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Validation of EMC near-field scanning amplitude and phase measurement data

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Abstract – **A frequency selection and data validation procedure is presented. It shows that using data from the reference channel it makes possible to estimate the validity of the measured data from an EMC near-field scan with phase on active circuits.**

Keywords-component EMC, near-field scanning, validation

I. Introduction

During the last decade many articles have been written in the field of Near-field scanning (NFS) for the purpose of ElectroMagnetic Compatibility (EMC) emission measurements. Initially the NFS measurements were done to find the location of the hotspots, i.e. noise generators, or as a prototype to prototype comparison for the purpose of troubleshooting. Simultaneously NFS has been used to determine the far-field radiation from antennas since the 1960s[1]. The measurement method has become increasingly popular for antennas since the cost of anechoic chamber construction can be greatly reduced due to smaller size requirements. The main disadvantage of the method is that it is necessary to measure both amplitude and phase of the near-field and that one needs to do advanced post processing such as the spherical wave expansion. The topic of near-field to far-field transformation will not be covered here but an overview can be found in[2].

In recent years there has been a growing interest in using the NFS measurements to predict radiated emission due to the advantage of cost reduction of the test facilities and the fact that near-field scanners can be used early in the design process. This introduces the measurement of both amplitude and phase from an Equipment Under Test (EUT). In contrary to the NFS on antennas, the EUT is now active instead of passive. Therefore the traditional measurement methodology of antenna NFS cannot be used in EMC NFS. Not many have succeeded in measuring amplitude and phase from an EUT with an EMC NFS. Usually antenna EUTs are small and have very well defined radiation characteristics but this will not be the case of a typical EMC EUT [3][4]. In the consortium "EMC Design – First Time Right" the goal is to apply the EMC NFS measurements on real devices. While doing this, a need for selection of frequencies and validation of the data was identified.

This article will discuss the findings on evaluating the validity of the data acquired from an EMC NFS. First, the measurements are made on a reference module, which will serve as demonstration of the method. Secondly the measurements are made on a module used in a real apparatus. Many considerations have to be taken into account and evaluated to be able to have a good outset for the simulation of far-fields from the NFS.

The general interest in the far-field prediction is to predict the performance in a radiated emission test at 3, 10 or 30 meter distance at an open area test site (OATS). Specifically the interest is in the frequency range from 30 to 1000 MHz with a resolution bandwidth of 120 kHz with a peak detector. The challenge of post-processing the data to quasi-peak levels will not be discussed.

II. Description of NF scanners

The EMC NFS at DELTA consists of a XYZ-positioner. This positioner holds the scan probe that is moved in a pre-defined pattern above the PCB in order to measure both amplitude and phase of the tangential E or H field over an EUT. The fact that only the tangential components need to be measured can be found in [2]. The scan probe can be an E-field or an H-field near-field probe. However, using only one scan probe will yield amplitude data from the scan. In order to measure the phase, a reference must be present. It has been widely discussed how this reference signal should be obtained but the general consensus is that it should be obtained by placing a reference probe below the EUT to influence the EUT minimally. The position of the reference probe must be carefully selected since all frequency components from the EUT should be present in the measurement point with sufficient amplitude.

The scan and reference probe signal should then be measured by an instrument. This has been done with 3 different approaches

1) *Vector Network Analyzer*
2) *Phase coherent Receivers*
3) *High-speed Oscilloscopes*

EMC noise can generally be combined into two different parts: Narrow- and broadbanded noise. The narrow banded noise can easily be characterized by the traditional vector network analyzers. The problem arises when the broad banded noise comes into the picture, since VNAs require a quite pure unmodulated carrier. This is due to the fact that the VNA must have a phase lock in the phase locked loop to determine the phase between two signals. Thus for a full scale EMC prediction, the VNA is not a suitable choice. The second option is to use two coherent receivers.

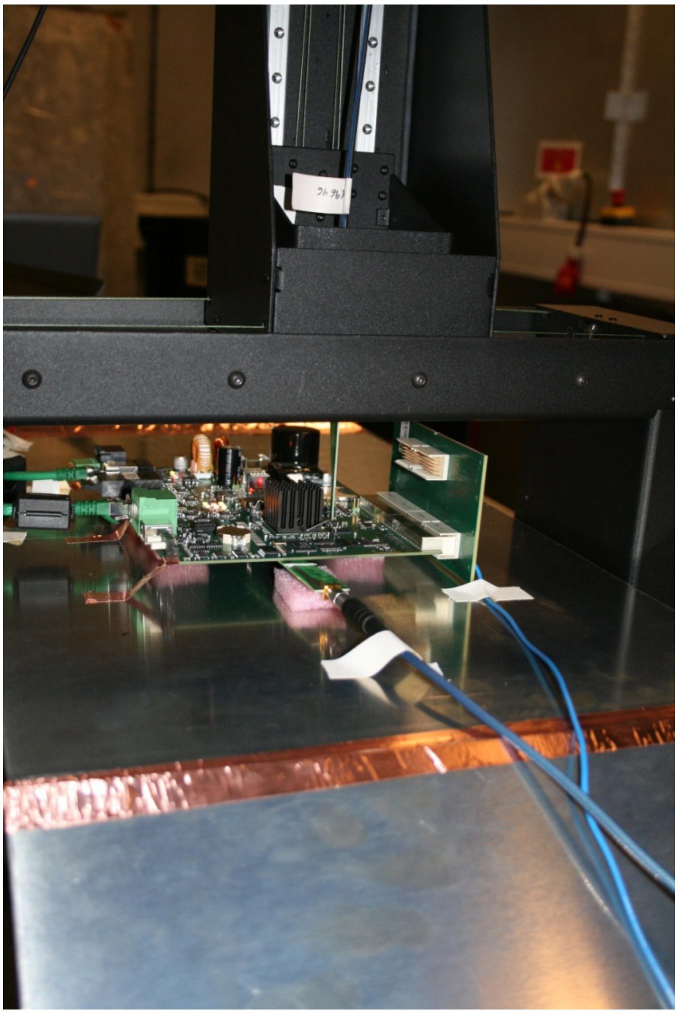


Figure 1. Picture of the scan setup showing the scanner mount, the EUT, the scan probe and the reference probe.

These can be combined to determine the amplitude and phase between two signals. The problem with this solution is that the measurement bandwidth is usually limited to around 120 MHz[5]. Firstly it requires that the range should be split into 8 sub-bands, which increases measurement time. Secondly, these sub-bands need to have their phase related to each other. This means that a rather large overlap must be present to determine the phase relationship between the sub-ranges. The third choice is an oscilloscope and suitable pre-amplifiers. The oscilloscope has usually been considered as a time domain instrument, but during the last decade the frequency range and SNR has increased considerably. They are usually equipped with 2 to 4 measurement channels, which are sampled simultaneously. Utilizing the fast Fourier transform, the amplitude and phase relationship between the two or more channels can be resolved.

III. Amplitude and Phase Measurements in Relation to EMC Radiated Emission Prediction

One of the major difficulties of determining the phase of the fields is that the signals are usually quasi stationary. That is, the EUT will have a certain profile of the noise, given the state that the EUT is in. It is well known that the EUT must be in a "worst case" state during the test. However, this worst case state is usually a combination of several states. Consider a data collection unit as EUT. It will first capture the signals in the analog to digital converter, do some post processing and finally transmit the data via LAN. Such a device would clearly have three different states and the worst case would be if all three functions could run simultaneously, this is not always possible and therefore a code cycle that cycles through the different states needs to be defined. This would give the first requirement to the minimum measurement time, and is often in the range of 1 ms to a few seconds. The second requirement is a traditional observation that something happens when the mains voltage crosses over from positive to negative voltage and vice versa. This means that a full cycle should be measured i.e. for 50 Hz mains a measurement time of 20 ms. Since the upper frequency is 1000 MHz the Nyquist criteria require that a sampling rate of at least 2 GSa/s is used. This can easily be calculated to 40 MSa where each consists of at least 8 bit resolution. Thus 40 MByte per channel will be required per point.

IV. Measurement Points

Usually the measurement points in antenna NFS are placed in a planar surface parallel to the EUT surface. When considering a real world EMC EUT the surface is no longer planar. Connectors, electrolytic capacitors, power supply inductors, heat sinks, etc. will generally make the surface uneven. One could use a very large scan distance to the PCB surface, but this would make the sensitivity of the scan probe too small, while keeping the probe small to still have a reasonable spatial resolution. Therefore a z variation in the scan surface needs to be implemented. In general it is sufficient to measure the tangential components of the E or the H-field [2]. Since the tangential component of the scan surface depends on the orientation of the plane currently being measured, it is obvious that scanning the plane parallel to the PCB surface the tangential components are the x and y components. Similarly for planes orthogonal to the PCB surface, the z-component in one of the tangential components. The other tangential component is either the x or the y component depending on the orientation of the plane w.r.t. x and y. If the plane is parallel to the x-axis, the x-component is the tangential component and for a plane parallel to the y-axis, the y component is tangential. An example of such a scan grid of measurement points is given in Figure 2.

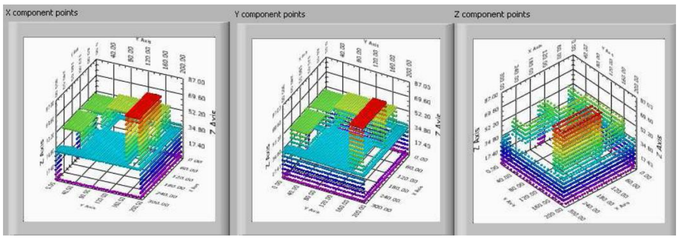


Figure 2. Scan grid pattern indicating measurement points for each rectangular component of the field to measure the tangential fields on the scan surface.

To determine the scan step size, the simplest estimate of the accuracy of the measurement of the field distribution over a trace, is done by evaluating the maximum amplitude error as function of step size. From this evaluation a 5mm step size is chosen based on the principles in[6]. This is also a good value when comparing to the guidelines from traditional planar near-field measurements of antennas[2]. For a PCB as shown in Figure 3 the number of points to be measured becomes approximately 10,500. If a measurement time of one second is assumed this will give a total measurement time of 10,500/3,600=2.92 hours. This indicates that for each second we spend in each measurement point the total scan time increases by almost 3 hours. Thus the speed of the measurement equipment is crucial.

V. OUTPUT DATA FROM THE NFS

From the previous two sections, it is clear that the amount of data that comes from a NFS is very large. The scan time combined with the number of points can create datasets that are in the range of 30-60 GigaByte. Several methods for predicting the far-field exist, but common to all is that some computation is required. Estimation of the radiated E-field based on a NFS is typically done by running a simulation, using the method of equivalent dipoles or current sources or carrying out the plane wave expansion[7][8][9]. However, since an EMC NFS will contain 970 MHz of data with a 120 kHz resolution more than 8000 simulations should be run. The minimal requirements for the processing power are probably from the plane wave spectrum near-field to far-field transform and this requires a 2 dimensional Fourier transform of each of the planes measured[2]. i.e. approximately a 100x100 2D-FFT. Running this for all frequencies would require enormous processing power. Thus, an algorithm that selects only the frequencies, that have potential to radiate above the limit in a SAC radiated emission measurement, is needed. Secondly, since this is a very new measurement method, the frequencies that are selected should be checked for validity. After the selection and validation, the simulations can be performed.

VI. ERROR SOURCES

Several error sources exist in antenna NFS. For the planar case a thorough investigation has been made in [10]. However, antenna NFS is measured in the Fresnel zone of the near-field. Since the lowest frequency in the EMC measurement is 30 MHz the wavelength is 10 m. Thus an EMC NFS is measured in the reactive near-field. This introduces the risk that the scan probe and scanner structure will disturb the reactive near-field which changes the conditions for resonance and therefore changes the radiation characteristics of the EUT. As previously mentioned there is also the risk that measurement times are not sufficient. The most typical errors are summarized in a list here:

1) Interference

If the measurement is not performed in a shielded room the NFS is prone to interference not originating from the EUT.

2) Probe influence

Because of low sensitivity EMC NFS is done in the extreme near-field and the probe will in many cases invade the reactive near field region. Since the metallic structures in the reactive near-field region determine the resonance of the EUT, the probe can influence the amplitude and the frequency of the near-field.

3) Scanner structure reflection

When constructing the NF scanner bed and positioner it is very important to avoid reflecting surfaces. Even though the near-fields decay much faster than the propagating EM fields the reflections can probably still influence the results significantly

4) Insufficient measurement time

A common problem especially in modern electronics is the problems with non-stationary operating EUTs. An EUT might have a code cycle of 50 ms or more. If the measurement time is shorter than the code cycle, it is possible that some noise emissions have not been measured correctly.

5) Insufficient distance to noise floor

Like any other measurement a NFS must have sufficient amplitude with respect to the noise floor of the measuring instrument.

6) Thermal drift

The large amount of measurement points and frequencies can lead to very long measurement times. Thus there is a risk that the EUT will drift during this measurement.

7) Reference probe displacement

Since the scanner must be able to scan many different EUTs, the position of the reference probe must be flexible. This however also means that care must be taken when mounting the probe. Half a mm in positioning displacement can mean several dBs difference in the measured near-field strength and the reference for the phase.

8) Scan channel to reference channel crosstalk

Disregarding the type of measurement instrument, there will always be a limited isolation between the two channels. That is, a small part of the signal in channel 1 can leak into channel 2 and contaminate the channel 2 data. When the scan probe is directly above a hotspot, the amplitude can increase in the order of 10's of dBs. Thus the signal from the scan channel can leak into the reference channel.

VII. VALIDATION PROCEDURE WORKFLOW

As described earlier, a typical NFS will produce very large amounts of data and each simulation requires substantial processing power. Thus, an automated procedure must be present.

1) Identify the frequencies of interest to reduce the size of the data set by investigation of the max hold spectrum of the scan channel.

2) Investigate the stability of the scan probe signal for the frequencies found in the first step.

3) Select frequencies (if any) that indicates bad stability in step 2.

4) Identify by visual inspection of the scan and reference signal at the frequencies found in 3, which of the errors mentioned in section VI are present.

The simplest procedure to find the frequencies for further investigation is to process the spectrum from each scan probe position and keep the maximum field value at each frequency over all positions of the scan probe. This is necessary since the spectrum from the scan probe signal is highly dependent on the position of the probe. In some points low frequency noise from the switch mode power supply can be seen and in other points the high frequency noise from the CPU. From this process a max hold spectrum is obtained. That is, a spectrum that displays the maximum amplitude seen at a certain frequency in any point. This spectrum we will denote "the max-hold-scan spectrum". To identify the interesting frequencies, a peak selection routine, which selects frequencies above a certain level is now run on the max-hold-scan spectrum. This will yield a peak frequency list that contains all frequencies that have sufficient amplitude to cause radiation above the limits. One very important comment should be stated at this point. The fact that the amplitude of the near-field is very high in one or more measurement points does not guarantee a high level of radiation in the far-field. That is why a simulation or near-field to far-field transformation is necessary. However, if the amplitude is low in all measurement points the simulation is not needed.

The frequency list from the max-hold-scan spectrum will identify the frequencies where the emission can be greater than the limit for the OATS compliance test. Thus also the frequencies that need to be simulated. However, to run the simulation, the phase of the fields is necessary. To get an accurate phase, sufficient power is needed in the reference probe spectrum. The first estimate, if this is the case, can be obtained by running the peak selection routine on a few reference probe spectra and checking if each of the frequencies on the list from the max-hold-scan spectrum is on the list from the reference probe. However, this is only the first quick validation of the data. This will show if power is available in the reference channel but not if the signal is stable. To fully analyze if the reference spectrum has a sufficiently reliable signal, that is free of the errors listed in section VI, the reference channel must be investigated for each of the frequencies in the peak pre-scan frequency list for all positions of the scan probe with the reference probe position constant. This is done by calculation of the standard deviation at each of the frequencies in the peak frequency list from the scan channel.

Finally the result of the stability analysis should be used for an investigation of the error sources. The stability analysis will not show which of the errors sources that are the cause of the problem, but it will show if the reference channel is varying with probe position, which indicates that there is an error in the scan data at that frequency. Thus, if the stability analysis indicates a higher standard deviation than expected, the frequency should be inspected by visual inspection of the spatial plots of the amplitude, showing the amplitude for each scan probe position, for both the reference channel and the scan channel. To determine which of the errors that are the source of the problem at that frequency is not a trivial task.

VIII. EXAMPLE WITH A SCAN OF A REFERENCE CIRCUIT

To investigate the setup of the NFS, a reference PCB was constructed. This had a 50 Ω microstrip, which was terminated with a matched load. This microstrip was fed with an input signal from a comb generator with a repetition frequency of 20 MHz. Besides the active microstrip, two other transmission lines were made on the PCB, to introduce the possibility of capacitive and inductive coupling to floating structures.

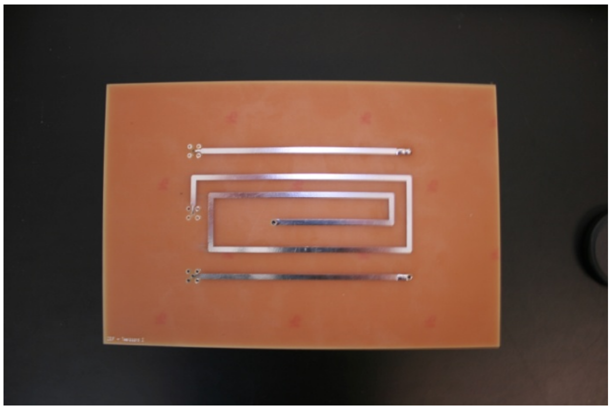


Figure 3. Picture of the reference PCB used for the scan.

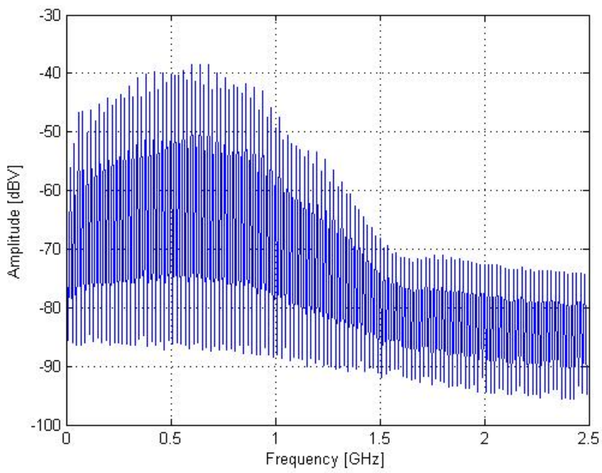


Figure 4. The max-hold-scan spectrum in dBV vs. frequency from the reference PCB.

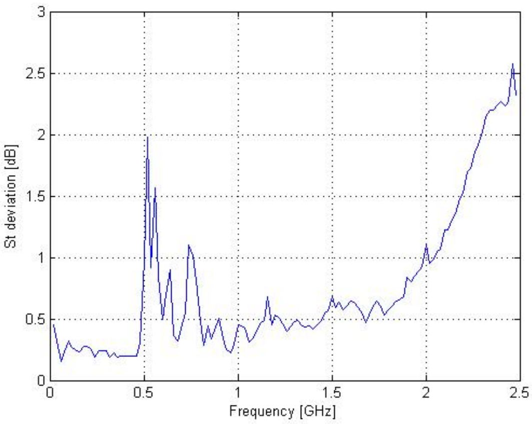


Figure 5. Result of error analysis on the reference PCB shown as standard deviation vs. frequency.

In Figure 5 the result of the stability analysis on the frequencies selected in Figure 4 is shown. It is clear to see that the stability, i.e. the standard deviation of the reference channel, is very good up to 480 MHz, from 500 MHz to 800 MHz there is a very poor stability due to the high standard deviation, and from 800 MHz and up the stability is reasonable. After the measurements a ground loop from the comb generator to the ground plane of the PCB was identified as source for a groundplane resonance. This resonance was affected by the coupling to the scan probe and scanner structure which was the origin of the variations between 500 and 800 MHz. This was corrected and another measurement was made. The validation analysis was run on the data obtained from the new scan. This gave the max-hold-scan spectrum shown in Figure 6 and the deviation in Figure 7.

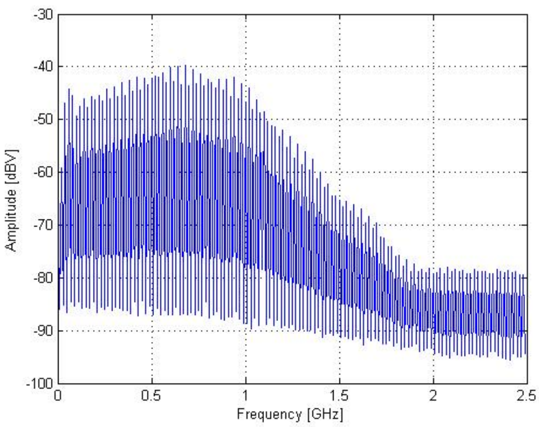


Figure 6. Max-hold-scan spectrum in dBV vs. frequency from the corrected reference PCB.

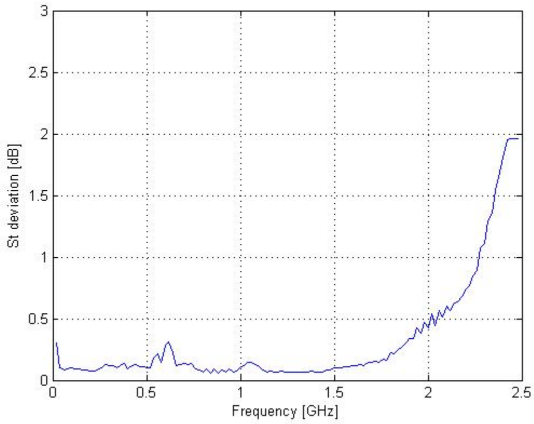
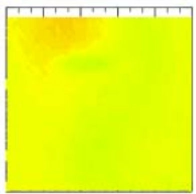


Figure 7. Error analysis on the corrected reference PCB shown as standard deviation vs. frequency.

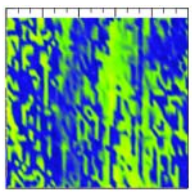
In the following figures some examples of difference errors that were observed during various measurement configurations are displayed. Specifically the amplitude at one frequency is shown as function of the position of the scan probe position. In case 1 without errors a plot with a standard deviation 0.12 dB is shown. In case 2 a case with interference, originating from a near by GSM basestation, giving a standard deviation of 3.2 dB. It was identified as interference since it could be repeated with the EUT turned off. In case 3 and 4 the disturbance appeared to be the probe and scanner structure disturbing the measurement giving a standard deviation of 2.5 dB. It was only seen on a particular implementation of a near-field scanner. Case 5 where the reference channel was so much lower than the scan channel that the isolation between the two was insufficient and some of the scan channel signal leaked into the reference channel. The standard deviation was 1.3 dB. The last case however could also originate from the probe disturbing the field.

1) No Errors

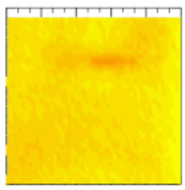
4) Scanner structure reflection



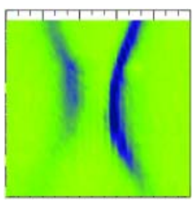
2) Interference



5) Scan channel to reference probe crosstalk



3) Probe influence



IX. EXAMPLE WITH A SCAN OF POWER CONTROL MODULE

As mentioned in the beginning of the article there is a great need to apply EMC NFS to real EMC cases. Therefore the theory was used on a Power control module that had failed in an EMC test.

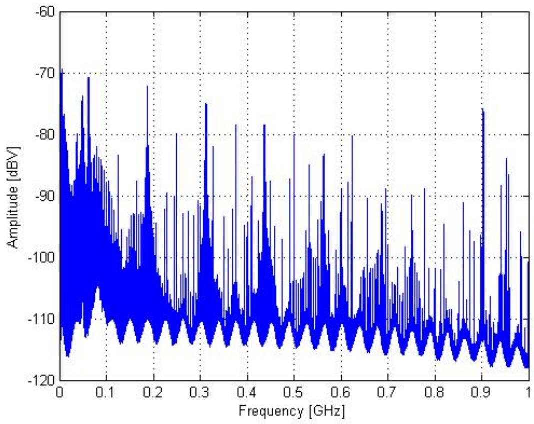


Figure 8. The max-hold-scan spectrum in dBV vs. frequency from the power control module.

From this graph displaying the max-hold-scan spectrum from the power control module, it is clear that a simple but efficient data reduction is needed, so that not all frequencies need to be simulated.

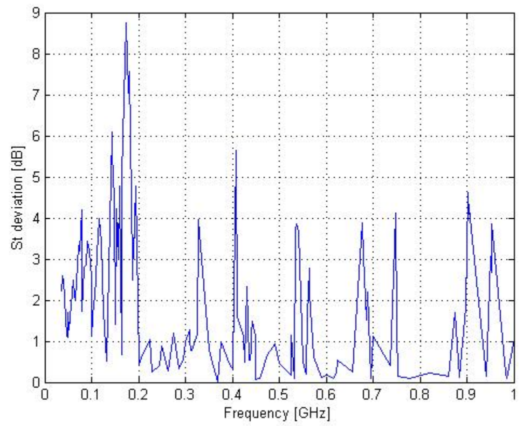


Figure 9. Result of error analysis on the power control module shown as standard deviation vs. frequency.

The standard deviation of the reference channel signal can be seen to be significantly higher than the standard deviation in the measurement of the reference PCB. This clearly gives an indication that the there are certain frequencies that need to be investigated further before a simulation will give reliable results. The first part of the investigation is to visually inspect the reference and scan channel at the problematic frequencies and from that determine which one of the errors listed in section VI can be the cause of the error in this case. It is not a trivial task but in many cases it is possible to deduct the possible source of error by examining the system and EUT properties at that frequency, fx. using a zero-span setting on a spectrum analyzer to investigate the scan channel probe as the scan probe is moved. The process of finding the errors is far more efficient when it is known where in the data and at what frequencies the errors can be found.

X. CONCLUSION

It was shown that using the method described in this article it is possible to select the interesting frequencies for further simulation. Creating a data reduction that makes the simulation or near-field to far-field transformation feasible. Secondly, a validation algorithm is described so that the data can be validated before entering the simulation to avoid time wasting simulation on non-valid data. This was done by calculating the standard deviation of the reference probe over all positions of the scan probe for each frequency of interest.

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