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## Application of Full-wave 3D Field Solvers to Predict EMI Behavior in SFP Cages

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# Abstract

This paper presents an investigation into the usage of modeling techniques to predict and improve the shielding effectiveness of rectangular, metallic Small Form-factor Pluggable (SFP) EMI cages. These cages house bi-directional SFP+ transceiver modules that can operate at data rates up to 11.1 Gbps. The simulation tools used for this investigation are Ansoft HFSS$^{TM}$, a full wave 3D EM simulator and CST Microstripes$^{TM}$. The usage of simulation tools allows for a more rigorous investigation of the application of alternative materials inside the SFP+ cages and for comparison with more traditional EMI springs and conductive elastomeric gasketing.

# Author's Biographies

**Alpesh U. Bhobe** received his B.E. degree in Electrical and Telecommunication Engineering from the University of Bombay in 1996 and Ph.D. in Electrical Engineering from the University of Colorado at Boulder, Colorado in 2003. He was a Post-Doc at NIST in Boulder, Colorado from 2003-2005. While at the University of Colorado and at NIST his research interest included the development of FDTD and FEM code for EM and Microwave applications. Currently, he is working as a Hardware Engineer at Cisco Systems, San Jose, CA where he is working on EMC design. Prior to joining Cisco, he was working as a Hardware Engineer at NVIDIA Corp. in Santa Clara, CA.

**Steven D. Dunwoody** has worked in electromagnetic, and especially shielding testing since 1984, when he joined Tyco Electronics, then AMP. Before this he worked in RF in the broadcast industry. He received a BSEE from Purdue University in 1974. In 1990 he published a new transfer impedance test technique for panel-to-cable connectors which was adopted by several organizations and later improved by the IEC. In 1996 he finalized a test procedure for detection of nanosecond discontinuities, adopted by EIA. In 2002 he design a dual-chamber 3 GHz (DC3) mode-stirred chamber for 3-50 GHz. His discoveries using this fixture laid the basis for the approach used in this paper.

**Michael Fogg** is a Senior Principal Engineer for the Circuits and Design Group of Tyco Electronics. His primary responsibilities include design, test, and analysis of high performance interconnects used in multi-gigabit applications. He has a MS in Engineering and a BS in Engineering Technology from the Pennsylvania State University. He has been active in connector development and EMI containment for 25 years. His 29 patents cover a wide range of products, ranging from RJ45 to SFP/XFP/CFP. Current responsibilities include design and development of I/O and EMI solutions for products used in 100Gbps Ethernet, as well as other high speed, low noise solutions.

**Richard Long** has worked in the signal integrity industry for 9 years. After graduating from Penn State University with a BEEE he joined Tyco Electronics as a Development Engineer. Rich has been involved in all aspects of signal integrity work including laboratory testing, modeling, validation, PCB design and programming. Rich has written custom software for s-parameter data collection and post-processing. He is well versed in many SI oriented software packages such as Agilent's ADS and Ansoft's HFSS. Rich worked on developing and maintaining software to control the 3 GHz mode-stirred chamber and has experience in the EMI lab with shielding effectiveness testing.

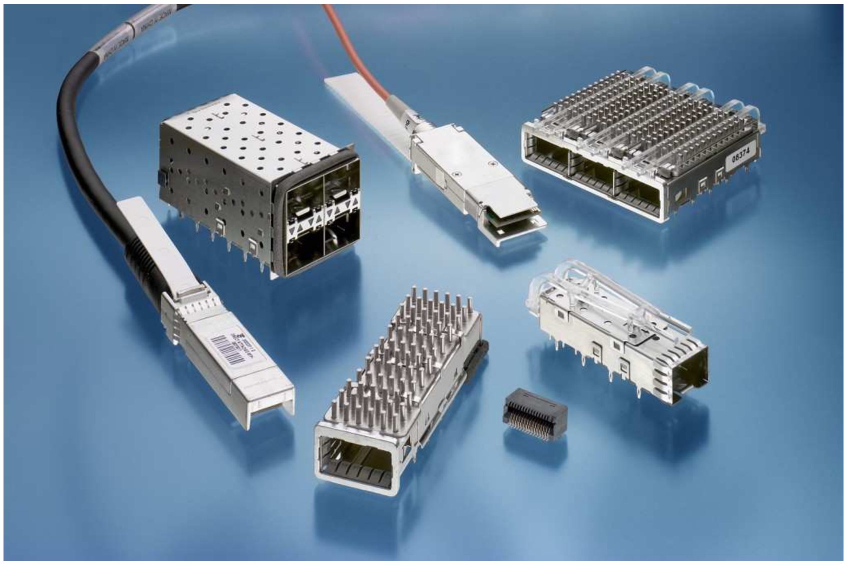
**Philippe Sochoux** received his B.S. and M.S. degrees in Electrical Engineering from Marquette University, Milwaukee WI in 1990 and in 1994, respectively. He joined Cisco Systems in 1998 and worked as an EMC and a Signal Integrity Engineer on the Catalyst 6000 family of Switches. Since 2001 he has managed CAD, Signal Integrity and EMC Design groups within Cisco Systems. He initiated and is currently leading the effort at Cisco Systems to transform EMC Design to become simulation-driven and to take place early in the design cycle. He developed and introduced innovative solutions for heatsink design, new CAD rules for SerDes differential pairs, and assisted in the development of the ASIC grounded thermal lid to reduce EMI. Prior to joining Cisco, he was a Regulatory Engineer at U.S. Robotics/3COM in Chicago, IL.

# Application of Full-wave 3D Field Solvers to Predict EMI Behavior in SFP Cages

## 1. Introduction/Problem

System speeds are increasing. Widespread adoptions of 10Gigabit Ethernet, 6 Gigabit SAS, and DDR/QDR InfiniBand (5Gbps/10Gbps) are just a few examples of how multi-gigabit data rates affect everyone. At these data rates, features as small as 3 to 5 cm in length could become ideal Electro-Magnetic Interference (EMI) radiators and features one tenth of that size can easily cause a product to fail required testing. Widespread adoption of products in these data rates is already underway, and plans for 16, 20, and 25 Gbps products are in the standardization and development process.

Many new I/O (Input/Output) products are used to transmit data rates in the gigahertz frequency range. These products are required by law to have minimal radiated noise, and cannot be shipped if found to be in violation of these limits [1][2][3]. As frequencies increase, small features such as slots, latch areas, or other design features approach one half the wavelength of the signals and high frequency leakage becomes unacceptable. Unfortunately, current methods of investigation are more of an art than a science, and rely upon the experience of a small number of engineers and time consuming component testing.



This testing requires expensive equipment with specialized fixturing, and can only be performed on near-production or true production product. An additional concern is that each customer application will have a unique distribution of potential noise sources that may require customized testing and unique solutions. Since the number of products used and the overall construction of the finished product varies from customer to customer, it is impossible to determine if a component provides acceptable performance in all applications. Therefore, most EMI investigations provide a comparative measurement to a known product. The goal of the modeling is to allow investigation of particular features or systems in the early stages of product development.

This paper will show initial work that has been done in a joint effort between Cisco and Tyco Electronics to utilize electromagnetic modeling software to predict the impact of specific design features on component level EMI. The final goals are to be able to evaluate new features without the need and time of building prototypes, or to use the simulations as a way of troubleshooting customer failures. This will allow the investigation of unique or innovative designs without the time and expense of prototype build and test.

## 2. Existing Solution

For this problem, there is no existing solution beyond the ‘build and test’ method. In many ways, EMI is considered to be more of a black art then a scientific effort. There may be many features contributing to observed leakage, and in many cases, there may be an interaction between features. To make matters worse, even small differences between samples can cause large changes in observed leakage, and there may be considerable variation from assembly to assembly.

Usually, only one feature is isolated for investigation for each pass. Due to the length of time required to test each iteration, even simple assemblies may require weeks of investigation. An additional variable is added in that the method of isolation requires soldering or sealing of features in the product which may alter or destroy the sample under test and enter as an additional variable in the test results. As an example of the complexity of this type of measurement, it was determined that features on the test boards used for SFP EMI testing dominated the measurements, therefore negating a years worth of testing. To further complicate the problem, one of the assembly leakage problems was intermittent in nature and took months of testing to isolate.

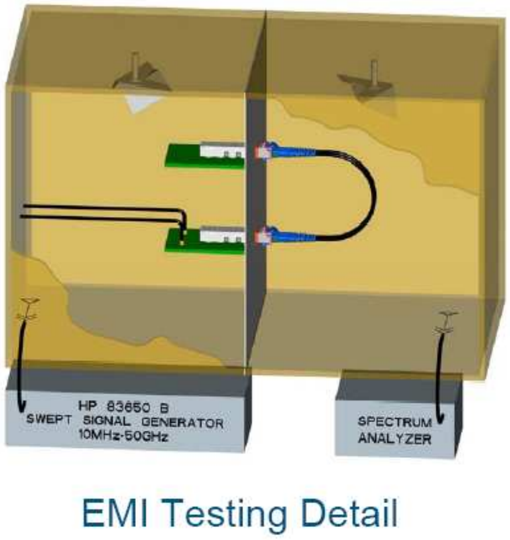


**Figure 1, EMI Testing Environment**

## 3. Proposed Solution

Obviously, this type of scientific investigation is ideal for simulation methods. The ability to control the exact geometry and to isolate specific features is an inherent strength of simulation. Combine this with the elimination of the sample build and fixturing time, and a reliable simulation approach becomes quite attractive.

The tools selected for investigation are Ansoft Corporation's HFSS$^{TM}$ and CST's Microstipes$^{TM}$. Both tools were readily available at both Tyco Electronics and Cisco, and utilize different solution techniques. The different methods for utilizing materials with complex or frequency dependent permittivity and permeability were also of considerable interest. Though quite different in their requirements, both component leakage and cabinet leakage investigations were undertaken simultaneously.

To assure confidence in the results, a simulation and test approach was chosen. The goal was to design simple structures that could be easily created in the model shop, therefore assuring that each simulation would have test data for comparison. These structures were also designed to share size and features with existing product, so that parallels to product performance could be drawn. Initial simulations have been performed on a simplified metal box that is of similar size and material composition to the popular SFP product family. As each phase is validated, additional complexity is added that brings the model closer to the actual product design. Key features to investigate include spacing of ground pins, size and orientation of seams, riding heatsinks, absorptive materials, and shield pin aspect ratios.

### *A. Module Generated Noise*

A unique aspect of this study is that the problem can be reduced to two specific investigations. The first is the amount of energy that leaks out of specific finished assemblies. For a few examples, the energy that leaks from a cable assembly when driven with a typical signal or the EMI that comes from a discrete, self contained optical module can be treated as a single, known source of energy. This is referred to as Module Generated Noise (or MGN). The simulations performed for this paper will all relate to MGN measurements.

### *B. Cabinet Ambient Shielding Effectiveness*

The second type of leakage is the tendency of noise sources from inside a shielded enclosure to leak out of openings from I/O products or other apertures in the panel. This is referred to as Cabinet Ambient Shielding Effectiveness (or CASE).

Since the first type (MGN) has a well defined signal and power level, the measurement is performed and recorded at an absolute power level (dBm).

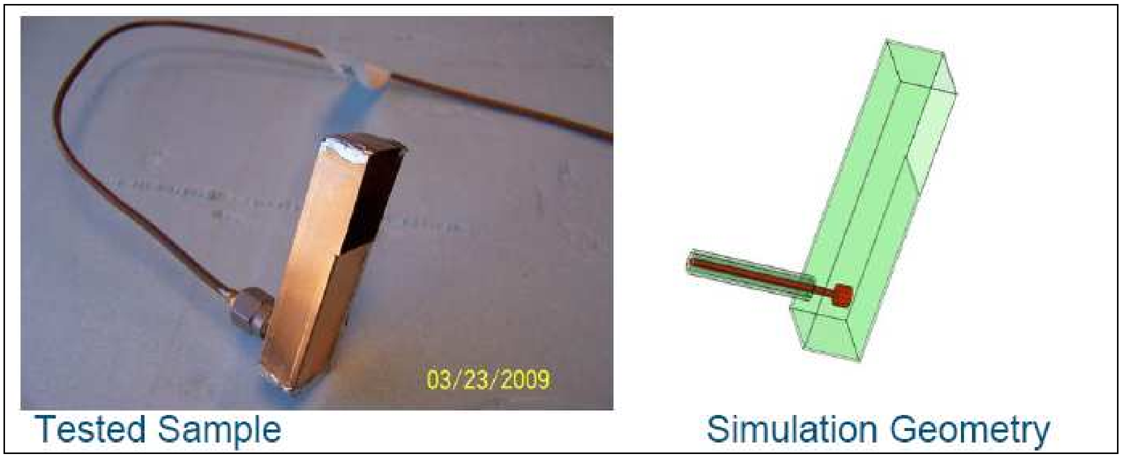
However, the CASE measurement has an unknown amount of energy inside the enclosure, and is presented as a ratio of the power measured external to the cabinet to the power introduced inside of the cabinet. In a CASE measurement, the unknown location and directivity of the noise source requires the assumption of a large number of sources placed randomly inside of the cabinet. Though a compromise, it does allow for comparative investigation of product performance and quantifiable measures of improvement. There is an on-going investigation focusing on methods to perform reliable CASE simulations, but due to the complex nature of the investigation and significant computational challenges, this will not be included in this paper.

## 4. Method (Module Generated Noise)

### *A. Simulation*

Since the phenomena being investigated is complex in nature, it was chosen to start with basic structures that could be easily validated. Due to the different natures of MGN and CASE, the computationally simpler MGN investigation was selected for this first study. MGN investigation requires only a single source of energy inside of the assembly, therefore eliminating the requirement for large numbers of simulations that are required in CASE.

The simplified cage is similar to the actual SFP cage in basic geometry. The length, width, height and bottom opening on the model and test sample are the same as a standard, single port SFP cage. All of the complexities such as grounding pins, seams, holes and grounding fingers have been removed from the simplified geometry in order to provide a simulation case that is simple to validate with test data.



Tested Sample

Simulation Geometry

**Figure 2, Module Generated Noise Simulation and Sample Details**

The first step was to duplicate the simplified SFP cage in modeling software. This was done by utilizing Pro-Engineer (Pro-E) CAD models provided by the mechanical engineering team. This geometry was used as the basis for the simulation. The same raw material utilized in the finished product and some basic features were included. Electrically, the cage is a 10 GHz waveguide. To drive this cavity, the front end was modified to function as a coax-to-waveguide converter. The converter probe and its placement were duplicated exactly to allow realistic comparison from test and simulation. **Fig 2** shows the tested assembly and its equivalent simulation geometry.

The finalized geometries are drawn in HFSS or CST by parameterizing the physical dimensions, thus making it easy to numerically analyze the EMI impact with respect to any parameter. Once the geometries are set, the material properties are assigned to each element in the design and the port settings and solution parameters are input.

One of the flexibilities of the HFSS and CST tools is that each allow evaluating the resulting simulation data in many different ways. The method chosen was to use the radiated power calculated over a sphere located an infinite distance away as the benchmark to compare to the test data. Radiated power is calculated as the integral of the Poynting vector over a pre-defined geometry [5]:

$$P_{RAD} = \frac{1}{2}\oint_S (E \times H^*) \bullet ds$$

The results from this simulation are then plotted as a function of frequency and compared with test data.

### *B. Testing*

The goal of the Module Generated Noise measurement is to determine the amount of energy that leaks out of a cable assembly or module when driven with its expected signal. For this measurement, the assumption was made to have a fixed source located inside of the assembly. This allowed for the investigation of energy propagating from a module through the shield ground pins. The same conclusion can be drawn for the inverse of this situation, and allows the study of energy from inside the cabinet propagating into the EMI cage. The probe radiator (source) that was fabricated for this test was duplicated in the simulations. Results are expressed in dBm, which is a measure of total radiated power, and is plotted as a function of frequency. An example of the initial cage assembly tested for MGN can be seen in **Fig 2**. For this specific test, the cable or module would be energized with a swept sinusoidal signal of a known power level (0 dBm), and the power measured on the right side chamber would provide the level of radiated energy.

## 5. Validation (Module Generated Noise)

For the initial MGN validation, the simulated and measured values were compared. The radiated power from both the simulation and test are shown in **Fig 3b**. As can be seen from the graphs, both the measured levels and feature specific trends are consistent. This same level of correlation between simulation and measurement continued with increases in sample complexity, such as the addition of a ground plane, shield pins, and other features. This strong correlation allowed the addition of more features to the part and for the first design decision to be made from results of this modeling.

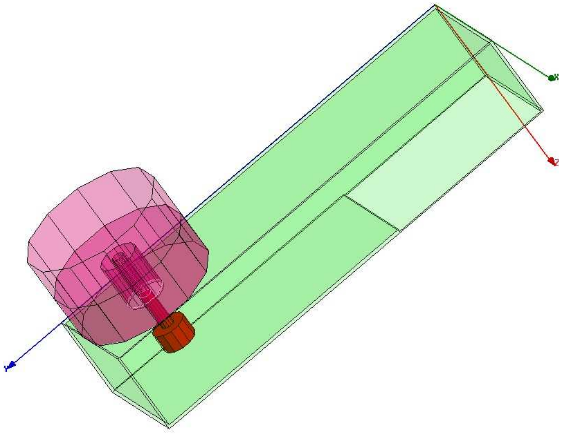


**Fig. 3a: Numerical Model of the simplified SFP cage**

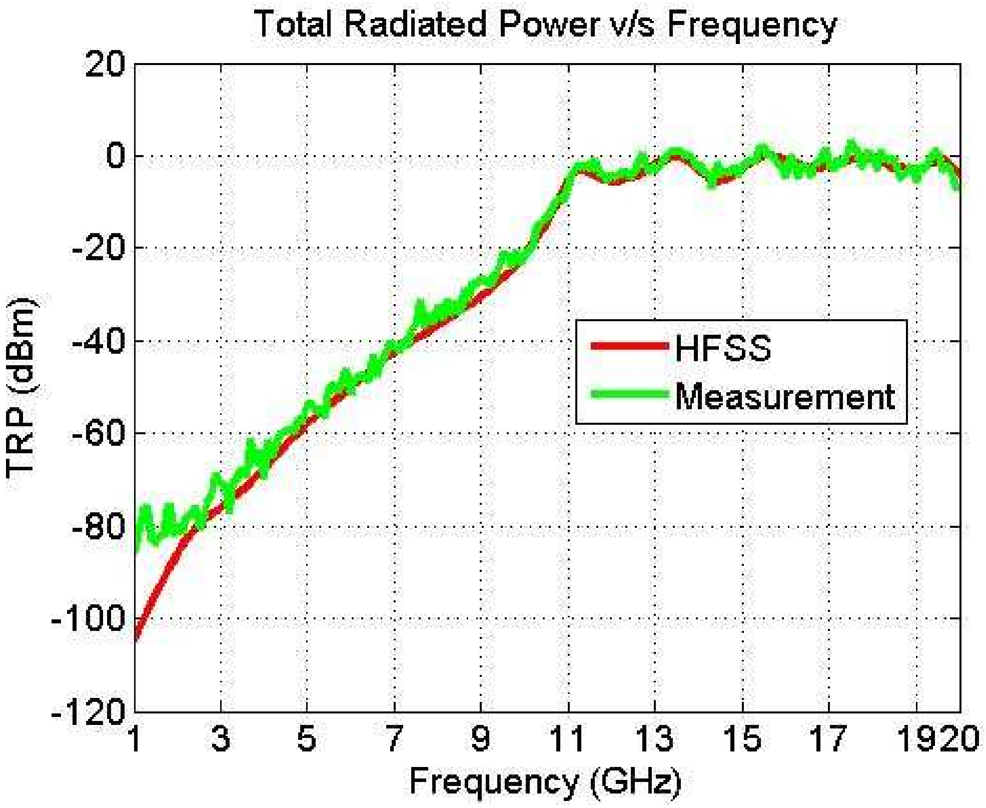


**Figure 3b: Measured and Simulated validation Module Generated Noise**

### *A. Application of Method-Vestigial Pins*

The first practical application of the EMI modeling has been the investigation into the effectiveness of shield pins on the SFP cage that do not make contact with the PWB (Printed Wiring Board). The initial design made the assumption that the pins would reduce the effective electrical length of any leakage apertures surrounding the connector opening. These pins have been referred to as 'vestigial pins' and are detailed in **Fig. 4** and **Fig. 5**. Three specific variants were selected for investigation, and included the existing solution, removal of all the pins, and soldering the pins to the host board. Results and test data from all three configurations are shown in **Fig. 6**. The conclusion reached from this data is to either make the pins press fit for improved EMI performance, or to remove them entirely to retain the same performance and reduce footprint constraints (**Fig. 7**).

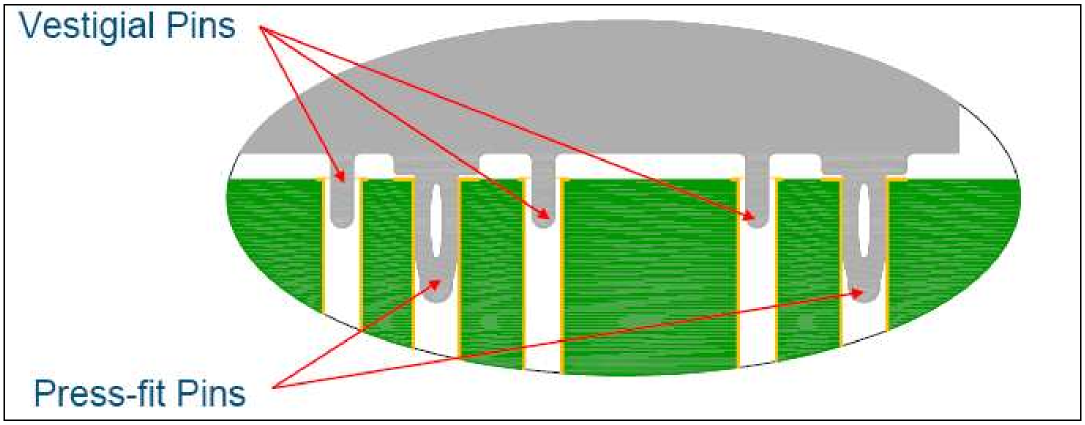


**Figure 4, Vestigial Pin Description**

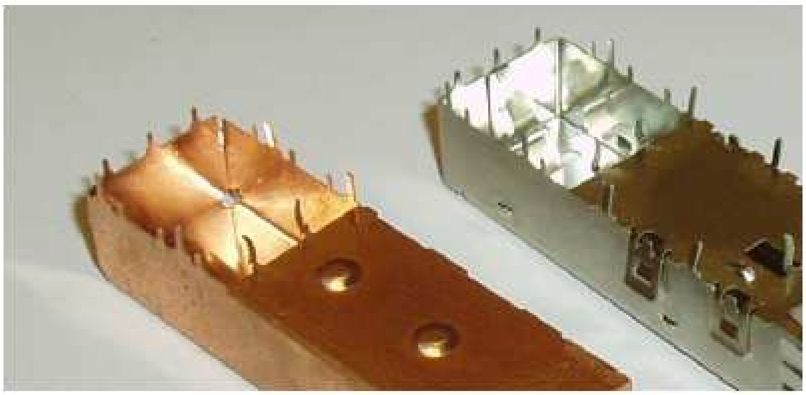


**Figure 5: Test Sample and Comparison to Production SFP Product**

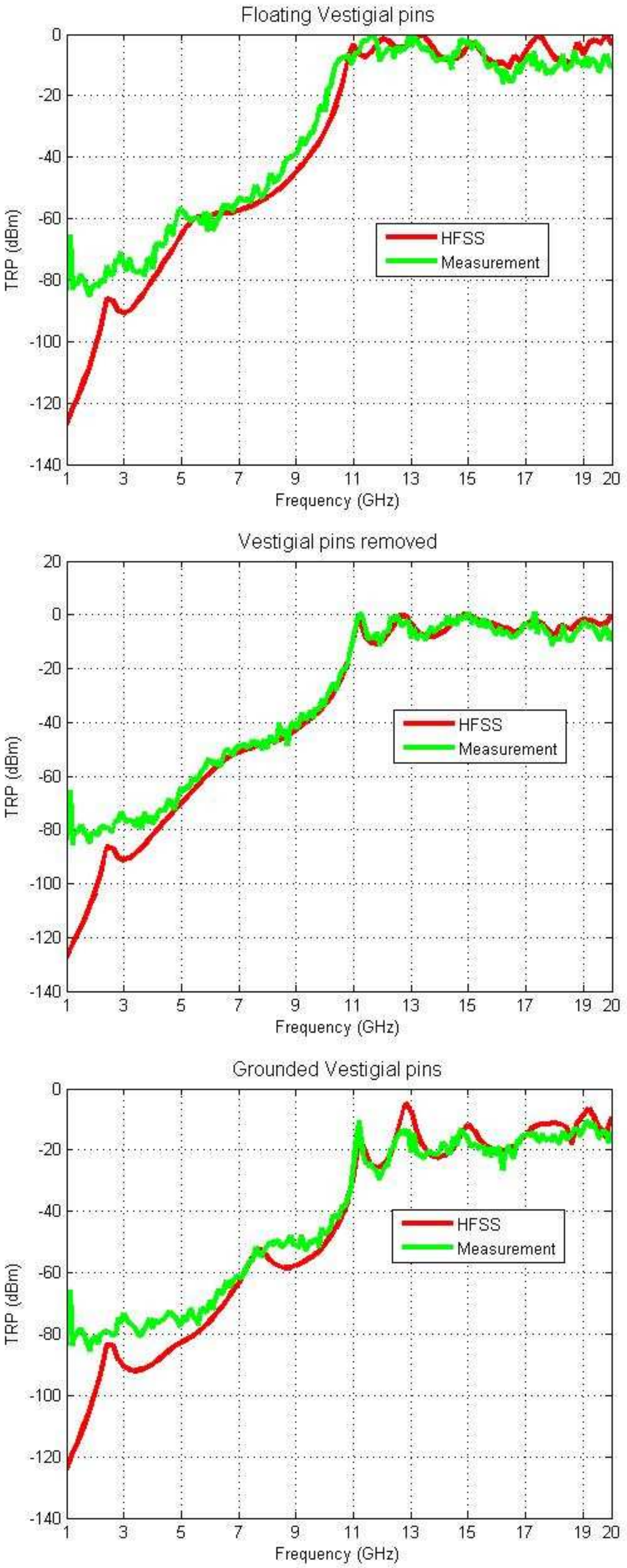


**Figure 6: Validation Studies, SFP Vestigial Pin.**
**Top: Floating Pins, Middle: Pins removed, Bottom: Grounded Pins**

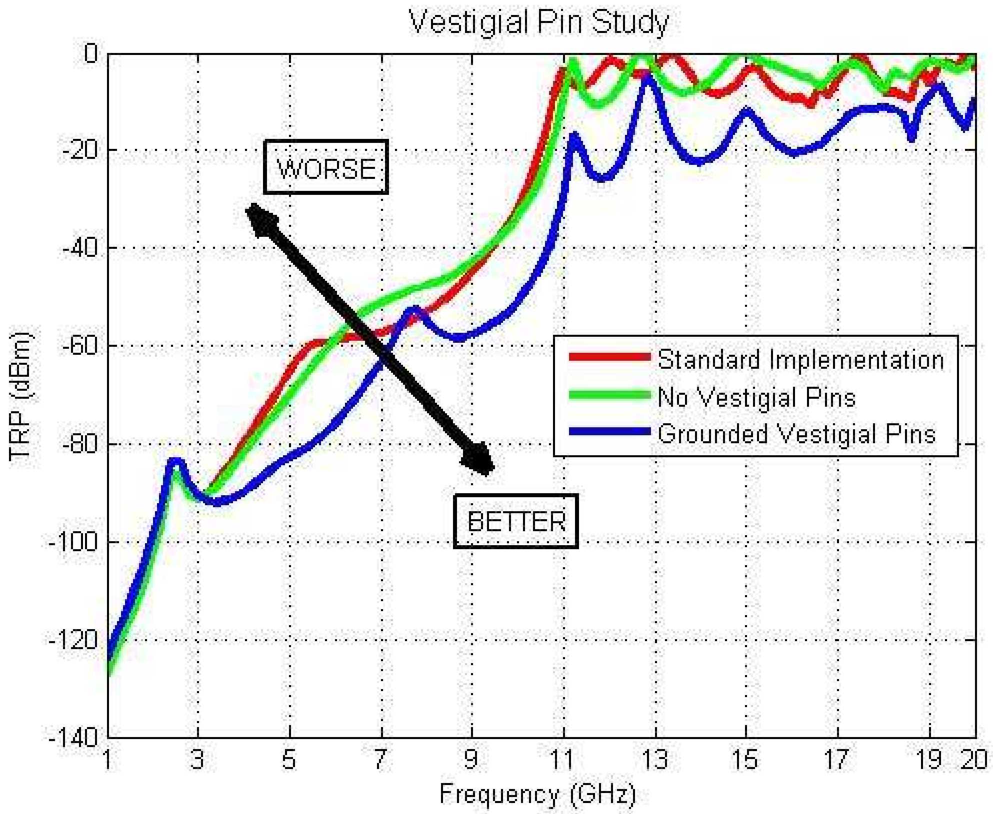


**Figure 7, Results Summary, Vestigial Pin Study**

## 6. Simulation of Conductive and Absorptive Materials

Introduction

Traditional shielding approaches have been to minimize apertures and leakage points through better overall cabinet shields and reduced spacing between shield contact points. More recent efforts have been to use conductive, compressive elastomers (carbon filled, metal impregnated, etc.). These methods can be made to be very effective, but still are relying on the approach of containing energy or keeping fields from getting to an undesirable area. The typical challenges of these types of materials are the material resistivity, and the mechanical forces need to assure sufficient (but not excessive) compression.

To overcome some of these problems, RF absorbing materials can be used. Typically, any given RF absorbing material has absorption only over a certain frequency band, thus making it suitable for applications limited only to its functional frequency range. Also, in general, the type of EMI absorption solution is determined by the boundary conditions of the object. In case of the SFP+ cages the tangential electric field just above its metallic surface is negligible (0 for perfect electrical conductor") whereas the tangential magnetic field is at maximum. Thus for SFP+ cages a lossy magnetic material is suitable for EMI absorption. An electrically lossy material will result in no RF loss. Such class of materials is known as permeable materials, and the magnitude of absorption depends on the value of the magnetic permeability. An example of a high permeability material being developed for high frequency applications is the Laird Technologies Q-Zorb™. The Q-Zorb™ elastomeric absorber can be installed easily with pressure sensitive adhesive directly onto high-frequency board-level components to absorb unwanted radiated and surface wave EMI. Q-Zorb material is formed by dispersing Carbonyl Iron powder in a nitrile rubber polymer matrix. For this simulation study, two different Q-Zorb materials (Q-Zorb01 and Q-Zorb02) were selected with iron filler concentrations of 50 and 42.5 % respectively.

Of primary concern is to determine how to properly engineer selective and appropriate placement of absorbent material. The cost associated with the raw material, difficulties in assembly and placement, and product size penalty are all significant drivers for simulation development. Attempts to apply these materials to existing products have resulted in some benefit, but are most likely far from optimal configurations.

### *A. Implementation of Lossy Materials*

Conductive gasketing is commonly used as a way of reducing the shortcomings of stamped and formed EMI springs. However, this material requires a controlled amount of compression, and still relies upon containing EMI within a structure, or preventing EMI from entering a structure. The option of using permeable materials or other products that could potentially absorb EMI, thereby reducing the energy present and it's potential to radiate is one of particular interest.

As mentioned above, Q-Zorb sheets are thin, magnetically loaded (iron filler) material which absorb the magnetic fields. The magnitude of absorption depends on the percentage loading of the iron fillers. Thus the real and the imaginary part of permeability of the Q-Zorb will vary with frequency. Numerical EM tools provide several frequency dependent models to implement absorbing materials. Each model has limitations on accuracy and validity. For permeable materials, HFSS v11.0 allows to import the data set for the frequency dependent µ' and µ''.

A more efficient method to implement the frequency-dependent behavior of permeable materials in numerical EM is by using the dispersive 1st order Debye (Relaxation Process) or the less common 2nd order Lorentz (Resonance process) models. Such models are available for use in CST Microstripes, for both electric and magnetic materials. However, only the Debye model is available for dielectric materials in Ansoft HFSS.

The 1st Order Debye Model (Relaxation process): The relaxation process, also called first-order Debye model is characterized as follows

$$\mu(\omega) = \mu_\infty + \frac{(\mu_s - \mu_\infty)}{1 + j\omega\tau}$$

where $\mu_\infty$ and $\mu_s$ are the high frequency and static permeability, and $\tau$ is the relaxation time, The relaxation time determines the frequency range of the change in the properties.

The second-order Debye model is a superposition of two different first-order models sharing the same high frequency limit.

To simulate these structures, the varying material parameters need to be added to the model setup. The first order Debye models for both, Q-Zorb01 and Q-Zorb02 were provided by Laird Technologies and are shown in Table 1. The corresponding real and imaginary part of permittivity and permeability for Q-Zorb01 and Q-Zorb02 are plotted in **Fig. 8** & **Fig. 9** respectively.

| | **Q-Zorb01** | **Q-Zorb02** |
|---|---|---|
| $\varepsilon_s$ | 18.1 | 14.8 |
| $\varepsilon_\infty$ | 10.4 | 8.3 |
| τ | 1.77e-10s | 1.77e-10s |

| | **Q-Zorb01** | **Q-Zorb02** |
|---|---|---|
| $\mu_s$ | 8.3 | 5.7 |
| $\mu_\infty$ | 1 | 1 |
| τ | 9.9e-11s | 9.90E-11 |

**Table 1: First-Order Debye model parameter of Laird Q-Zorb01 and Q-Zorb02 materials**

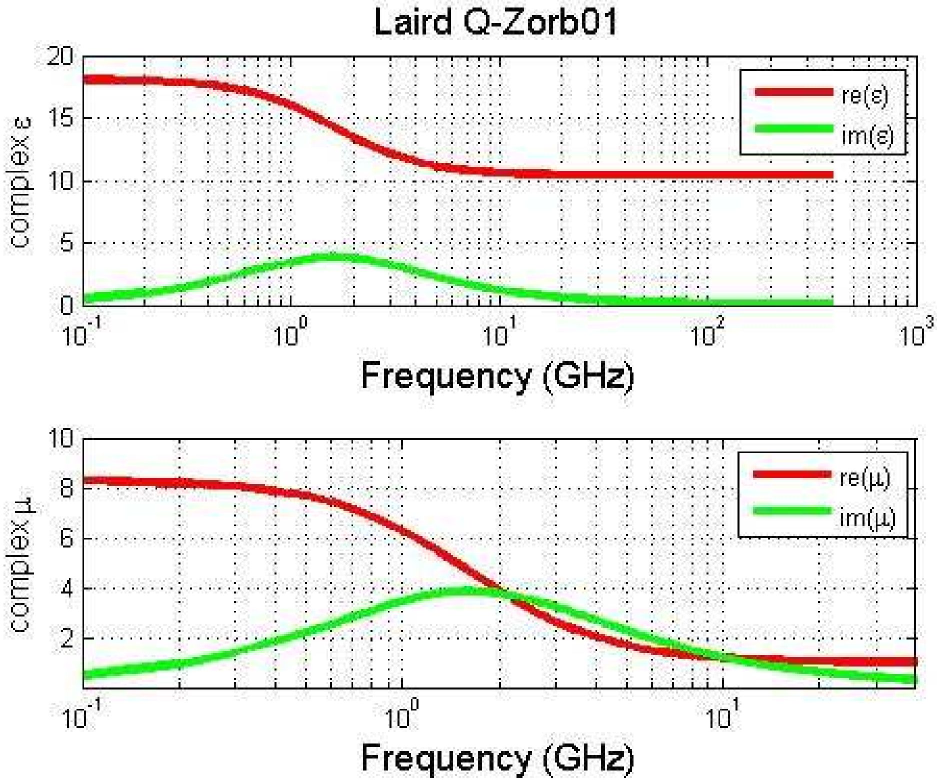


**Fig. 8: Q-Zorb01: Real and Imaginary μ and ε**

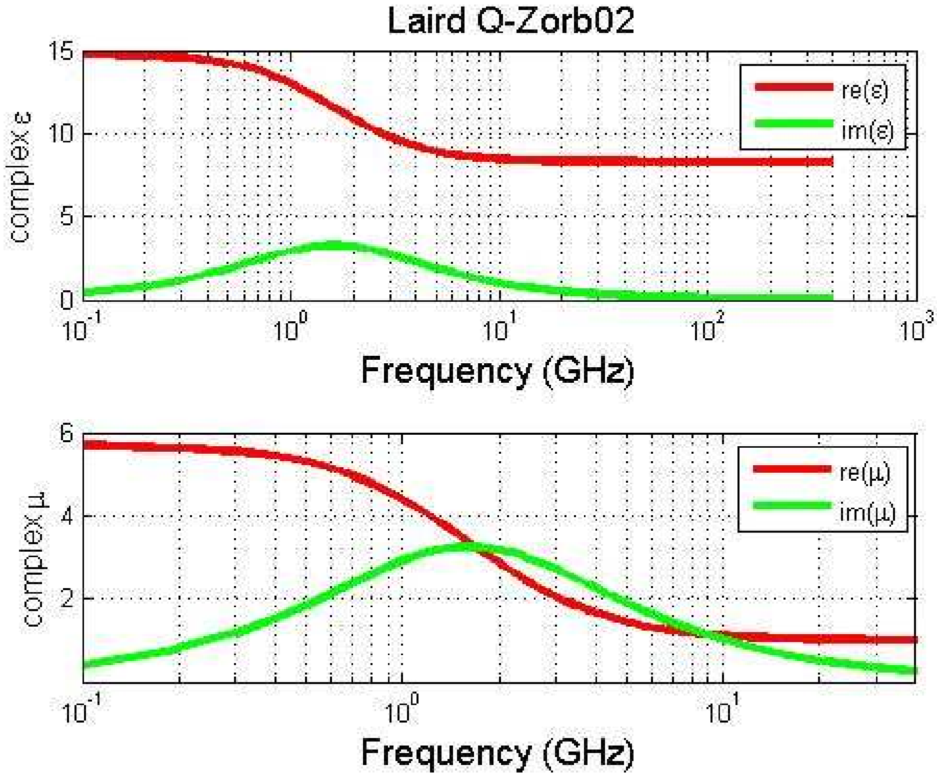


**Fig. 9: Q-Zorb02: Real and Imaginary μ and ε**

In HFSS, custom materials with magnetic properties can be created like any other materials such as metals or dielectrics. The frequency dependent material parameters for permeability and permittivity are provided by the material manufacturer in real/imaginary format. From these values, the dielectric and magnetic loss tangents are computed and imported into HFSS as a frequency dependent material. The tabular data is read directly into HFSS.

As mentioned previously, the absorption of EMI will depend on the type of absorber used, but more importantly, it will depend on the placement of the absorber inside the cavity and also its thickness. For analysis, two different material placements were considered.

1. 3.125 mm thick Q-Zorb01 (and Q-Zorb 02) was place only on the back wall of the SFP+ cage as shown in **Fig. 10a.**

2. All interior walls of the SFP cage were lined with 0.5 mm thick Q-Zorb material as shown in **Fig. 10b**.

The total radiated power was computed in both, CST Microstripes as well as HFSS. **Fig. 11** shows the EMI comparison for the two materials with respect to the original SFP cage without any absorber. As shown in the plot, putting a 3.125 mm absorber does not provide significant EMI suppression. However, a 17 dB and 12 dB reduction is EMI is observed with the inlining of Q-Zorb01 and Q-Zorb02.

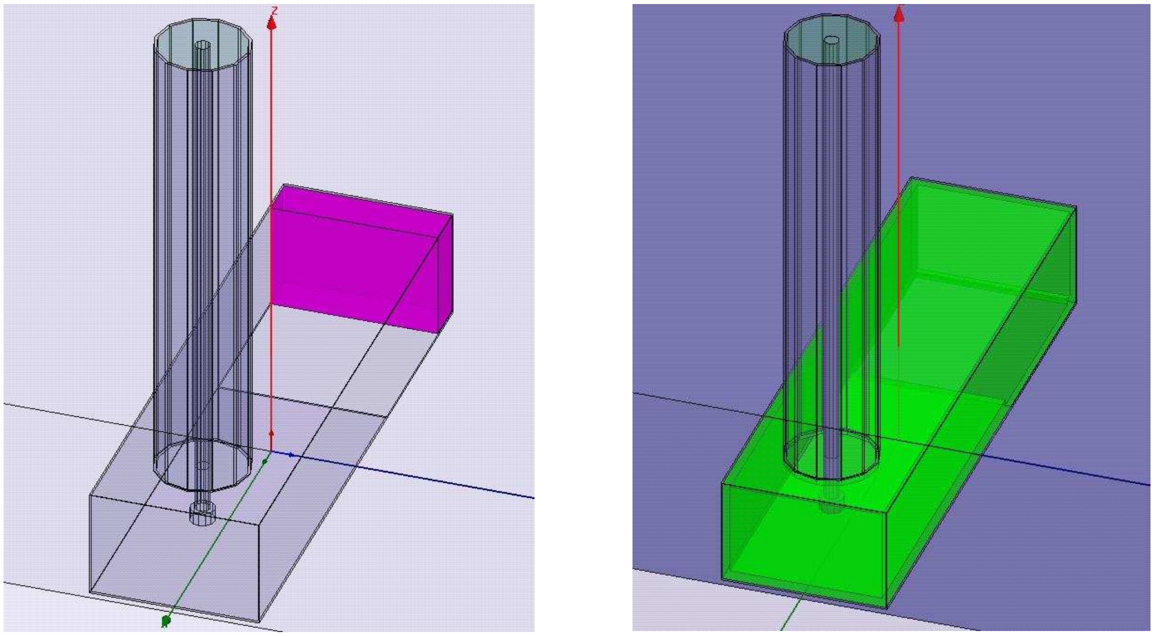


**Fig. 10: (a), SFP+ Cage with 3.124 mm Q-Zorb material on the back wall, (b), SFP+ cage with 0.5 mm Q-Zorb on all interior walls**

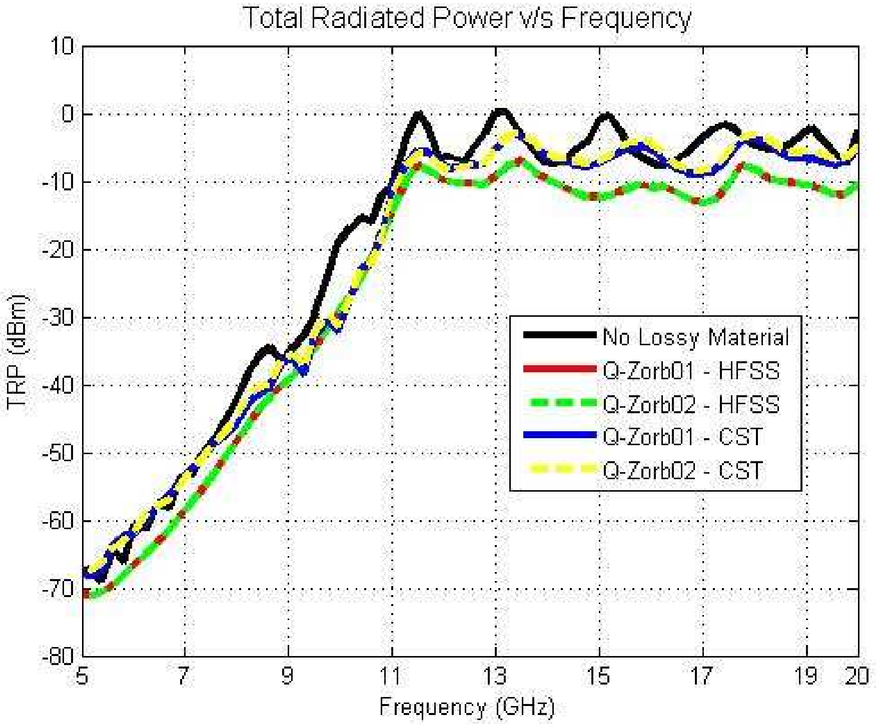


**Fig. 11: Total Radiated Power for SFP+ cage with 3.125 mm thick Q-Zorb materials on the inner back wall**

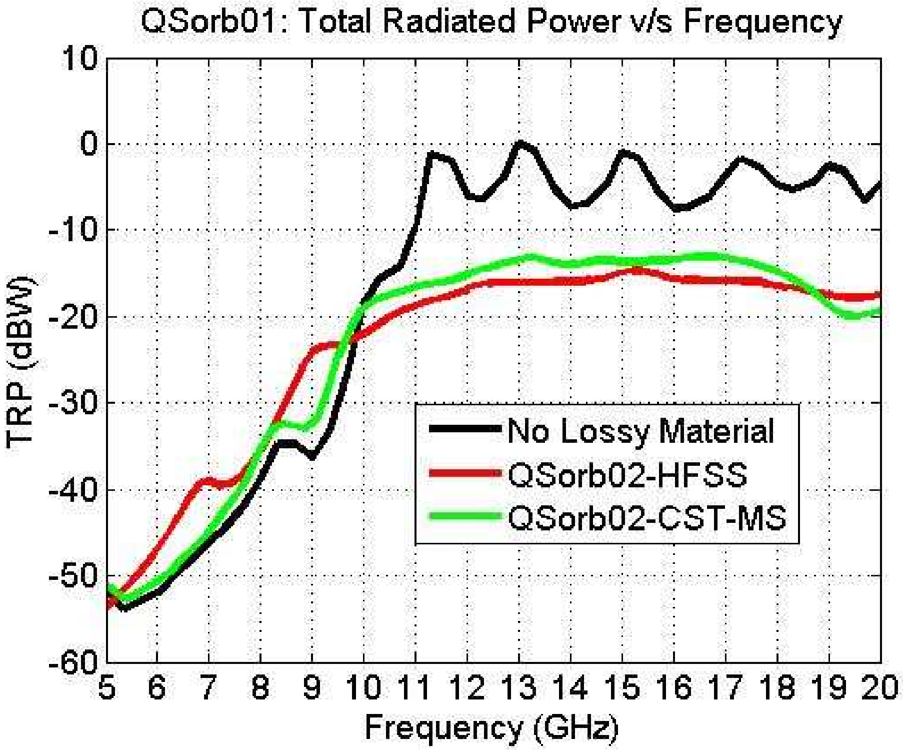


**Figure 12: Comparison between HFSS and CST**

*B. Testing*

## 7. Validation of Conductive and Absorptive Material Simulations

For validation, an approach similar to the initial simulations was chosen. The SFP sized cage with all pins (See Figure 13) had absorptive material selectively placed on the inside surfaces. This assembly was then attached to a PCB with a 0.5mm space, with all ground pins attached to the ground plane. Excitation of the sample was the consistent with the method detailed in section 4B.

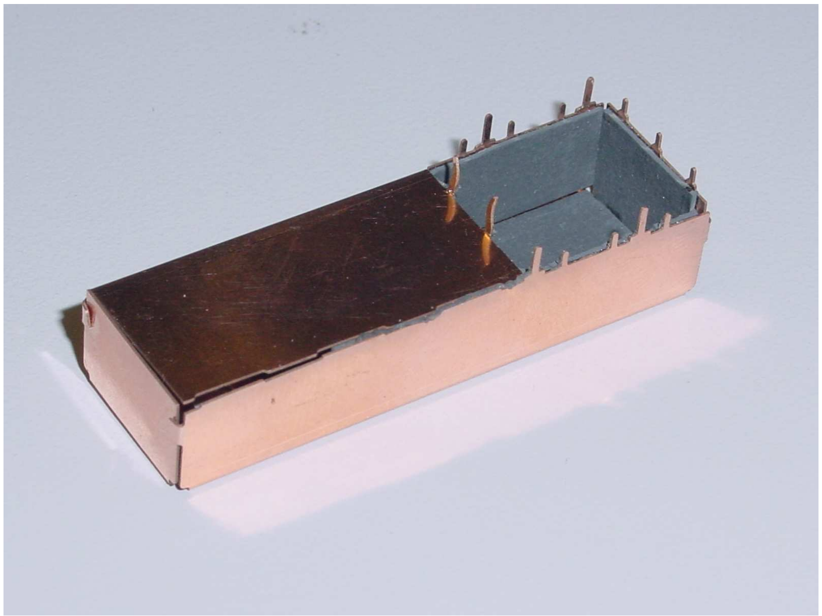


**Fig. 13: Q-Zorb lined Simplified SFP Cage**

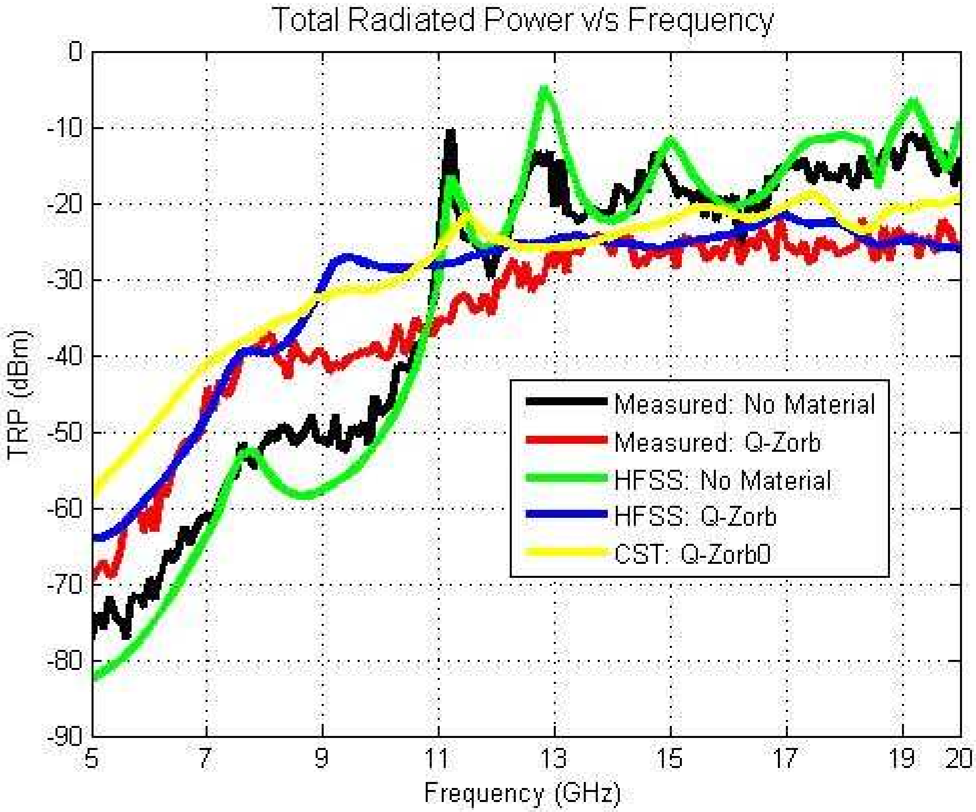


**Figure 14: Comparison between Measured, HFSS and CST results for the Q-Zorb Lined simplified SFP Cage**

## 8. Conclusions

Though this process is still in its infancy, the potential ability to reduce design cycles and to encourage innovative solutions is quite evident. As with all simulation tools, considerable care is required to assure that efficient, accurate, and effective usage is well understood before design decisions are made.

The strong correlation found between the simulation data and test data show that the methods presented are viable for evaluating EMI in SFP cages. The vestigial pin investigation showed that removal of the vestigial pins would not harm the current EMI performance, and that grounding the pins would slightly improve the performance.

It was also shown that it is possible to accurately model absorptive materials with frequency dependent material properties such as permittivity and permeability, at least from an EMI perspective. These materials, when utilized properly can provide opportunities for product enhancement, albeit at an added cost. With proof that the techniques provide valid data, these methods can be utilized to enhance the effectiveness of the material and minimize the amount to create the most cost effective product improvement.

## 9. Implications and Next Steps

There are a large number of potential next steps for the simulation development effort. In the short term, the primary effort will be to continue increasing complexity of the simulations to learn where the best compromise of solution time and accuracy exists. As HFSS and CST are now used for signal integrity analysis on a large number of problems, their usage for EMI prediction will at some point become an initial design tool. A large number of materials have been characterized for their dielectric properties (relative permittivity and loss tangent), but new test methods will need to be defined to provide more accurate measures of relative permeability. Efforts are underway to provide accurate material properties for absorptive materials, and this information will be essential for the design of products to improve EMI performance.

Due to the simpler nature of the Module Generated Noise simulations, it is expected that models of fully featured product will be investigated in the near future. Also scheduled for this study is the impact of noise propagating between ports on stacked SFP products. Potential future simulations include the impact of seams on die cast shields of cable assemblies, and affect of adding conductive or absorptive materials into new designs.

## 10. References

[1] FCC part 15 – Radio Frequency Devices, Title 47 – Telecommunication

[2] European Norm (EN) 55022

[3] CISPR 22 – Radiated Emission Limits

[4] EIA-364-66A – EMI Shielding Effectiveness Test Procedure for Electrical Connectors

[5] Ansoft HFSS v11.1 product documentation