An Integrated Near-field EMC Measurement System

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This paper briefly describes the theory and application of a small near-field imaging system designed for EMC precompliance applications. This system produces EMI and EMS images of circuit cards, cables and related items. If extended by using a phase coherent receiver in a region of free space propagation, this same system can precisely measure the radiation pattern of directive antennas and image the multipath within an anechoic chamber or TEM cell.

Introduction

Near-field methods provide a powerful tool in the measurement and analysis of electromagnetic interference (EMI) and electromagnetic susceptibility (EMS). The near-field measurement system can produce high resolution images of radio frequency (RF) emissions and susceptibility of circuit cards, cables, electronic enclosures and similar items. Additional extensions to the near-field measurement system allow imaging of anechoic chamber quiet zone and TEM cell problems and the precise measurement of antenna radiation patterns.

Near-Field Measurement Theory

Antennas, circuit boards, and other conductive components all radiate or reradiate RF energy. The RF energy from a radiating or reflective (reradiating) object can be coupled into a field probing antenna by capacitive coupling, inductive coupling or by free-space propagation. The first two coupling methods, also known as reactive or evanescent coupling, exist only for a distance of a few wavelengths from the object surface. Conversely, free-space propagation exists over very large distances. There are three regions of propagation relative to a radiating or reflective object:

1. The region nearest the radiating object is the reactive or evanescent near-field region. This region includes both propagating and reactive energy. The evanescent energy component decays very rapidly with distance and has completely decayed at a distance of several wavelengths away from the object surface. Properties of this region include:

    a. Separate E- and H-field measurements are required to determine the power density and field impedance.

    b. The power density decays very rapidly with distance.

    c. This region is where near-field circuit board and cable EMI emission measurements are generally made.

2. The second region is the radiating near-field or Fresnel region which starts approximately one wavelength away from the radiating object. This region consists of propagating energy with a relatively constant power density. Properties of this region include:

a. E- and H-field measurements are directly interrelated by the impedance of free space (377 ohms).

b. The power density remains relatively constant with distance.

c. This region is where near-field antenna measurements and chamber imaging measurements are typically made. These measurements can be converted to a far-field angular equivalent by a Fourier transformation.

3. The region furthest from the radiating object is the Fraunhofer or far-field region. The transition distance (R) for the far-field region is generally a distance where the phase curvature of the phase front is 22.5 degrees or:

$$R = 2D^2/\lambda$$

where: D = largest dimension of radiating object

λ = wavelength

Properties of the far-field region include:

a. E- and H-field measurements are directly interrelated by the impedance of free space (377 ohms).

b. The power density decays according to the inverse square law.

c. This is the region for far-field testing.

While approximate distance limits between regions are shown, the actual transition between the regions is quite gradual. Phase coherent measurements of a phasefront in either a propagating near-field or far-field region can be converted into an angle domain far-field equivalent by a Fourier transform based algorithm.

Near-Field Measurement System

A near-field measurement system measures the E and/or H field distribution over a planar, cylindrical or spherical scan surface. A near-field measurement system consists of a RF sensor subsystem, a high precision robotic scanner mechanism and a personal computer (See Figure 1). The sensor to be positioned by the scanner depends upon the type of test. Generally, the sensor consists of a probe antenna and a receiver. The computer is used both for data acquisition and processing. The data acquisition software is capable of acquiring several thousand multifrequency measurements per second. The data processing segment includes extensive Fourier transform and polarization analysis capabilities.

The RF probing system may be either non-coherent (amplitude only) or phase coherent (amplitude/phase) depending upon the particular application. The most common configuration uses a non-coherent receiver such as a spectrum analyzer or EMI receiver. For EMI measurements, the receiver is connected to an E or H field probing antenna (See Figure 2). For EMS measurements, the receiver is connected to a circuit trace in the device under test.

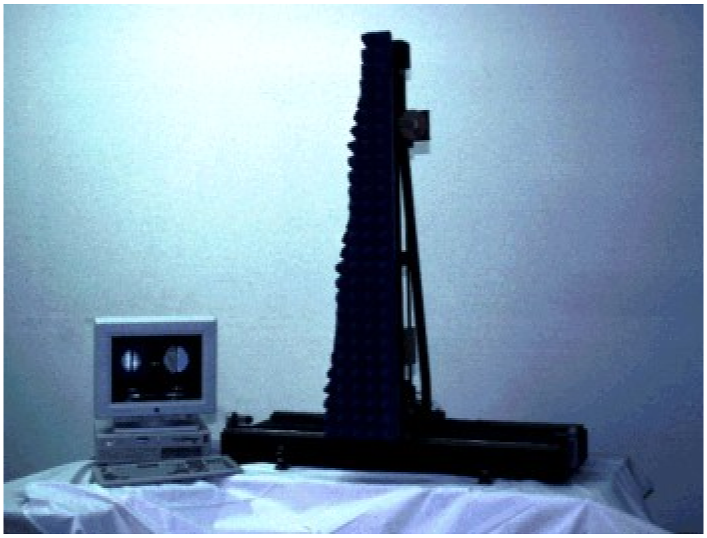

Figure 1 - NSI Model 233L portable near-field scanning system.

EMI Imaging

Most EMI measurements are made at frequencies below 1 GHz. Because the wavelengths at these lower frequencies is large, the EMI measurements are generally made in the reactive near-field region. The E and H field signal levels separately indicate the levels of the stray electric and magnetic fields. It is possible to form a photograph like image of the field strength by scanning the near-field probe over a two dimensional surface. Near the test article the resultant measurements can be displayed as a photographic image, as contours of constant E or H field level or as a listing (See Figure 3). This type of system is useful over the full bandwidth of EMI significant frequencies.

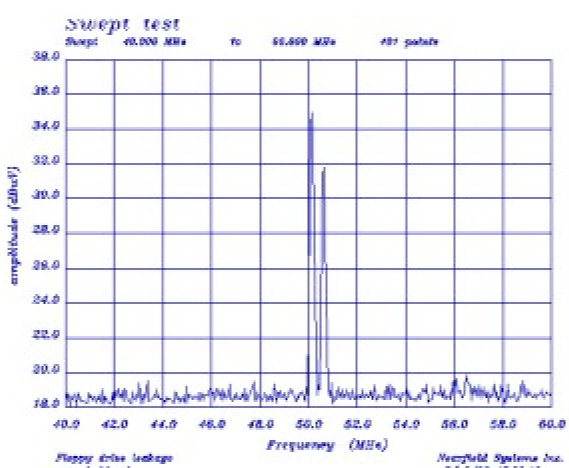

Figure 2. Frequency plot showing maximum near-field electromagnetic interference levels near a floppy disk drive

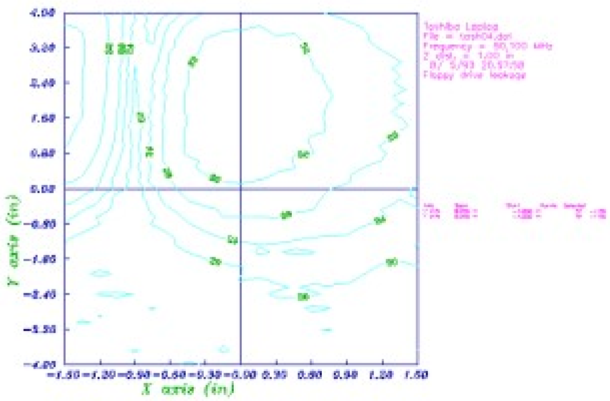

Figure 3. This contour plot shows a spatial (XY) image of EMI emission near a floppy drive

EMS Imaging

Electromagnetic susceptibility (EMS) tests inject an interfering signal into a system under test to determine the system sensitivity to that interference. Susceptibility images of circuits can be formed by injecting an interference signal into the E or H field probe antenna while scanning in the near-field region. The influence on the circuit can be measured by connecting an EMI receiver, spectrum analyzer or other detector to the unit under test circuit traces or output.

Antenna Measurements

Near-field methods can quickly and very accurately measure antenna gain, pattern and polarization characteristics. It is in this area that near-field measurement systems have been most often used. For accuracy, it is necessary to measure all significant radiated energy. High gain antennas are typically measured with a planar scan while broadbeam antennas require a cylindrical or spherical scan. Furthermore, the measurement cannot be made in the reactive (evanescent) near-field region as the measurements are corrupted by non-propagating energy. The smaller near-field scanners described in this paper are useful for measuring antennas operating at frequencies above approximately 500 MHz. Measurements at lower frequencies are limited because of the need to remain outside of the reactive near-field region.

It is necessary to use a phase coherent receiver such as a HP-8720C vector network analyzer in order to correctly measure the wavefront distortion in the antenna phasefront. In this case, the vector network analyzer is used to make an S21 measurement through the antenna/probe path. Once the near-field phase front measurement has been acquired, the equivalent far-field performance can be computed by a Fourier transformation process. This is one of the most precise methods known for measuring the radiation pattern, gain, polarization and other properties of an antenna.

Anechoic Chamber and Test Cell Imaging

A planar near-field measurement system can be used as a radio camera to image the propagating energy within an anechoic chamber or TEM cell. The best results are obtained if the measurements are made outside of the evanescent region. The theory and setup are very similar to that of the antenna measurement system. An important difference is the need to apply an apodizing function to the measurement set to minimize induced side lobes.

Conclusions

Nearfield measurement methods can provide a new precompliance tool to measure and understand EMC problems. Typical applications include imaging the EMI hot spots on circuit boards and RF leakage around gaskets, connectors, CRT displays, etc. Advantages of near-field methods include a photograph like high resolution view into the causes of certain EMI and EMC problems, and minimal facility requirements. With the addition of a vector network analyzer, the same system can be used to measure quiet zone distortions in anechoic chambers and TEM cells and to measure antenna radiation patterns. The primary disadvantage of the near-field technique is the inability to directly produce measurements in the form required by compliance testing.

References:

Hindman, G., D. Slater, "Anechoic Chamber Diagnostic Imaging", Proceedings of the Antenna Measurement Techniques Association, 1992.

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