways and at various measurement distances. For example, the turntable may be rotated, then the antenna elevation varied, or the antenna elevation may be varied, and then the turntable rotated. For very high frequencies the rotation and elevation variations must often be done in an iterative manner to find the true peak emission levels. Each process can easily result in a different combination of 'highest' emissions. The result of this manual manipulation is very dependent on the skill of the person, and how much time is spent to find the maximum signal position. Test laboratories are under pressure to minimize the time taken for a test and are able to do so by severely limiting the amount of time that the test technician looks for the optimum signal level (at a cost of less than accurate results). The only way to reduce the test process deviation is to provide proper training to the technicians, and to allow them the time to make sure they have found all the signals.

Since the maximizing of emissions is a personal skill it is important to keep complete records of the tested system. Photographs are essential to providing a record of the exact configuration tested. While the regulatory agencies require only a few of the highest emission frequencies be recorded in the test report, a much more complete emission list is essential to help ensure site to site correlation. If a different but equally high emission frequency is optimized during subsequent testing of a product, an entirely different test report could be generated and little correlation would be seen between the tests. Having a complete data set and photographs enables this to be tracked.

The accuracy of the measurement equipment is one of the primary sources of deviations in test site correlation. If it is assumed that the test facility is a 'good' facility, the technicians are properly trained, and the test process is optimized for accuracy, then the measurement equipment becomes the most important parameter in the development of accurate site correction factors and the reduction of measurement uncertainty.

The measurement equipment at EMC test laboratories include EMI receivers and spectrum analyzers with peak and quasi-peak detectors, signal generators, power meters, network analyzers and various types of antennas. Each piece of equipment must be calibrated against a known standard to ensure accuracy. Because all uncertainties in these calibrations are basically added together, it becomes extremely important to minimize these uncertainties. An alternate method for increasing accuracy and minimizing uncertainty is to calibrate measurement systems comprising as many pieces of equipment as possible in a single calibration operation.

Measurement Equipment Accuracy

The current standard for calculating measurement uncertainty is the NIS81 from the National Physical Laboratory in England. Individual uncertainties are combined to find the overall measurement uncertainty. The highest individual contributors are the antenna calibration, the receiver specification, the antenna factor variation with height, and site imperfections.

It was decided that each of these individual contributors would be evaluated separately, and calibrated (if possible) to reduce their contribution to the overall measurement uncertainty.

Receiver Calibration

The accuracy is most important when measurements are made in the quasi-peak mode, since that is the ultimate measurement comparison to the regulatory limits. Three different receivers with quasi-peak measurement capabilities were available. They were the HP8568B/85650A spectrum analyzer QP detector combination, R & S ESVP/ESH-3, and HP8546A EMI receiver. In addition to these receivers, the R&S ESVP/ESH-3 had the capability to measure in the 'low noise' mode or the 'low distortion' mode. Results from these two modes were different, and so they were treated as individual receivers.

The accuracy was measured by first calibrating a signal generator with a power meter. The power meter calibration accuracy was specified at 0.5 dB. This generator was then directly connected to the receivers, and used as the source for all receiver measurements.

Figure 1 shows the measurement error for quasi-peak measurements for the HP8568B spectrum analyzer and HP85650A quasi-peak adapter when the input level was 0 dBm. A number of identical units were measured, and the variation between receivers was less than 2 dB.
Figure 2 shows the same set of measurements for four different R&S ESVP/ESH-3 receivers operated in both the low noise (LN) and low distortion (LD) modes. In this case, the variation between receivers was about 2.5 dB.

A set of measurements was made to compare the peak and quasi-peak detectors in the receivers. Figures 3 through 5 show the deviation between the peak and quasi-peak measurements. Since a sinewave signal was used as the input, the resulting measurement should be identical for both detectors. The best results were from the HP8546A receiver.

Since most EMI measurements are not made at 0 dBm, but at much lower signal levels, the above measurements were repeated at –62 dBm (45 dBuv). Figure 6 shows the results for the R&S ESVP/ESH-3 receivers in peak, QP/LN, and QP/LD modes. These results show the measurement accuracy to worsen as the signal level is lowered. Figure 7 shows the results for the HP8546A receiver in both peak and QP modes at the low signal level. The difference in measurement accuracy showed a dramatic increase, and the graph scales had to be modified to show the results clearly.

Another important point is that not only is the measurement accuracy important, but the spread of the results is also very important to measurement repeatability between different test laboratories. The HP8546A had both the best absolute accuracy as well as the best (least) spread between receivers.

These results quickly pointed to an obvious way to reduce the measurement uncertainty contribution of the receiver, in this particular case, by simply using the HP8546A as the primary instrument for these measurements.

Antenna Factor Variation

It has been known for some time that the antenna factor of some antennas will vary as the antenna is moved closer or further from the metal ground plane in the test environment. Trying to predict the change in antenna factor is difficult. A series of measurements were made on biconical and log periodic antennas to evaluate this change in antenna factor.

The measurements were made using a HP network analyzer. The impedance of the antenna was measured at the antenna port itself, while the antenna height was varied. The antenna impedance is a key contributor to the change in the antenna factor.

Figures 8 and 9 shows the impedance change for a horizontal and vertically polarized biconical antenna relative to the four-meter height. The assumption is that the antenna impedance is as close to 'free-space' antenna impedance as possible. The impedance variation is almost 6 dB for the horizontal polarization, and nearly 7 dB for the vertical polarization.

Figures 10 and 11 show the impedance change for a horizontal and vertically polarized log periodic antenna relative to the four-meter height. The assumption is again made that the antenna impedance is as close to 'free-space' antenna impedance as possible. The impedance variation is about 2 dB for the horizontal polarization, and only 1 dB for the vertical polarization. There are two factors, which help the log periodic antenna in this test. Electrically it is much higher above the ground plane, and the strong inter-element coupling dominates over the ground plane effects. It can be clearly seen in the figures that the log periodic antenna is affected much less than the biconical antenna.

These tests were repeated with additional antennas (of the same type), and the results were consistent with the data in Figures 8 though 11. However, while the variation was consistent, the exact impedance at a given frequency could vary by 1 to 2 dB, as shown in Figure 12. This implies that any characterization of antennas with height must be done individually and not for a given antenna type.

Having a set of antenna factors for different heights could reduce the measurement uncertainty due to the antenna factor variation. While this initially sounds like a bookkeeping nightmare, it is much less hassle when the measurement system is automated. The antenna factor becomes a simple table lookup function.

Overall Site Accuracy

Establishing the overall measurement site accuracy is not a trivial task. The first requirement is to have an electric field source that is well known in the environment in which it is used. A simple dipole antenna would have to be carefully calibrated in a metal ground plane environment, and then the repeatability and accuracy would still be doubtful as different signal generators are used as the source.

To overcome this problem, a spherical dipole source (SRS-2100)[1] was calibrated at the NIST open field site in Boulder, Colorado. Testing showed this unit to have a calibrated accuracy of about 0.5 dB, and a repeatability of about 0.25 dB. Having a total uncertainty of only 0.75dB this was considered the best possible electric field source for this type of site comparison.

The spherical dipole source was taken to a number of different test sites, all of which were fully approved. A series of measurements were made to determine how accurately each test site reported the field level. Figure 13 shows a typical result from a laboratory. The tests were repeated a number of times over a period of a few months to determine repeatability. As can be seen from Figure 13, the repeatability was very good. However, the absolute accuracy varied from –6 dB to +4 dB. This measurement included all the 'normal' correction factors. That is, no special calibration of receivers, antennas (height), etc. was used.

Figure 14 shows a typical example of the variation between different measurement sites. Each site was measured using the same source. As can be seen in the figure, the variation from site to site could be as much as 4 dB. While this is very good it does place a requirement for all products to have a minimum of a 4dB guard band in order to ensure passing at any test facility.

The accuracy and consistency results are somewhat lower than desired. It is certainly undesirable to either overdesign a product (due to reporting the emissions as higher than they really are), or underdesign a product (due to reporting the emissions as lower than they really are). However, the overall accuracy (and therefore site-to-site consistency) can be improved using the data from these tests.

[1] Note: because of the level feedback provided in this unit, the dependence on the signal generator calibration was eliminated.

Figure 15 shows an example of a 'site calibration factor' for a given test site based upon the average of a number of tests as shown in Figure 13. This site calibration factor includes all errors due to the site, the antennas and the test equipment, so is therefore dependent on all of these being stable. If an antenna was changed, or a receiver changed, then the calibration factor would have to be recalculated. Figure 16 shows an example of the relative accuracy for a test laboratory using its site calibration factor. The accuracy has been improved, and of course, so has the site-to-site consistency once both sites use their individual site calibration factors.

Regulatory Issues

The work presented here does go against a number of existing regulatory requirements. Site attenuation measurements are made to verify the suitability of a test site for compliance testing. It is not permissible, however, to correct measured data for any imperfections in the test site. This leaves the potential to have data errors of up to +/-4dB when compared to the ideal site.

A similar, though more complex, situation arises when considering the antenna factor behavior of the measurement antenna. It has been shown that the effective antenna factor can vary by over 2dB with height. By using a matrix of antenna factors for height, polarization, and frequency, it is possible to increase both site to site correlation and overall accuracy. However, for regulatory compliance, a single antenna factor is required, theoretically the free space values, though more usually the values are determined at a height of 4m above the ground plane.

These two issues severely limit the application of site correction techniques. However, within a given group of test sites there is no reason not to use this approach to ensure consistency and to create a tool to rapidly pinpoint when one site has a problem.

Summary

The technique of calibrating both the measurement equipment and the physical test site as a single entity has been presented. Additionally a key individual effect, the variation of effective antenna factor with height and polarization has also been shown. These considerations provide a mechanism for reducing measurement uncertainty and improving site to site correlation.

Measurement uncertainty can be reduced, while increasing site-to-site measurement correlation by increasing the accuracy of the measurement receiver. This can be accomplished either by selecting a more accurate receiver, or by additional calibration. Additional calibration of the antenna (vs. height) can also increase measurement accuracy. Finally, the overall measurement system can be calibrated (eliminating the need for individual calibrations) by using an accurate field source and combining all the various factors into one overall correction factor.

While accurate EMI measurements are difficult, and large measurement uncertainties have been accepted in the past, most companies can no longer afford to place large guard bands on their products, effectively lowering the regulatory limits to ensure product passing. The only way to reduce the large guard bands used by most responsible companies is to increase the measurement accuracy. This increase in measurement accuracy (and reduction in measurement uncertainty) requires additional effort and calibration by vendor's beyond that called for by regulatory agencies. However, the tools are available today, for those wishing to use them.

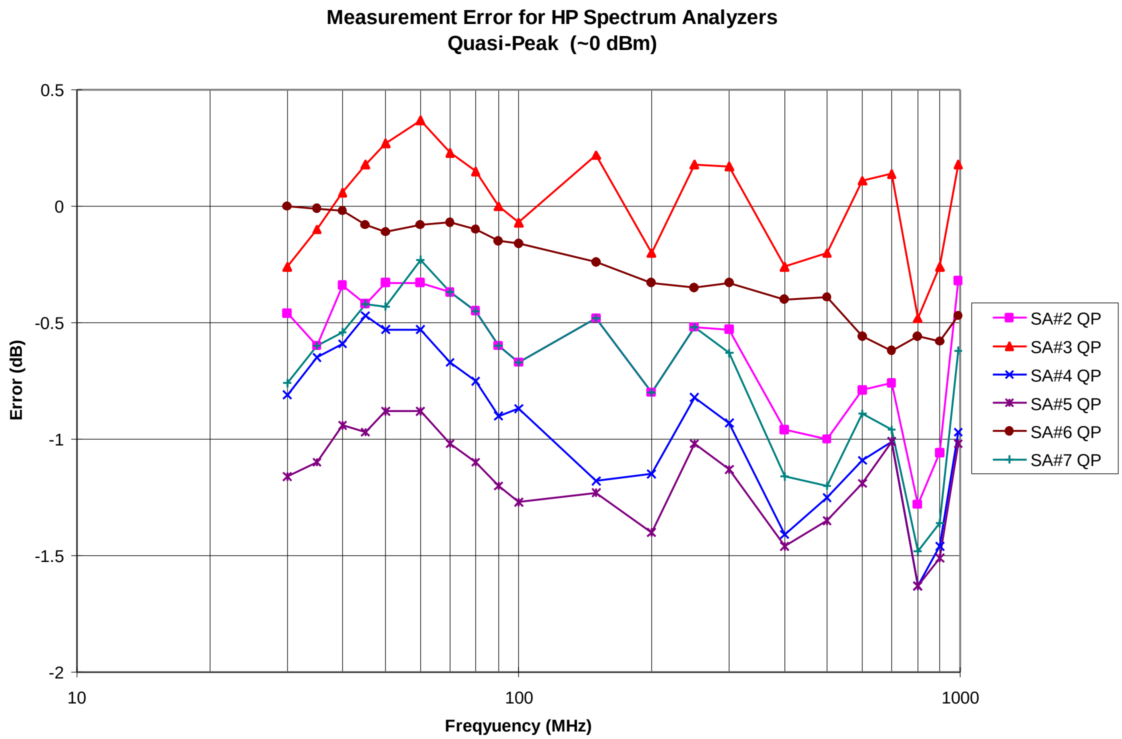

Figure 1

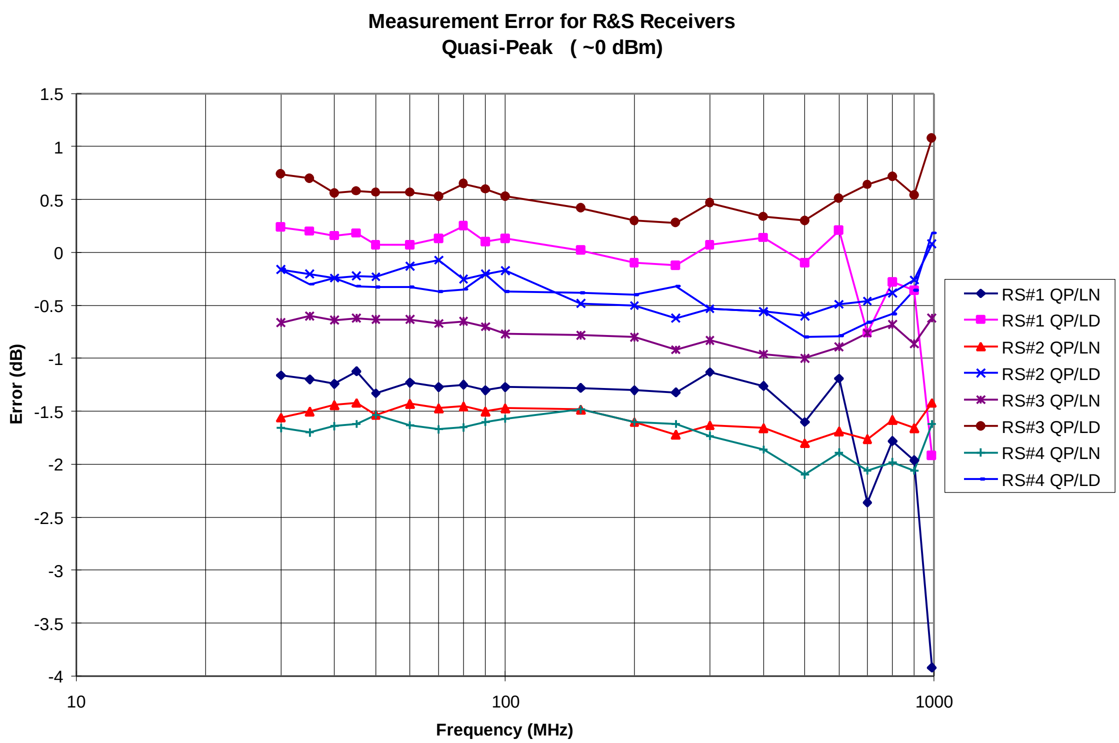

Figure 2

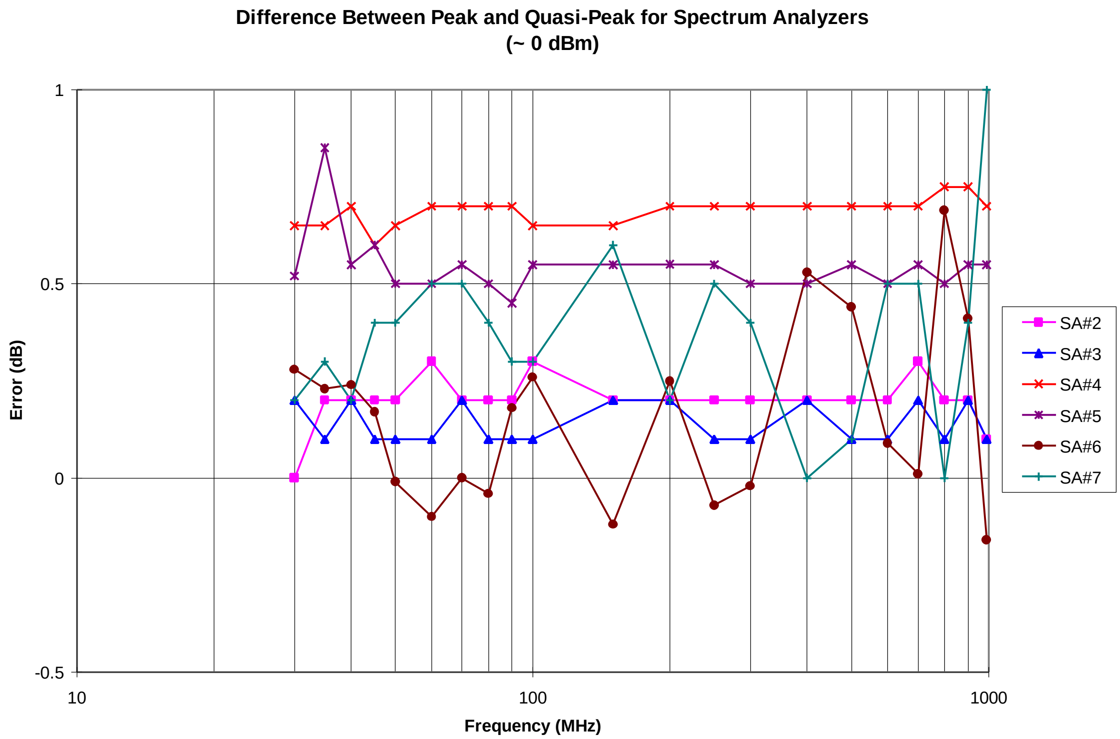

Figure 3

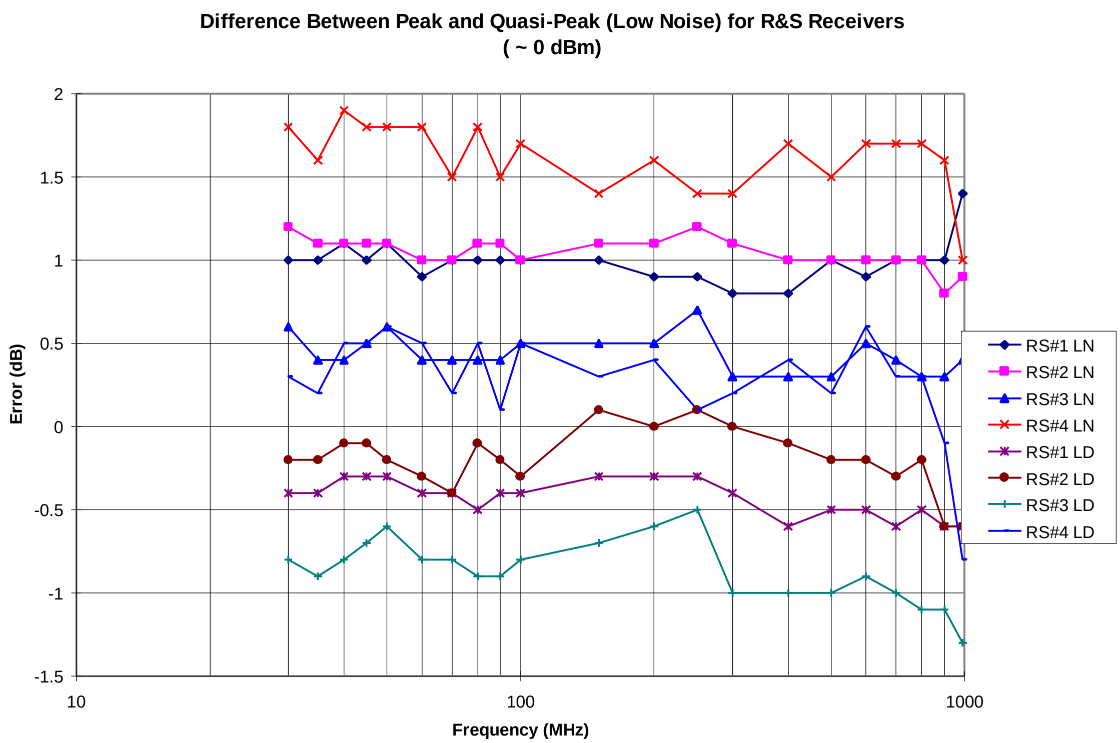

Figure 4

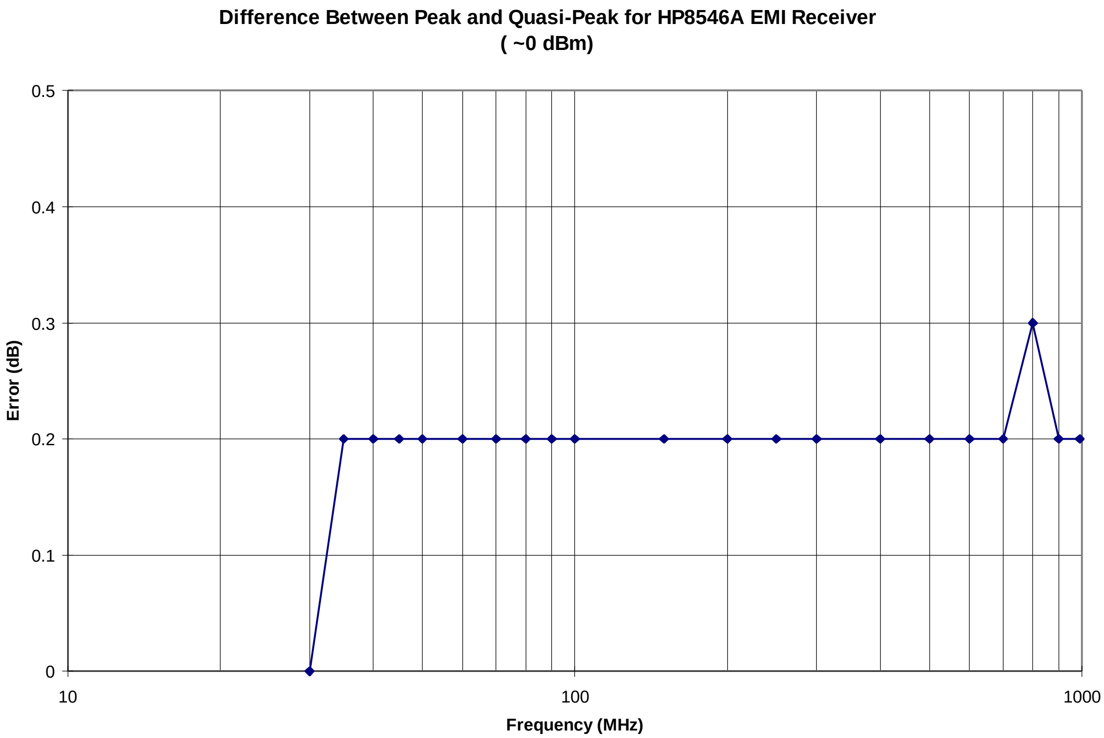

Figure 5

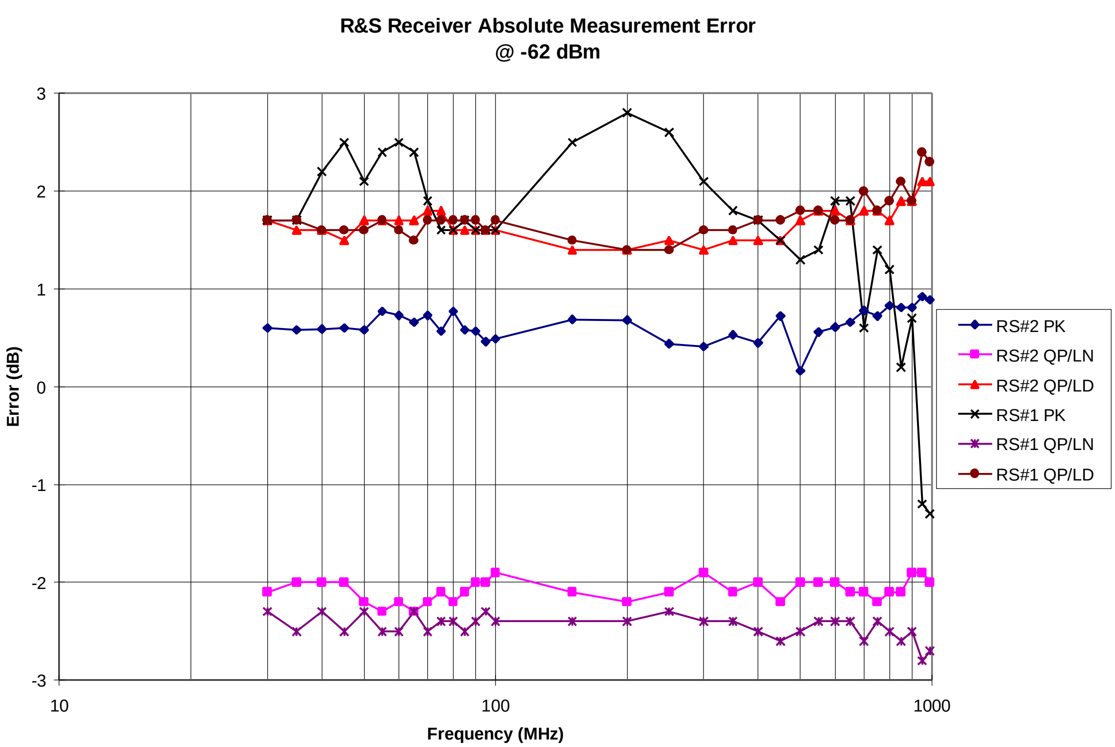

Figure 6

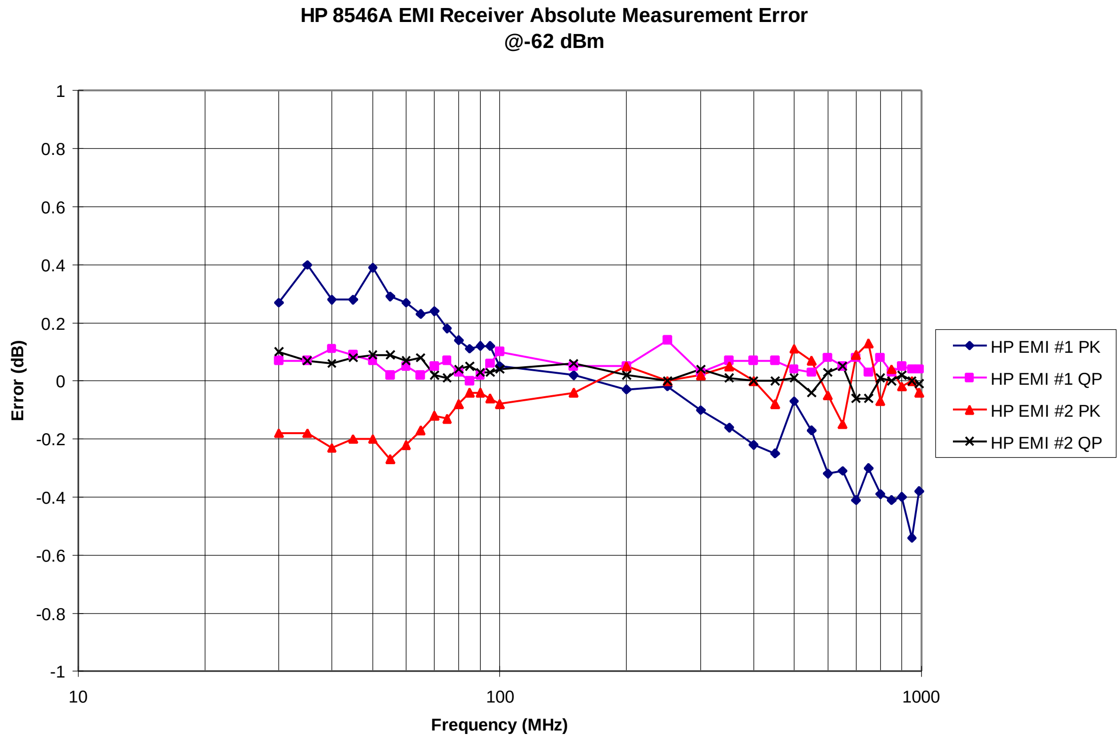

Figure 7

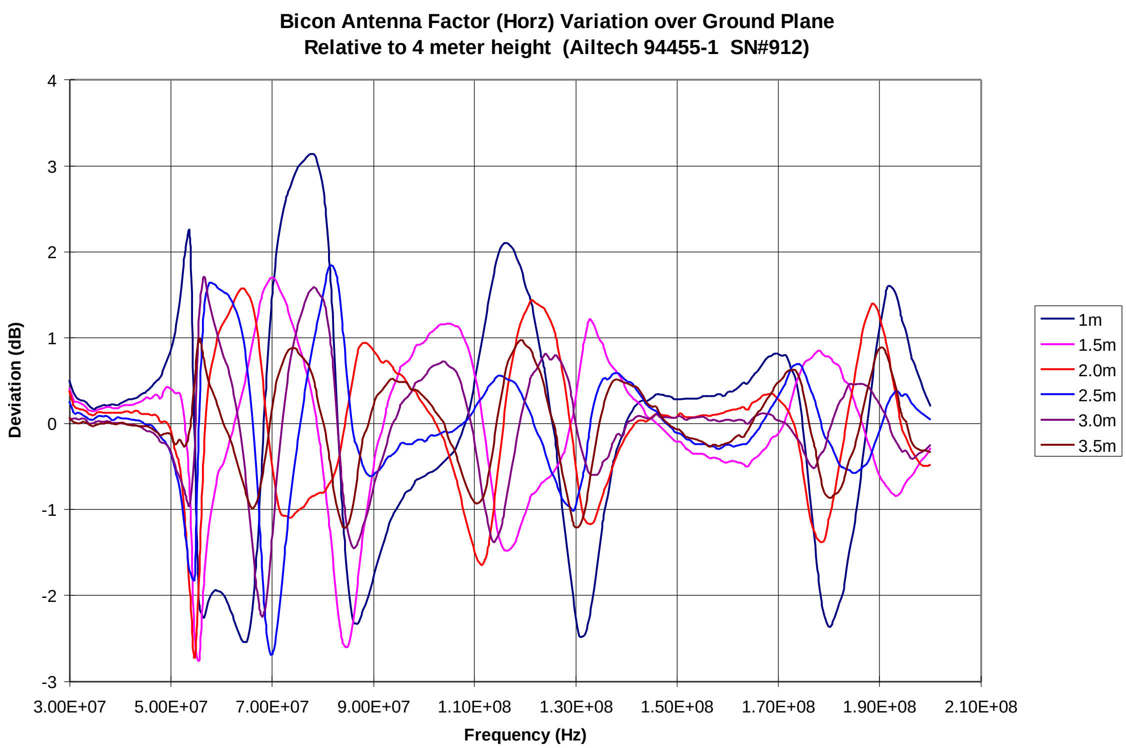

Figure 8

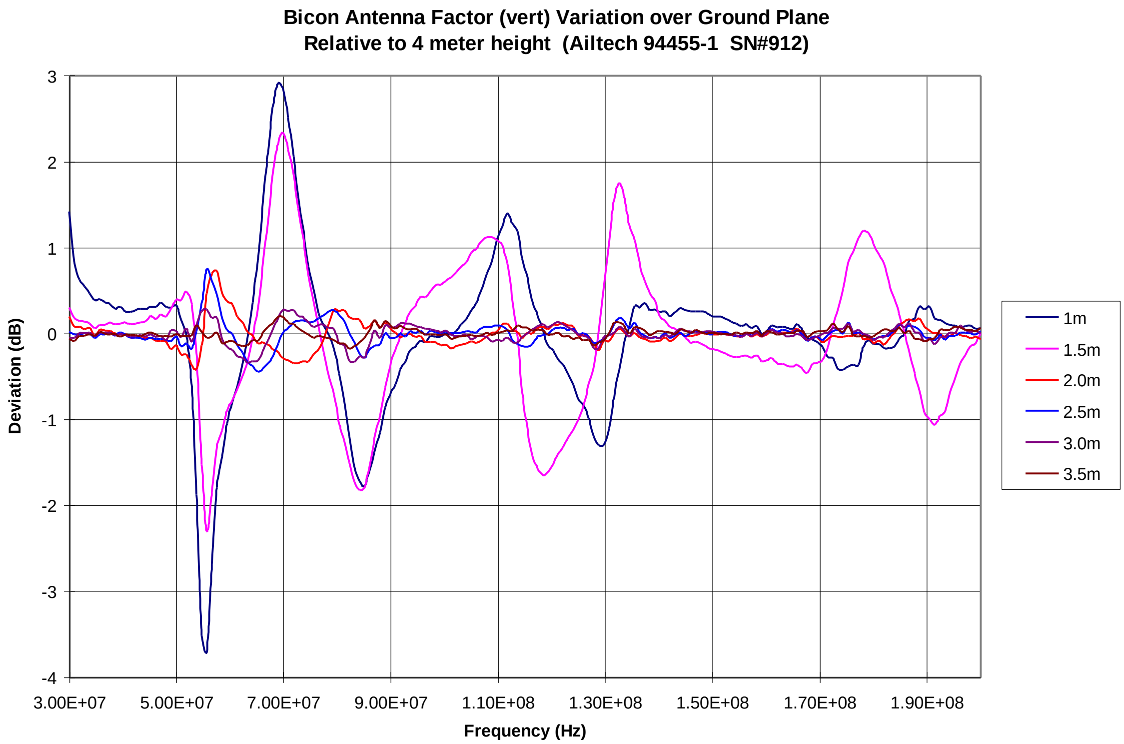

Figure 9

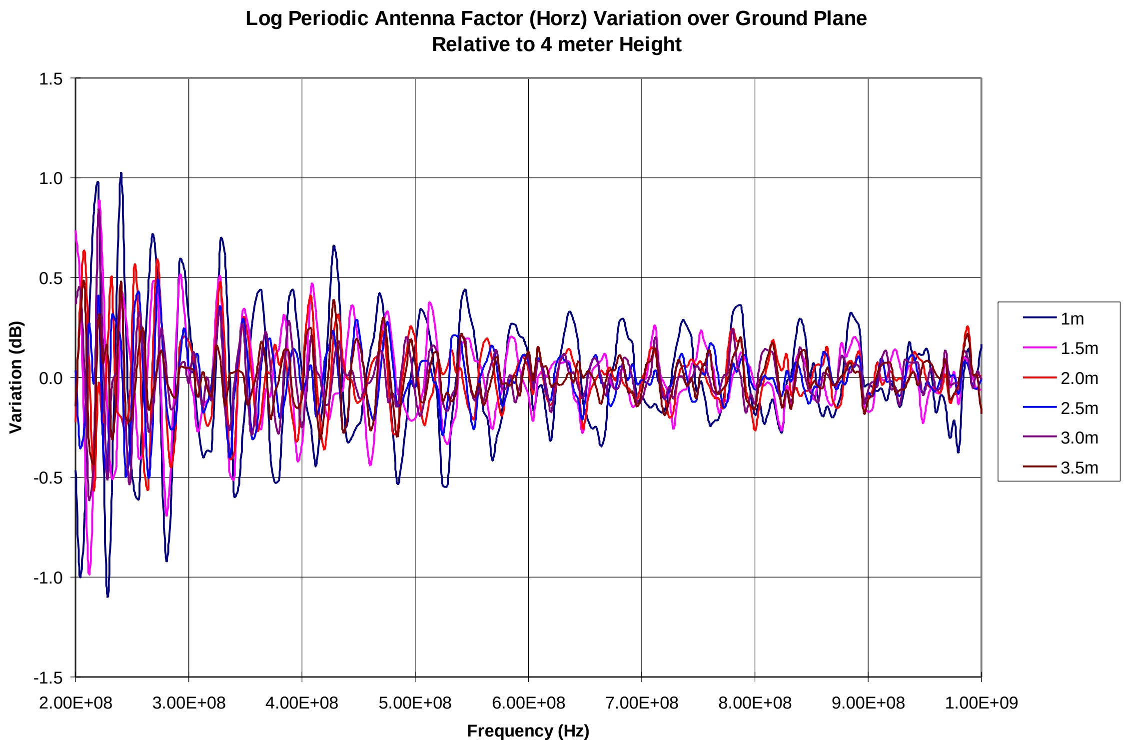

Figure 10

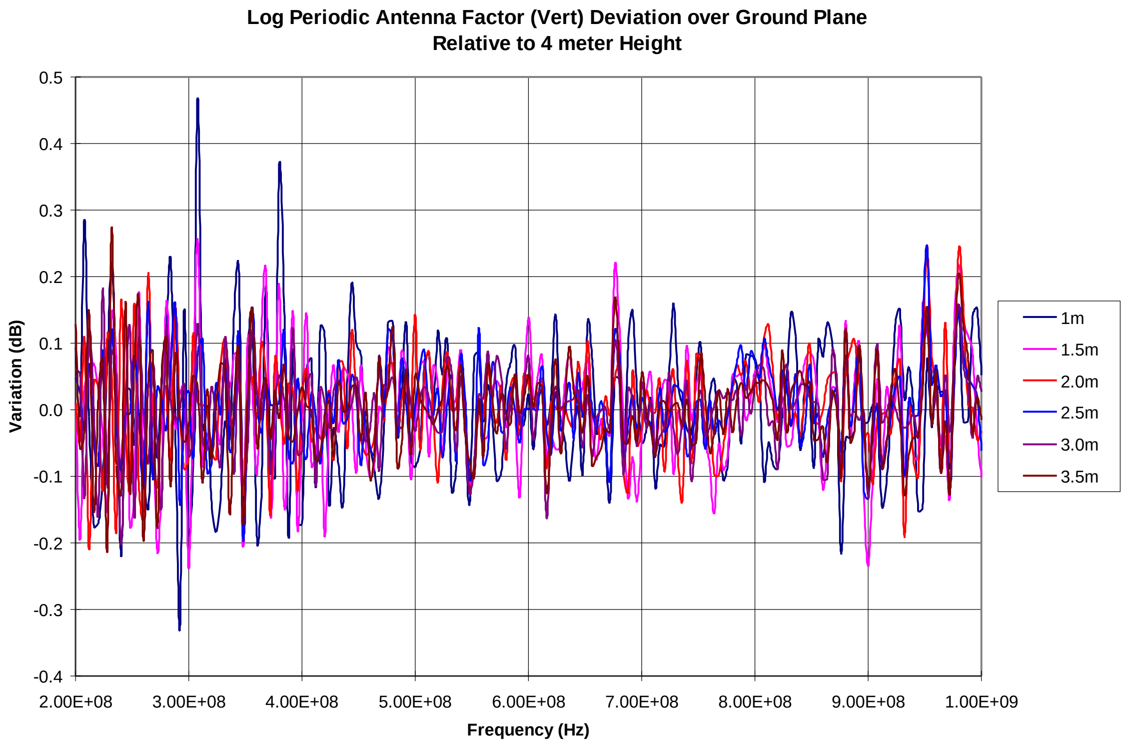

Figure 11

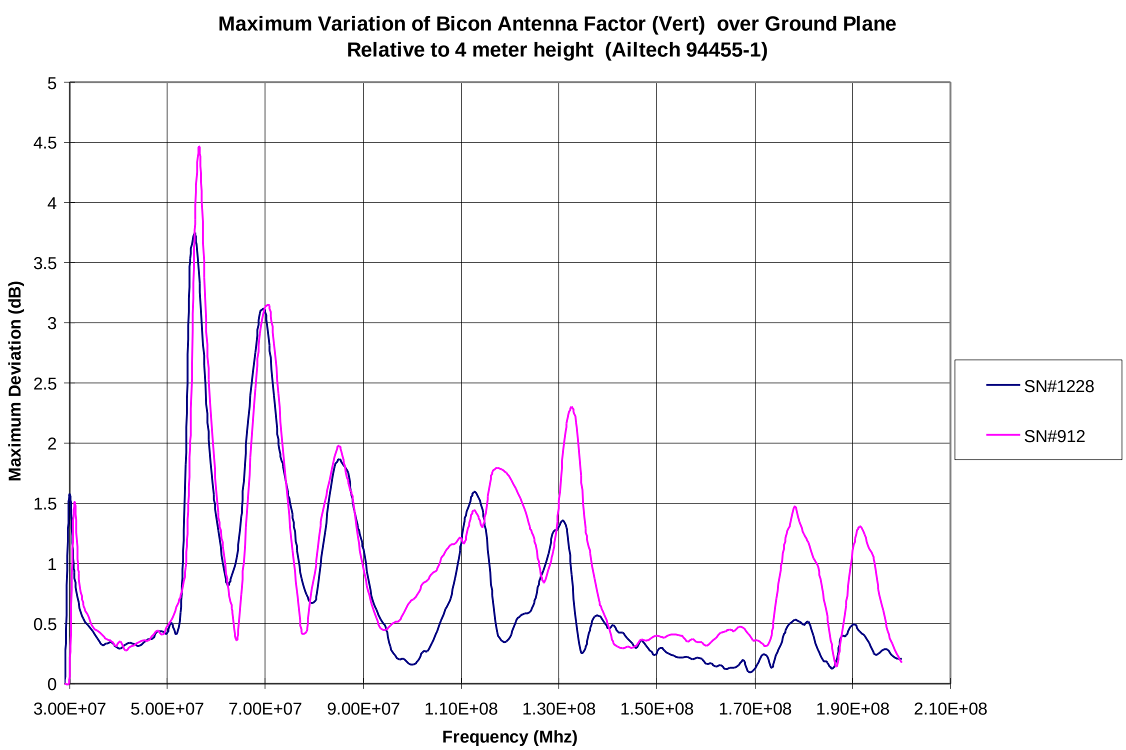

Figure 12

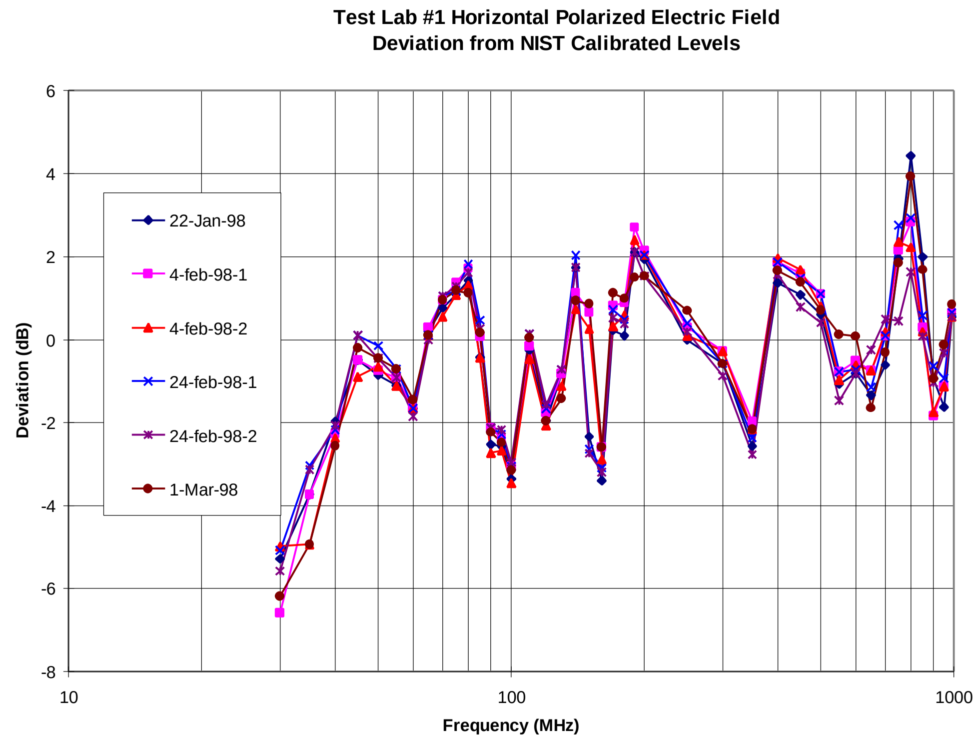

Figure 13

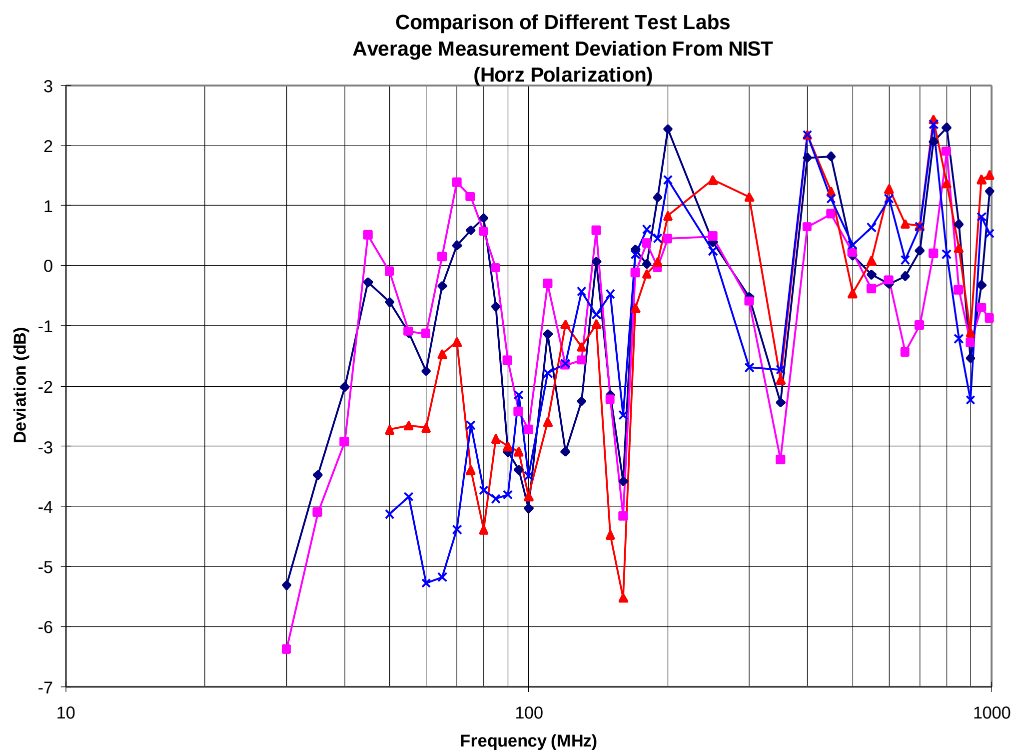

Figure 14

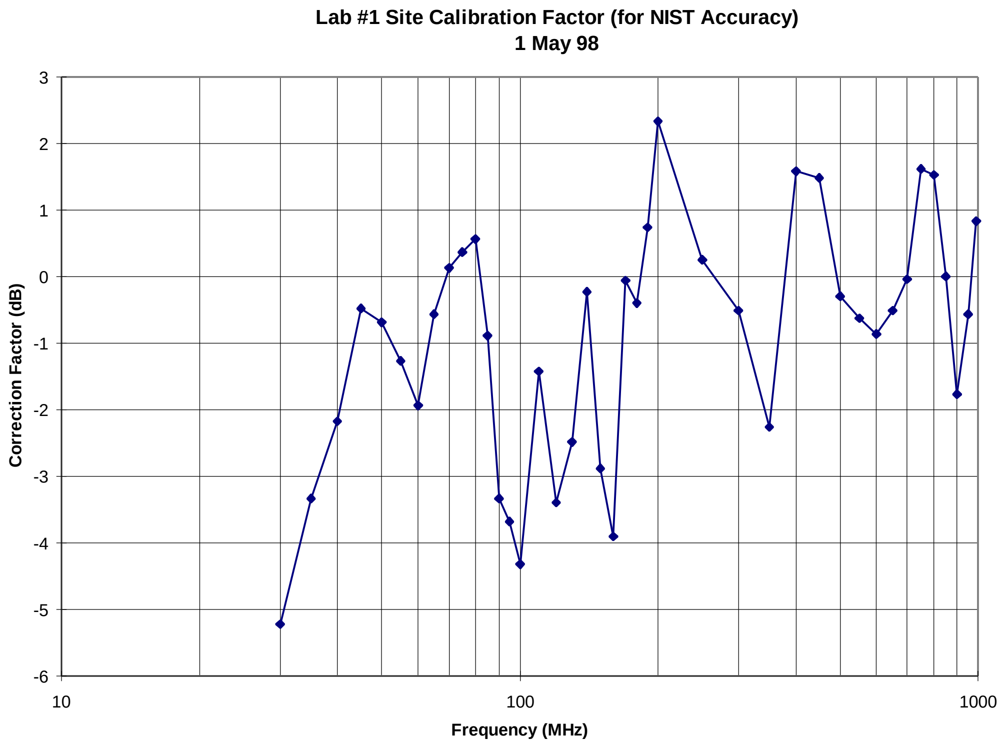

Figure 15

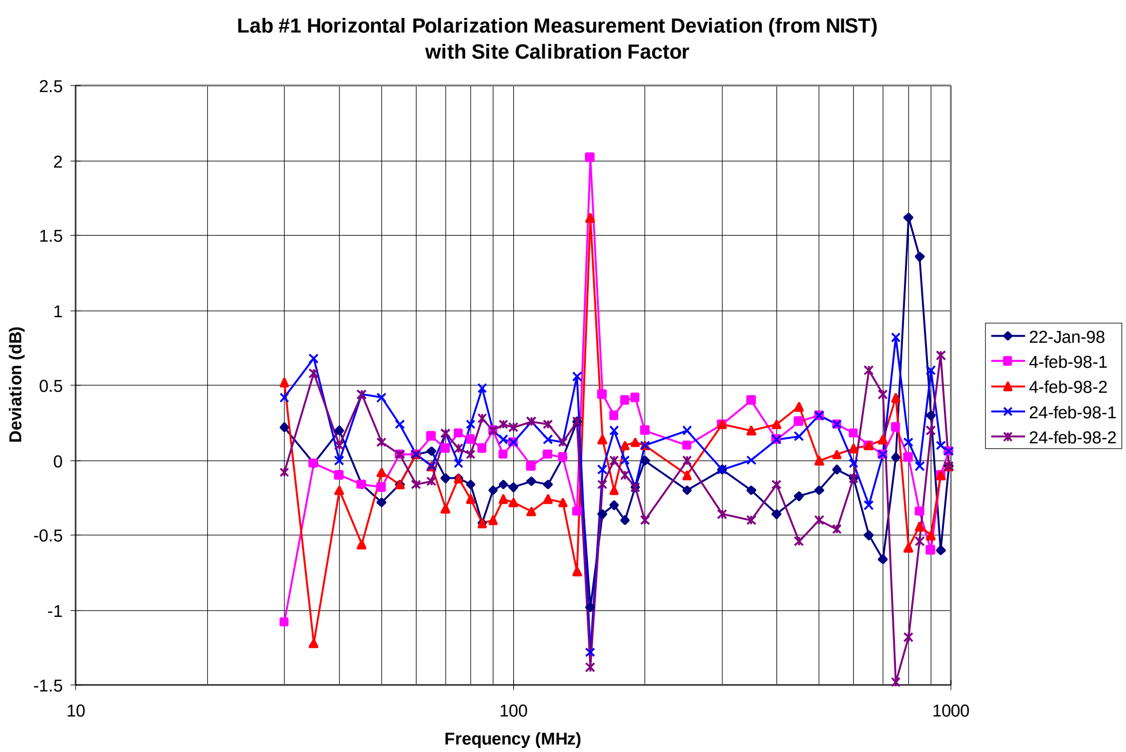

Figure 16