Proper Model Validation is Important for all EMI/EMC Applications

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Abstract
The need to perform validation of simulation results is often ignored because commercial (and non-commercial) software tools are 'trusted' due to previous results. However, previous results from different models do not indicate the current model was created properly. This paper discusses the need to validate simulations and discusses various means for the quantification of the agreement between different simulations used for validation.

Introduction
Computational electromagnetic (CEM) has been in use for a number of years and validation has been a constant concern [1]. Recently, modeling and simulation has enjoyed even more popularity as new simulation techniques become available and commercial codes for different computational techniques become available. With this increase in modeling and simulation activity comes the danger of incorrect results being applied to a particular problem without advance knowledge.

In the early years of EM simulation, the practitioners were experts in EM theory and simulation techniques and who often wrote their own programs to perform the simulations. However, modeling and simulation is no longer restricted only to experts. The commercially available codes are diverse, easy to use, and provide the user with convenient means to display results. New users can begin using these codes quickly without the requirement of being 'expert'.

The danger that is not highlighted by vendors or creators of simulation software is the need to validate the simulation results. It is not sufficient to simply 'believe' a particular software tool provides the correct answer. Some level of confidence in the results are needed beyond a religious-like trust in a software tool simply because others use it, because the vendor assures their customers of the tool's accuracy, or because others have validated their results in the past.

Levels of Modeling Validation
There are a number of different levels of model validation. When deciding how to validate a model, it is important to consider which level of validation is appropriate. The levels are:
-- Computational technique validation
-- Individual software code implementation validation
-- Specific problem validation

Computational Technique Validation
The first level of model validation is the computational technique validation. This is usually unnecessary in most CEM modeling problems, since the computational technique will have been validated in the past by countless others. If a new technique is developed, it too must undergo extensive validation to determine it's limitations, strengths, and accuracy but, if a "standard" technique such as the Finite-Difference Time-Domain (FDTD), Method of Moments (MoM), the Partial Element Equivalent Circuit (PEEC) technique, the Transmission Line Matrix (TLM) method, and Finite Element Method (FEM), etc. is used, the engineer need not repeat the basic technique validation. This is not to say, however, that incorrect results will not occur if an incorrect model is created, or if a modeling technique is used incorrectly.

Individual Software Code Implementation Validation
The next level of validation is to insure the software implementation of the modeling technique is correct, and creates correct results for the defined model. Naturally, everyone who creates software intends it to produce correct results; however, it is usually prudent to test individual codes against the *types of problems* for which they will be used.

For example, a software vendor will have a number of different examples where their software code has been used, and where tests or calculations have shown good correlation with the modeled results. This is good, and helps the potential user to have confidence in that software code for those applications where there is good correlation. However, this does not necessarily mean that the software code can be used for any type of application and still produce correct results. There could be limitations in the basic technique used in this software, or there could be difficulties in the software implementation of that specific problem. When a previous validation effort is to be extended to a current use, the types of problems that have been validated in the past must closely match the important features of the current model.

Specific Problem Validation

Specific model validation is the most common concern for engineers. In nearly all cases, software modeling tools will provide a very accurate answer to the question that was asked. However, there is no guarantee that the correct 'question' was asked. That is, the user may have inadvertently specified a source or some other model element that does not represent the actual physical structure intended.

There are a number of ways to validate the specific problem simulation:

-- Validation using closed form equations
-- Validation using measurements
-- Validation using other modeling techniques
-- Validation using intermediate results
-- Validation using convergence.

Validation Using Closed Form Equations

Very few real-world models include a structure where the geometry is simple enough for solution using closed form equations. However, some indication of the proper results from a model compared to electromagnetic theory is possible. For example, the effects of a dielectric on a propagating plane wave (amount of wave reflected and transmitted), or the propagation velocity of a signal in a dielectric, can be observed to help increase confidence in the proper simulation of the dielectric. Reflections from a circular disk, sphere, etc. can be found using closed form equations, and can be compared to simulation results. However, these cases are specialized, and may not represent the real-world problem of interest to the user. Accurate simulation of the reflection from a perfectly conducting sphere is no guarantee that a printed circuit board, shielded enclosure, or complex object (such as an airplane or tank) will result in a correct result.

Validation Using Measurements

The most common type of validation for CEM applications will be actual measurements. This is largely due to the fact that real-world problems do not easily lend themselves to closed-form calculations. The same problem must be used in both the modeling and the measurement cases, and this is often overlooked. All important features must be included in both. Laboratory measurement limitations must be included in the model. For example, the test environment (OATS vs. anechoic vs. semi-anechoic, etc.), antenna height, and the antenna pattern will likely have a significant effect on the measurement, which, if not included in the simulation will cause the results to differ. One of the advantages of simulation is that a 'perfect' environment can be created, allowing the user to focus on the desired effects without consideration of the difficulties of making a measurement of only the effect desired.

Another important consideration is the loading effect of the measurement system on the device under test. For example, when a spectrum analyzer or network analyzer is used to measure effects on a printed circuit board, or the signal on a small probe in a shielded enclosure, the loading effect of the input impedance for the spectrum/network analyzer (typically 50 ohms) must be included in a simulation. While the 50 ohm load of the analyzer does not necessarily represent the real-world environment that the PCB will be operating in, it becomes very important when a simulation is to be compared to a laboratory measurement.

Another consideration to model validation by measurement, depending on the application, is the accuracy of the measurement itself. While most engineers take great comfort in data from measurements, the repeatability of these measurements in a commercial EMI/EMC test laboratory is poor. The differences between measurements taken at different test laboratories, or even within the same test laboratory on different days, can be easily as high as +/- 6 dB. The poor measurement accuracy (or repeatability) is due to measurement equipment, antenna factors, site-measurement reflection errors, and cable movement optimization. Laboratories that use a plain shielded room test environment are also considered to have a much higher measurement uncertainly. Some CEM applications (such as RCS) have a much more controlled environment and therefore measurement validation is a good choice.

The test environment's repeatability, accuracy, and measurement uncertainly must be included when evaluating a numerical model's result against a measurement. The agreement between the modeled data and the measurement data can be no better than the test laboratory's uncertainty. If measurement data disagrees with modeled data, some consideration should be given to the possibility that the measurement was incorrect and the model data correct. Therefore, it is essential to avoid measurement bias and to equally consider both results as correct. When two different techniques provide different results, all that can be logically known is that one of them, or even both of them, is/are wrong.

Model Validation Using Multiple Simulation Techniques

Another popular approach to validating simulation results is to model the same problem using two different modeling techniques. If the physics of the problem are correctly modeled with both simulation techniques, then the results should agree. Achieving agreement from more than one simulation technique for the same problem can add confidence to the validity of the results.

There are a variety of full wave simulation techniques. Each has strengths, and each has weaknesses. Care must be taken to use the appropriate simulation techniques and to make sure they are different enough from one another to make the comparison valid. Comparing a volume based simulation technique (i.e. FDTD, FEM, TLM) with a surface based technique (i.e. MoM, PEEC) is preferred because the very nature of the solution approach is very different. While this means that more than one modeling tool is required, the value of having confidence in the simulation results is much higher than the cost of a few vendor software tools.

By the very nature of full wave simulation tools, structure-based resonances often occur. These resonances are an important consideration to the validity of the simulation results. Most often, the simulations of real-world problems are subdivided into small portions due to memory and model complexity constraints. These small models will have resonant frequencies that are based on their arbitrary size, and have no real relationship to the actual full product. Results based on these resonances are often misleading, since the resonance is not due to the effect under study, but rather it is due to the size of the subdivided model. Care should be taken when evaluating a model's validity by multiple techniques to make sure that these resonances are not confusing the 'real' data. Some techniques, such as FDTD, can simulate infinite planes[1]. Other techniques allow infinite image planes, etc.

Validation Using Intermediate Results

Computational modeling provides a tremendous advantage over measurements since physical parameters may be viewed in the computational model where they could never be physically viewed in the real world. Electric fields, magnetic fields, and RF currents on a plane can all be viewed within the computational model, but can not be viewed directly in the measurement laboratory.

These parameters are used as an intermediate result within the computational model, and can be very useful to help validate that the model has performed correctly. Whereas the final far-field result may be the goal of the simulation, the intermediate results should be examined to ensure the model is operating as theory, experience, and intuition require.

RF Currents on a Conducing Surface. Some of the different simulation techniques (such as MoM and PEEC) will calculate the currents over the entire structure. The radiated electric fields are determined from the RF currents. These currents provide significant insight to the computational result's validity.

Viewing the currents at specific frequencies, especially near resonance frequencies, can allow the user to observe the standing wave patterns, currents in the areas of discontinuities and breaks in the metal surfaces, etc. The currents should not vary rapidly in adjacent patches/segments and should be near zero at the ends of wires/planes. If these requirements are not met, it indicates that the model's gridding/segmentation is not fine enough for the given frequency, and must be changed.

[1] Some FDTD tools allow metal plates to be placed against the absorbing boundary region, resulting in an apparent infinite plane.

Animated Electric Fields. When using time domain simulation techniques (such as FDTD, PEEC, TLM), the fields/currents/voltages are found for all the cells within the computational domain for each time step. Typically, the final result desired is the field strength at a specific location or number of locations. However, viewing the fields/currents/voltages as they propagate through the computational domain can provide significant insight to the computational result's validity.

While observing the fields within a volume-based simulation technique, such as FDTD, the user should observe the field animation to insure that the fields were not reflected from the computational boundary, that they did propagate past all observation points, and that all resonances were dampened to a sufficient point to indicate that the simulation is complete. Simply observing the final field results at some location is not a guarantee that all the above possible effects were properly simulated.

Simulation techniques that are current/voltage based (such as PEEC and TLM) are especially useful for circuit board models. The animation of the currents/voltages may be observed to insure that the intentional signal propagated along the intended path, and that any resonances were dampened to a sufficient point to indicate that the simulation is complete.

Validation Using Convergence

There are a number of model parameters that must be decided before the actual simulation can be performed. The size of the grids/cells, etc. are often set to lambda/10 to satisfy the assumption that the currents/fields/etc. do not vary within each grid/cell/etc. However, this size may not be small enough to correctly capture the currents/fields/etc. if the amplitude of the currents/fields/etc. varies rapidly on the structure. Changing the size of the grid/cell/etc. is a good way to insure that the proper size was used. If the results change when the grid/cell/etc. size is changed, then the correct size was not used. Once the grid/cell/etc. size is correct, the final results from the simulation will not change.

Another convergence check that is important with some simulation techniques, such as FEM, is to vary the size of the computational domain to make sure there are no spurious responses, or absorbing boundary mesh truncation effects that interact with the physical model. Again, the final result should not be dependent on the size of the computational domain or the distance between the absorbing boundary mesh truncation and the physical model. If the results are seen to change as these parameters are changed, the model must be modified and re-run until these parameters do not affect the final result from the simulation. Other volume based techniques (such as FDTD, FEM, TLM) are typically not as sensitive to mesh truncation effects, but they should also vary the size of the computational domain to insure they do not influence the final results.

Model Validation Using Standard Problems

A number of Standard Validation problems have been proposed over the recent years [6-10] to assist engineers who wish to evaluate the various vendor modeling tools against specific problems that are similar to the types of problems that they wish to simulate. A wide variety of problems have been developed and are available on the joint ACES & IEEE/EMC Society's modeling web site. Problems for printed circuit board problems, antenna-like problems, shielding problems, and benchmark problems, etc. have been specified and can be used to validate modeling tools and to validate individual models when they are similar to the desired model. Most of the standard modeling problems have published results that can be used directly to compare against the new model's results.

Model Validation Using Known Quantities

Under some circumstances, it is possible to use known quantities to validate a model. For example the radiation pattern of a half-wave dipole is a well known quantity, and if the model is similar to a half-wave dipole, then a dipole pattern simulation may help increase confidence in the simulation results from the primary model.

Another example is for shielding effectiveness simulations. A six-sided completely-enclosed metal enclosure should have no emissions when a source is placed inside the enclosure. However, depending on the implementation, some simulation techniques, such as the Method of Moments (MoM) and most scattered field formulation techniques will show an external field even from a completely enclosed metal box.

Model Validation Using Parameter Variation

Within a model, there are usually a number of parameters that are critical to the model's results. Size of apertures, number of apertures, component placement on PCBs, etc. can vary the final result from the simulation. In many cases, the effect of changing a parameter can be predicted from experience, even though the actual amount of variation may not be known in advance. In this example, the size of the aperture can be increased, and the shielding effectiveness for the different aperture sizes examined for 'reasonableness'. Also, resonant frequencies for the aperture, etc. can also be seen to vary as the size of the aperture varies, providing another opportunity to check the results from the simulation.

How good is "good"?

A common observation at conferences where simulation data is presented along with measured (or other) validation data is that the "agreement is good", without specifying the degree of goodness. Various ways to quantify the amount of agreement have proposed in the past, and one of the most promising techniques is the Feature Selective Value (FSV) [3-6]. The details of how the FSV works are in the references and will not be repeated here. However, it is illustrative to show a couple of demonstrations of the data obtained using FSV.

FSV Example #1

Figure 1 shows and example of two data sets that have pretty good agreement. Figures 2, 3, and 4 shows the ADMc, FDMc and GDMc, respectively. These result in an 85% Grade and Spread that is shown in Table 1 and most of the agreement for the ADM is Excellent-to-Good, and Excellent-to Fair for the FDM and GDM.

FSV Example #2

Figure 5 shows and example of two data sets that do not agree as well as the first example. Figures 6, 7, and 8 shows the ADMc, FDMc and GDMc, respectively. These result in an 85% Grade and Spread that is shown in Table 2 and the agreement for the ADM , FDM, and GDM is not as good as in Example #1.

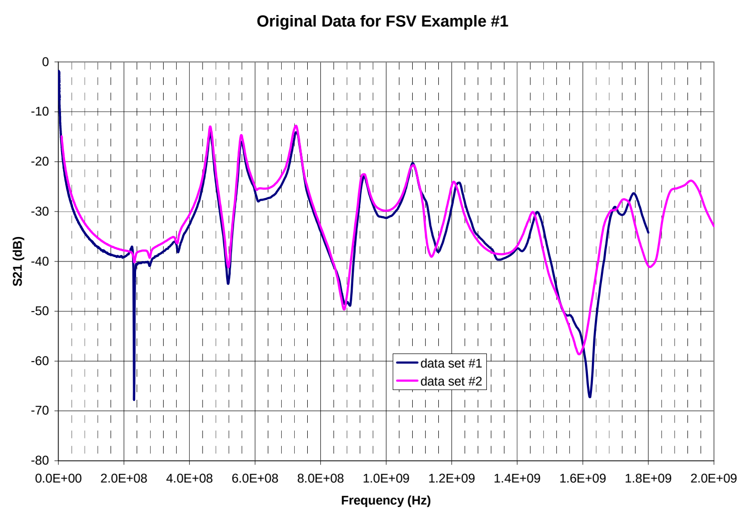

Figure 1 Example #1 Original Data.

Table 1 ADM/FDM/GDM Grade and Spread for Example #1.

	Grade	Grade Range	Spread	Spread Range
ADM	3	Excellent-Good	3	Excellent-Good
FDM	4	Excellent-Fair	4	Excellent-Fair
GDM	4	Excellent-Fair	4	Excellent-Fair

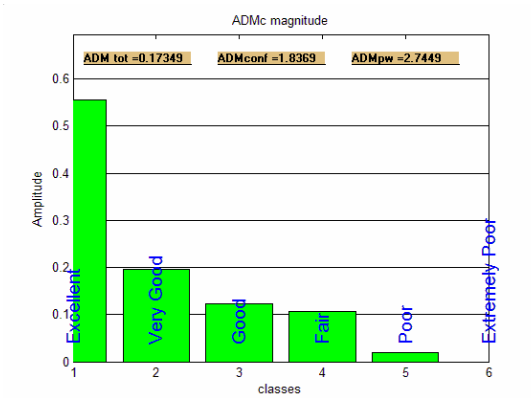

Figure 2 ADMc for Example #1.

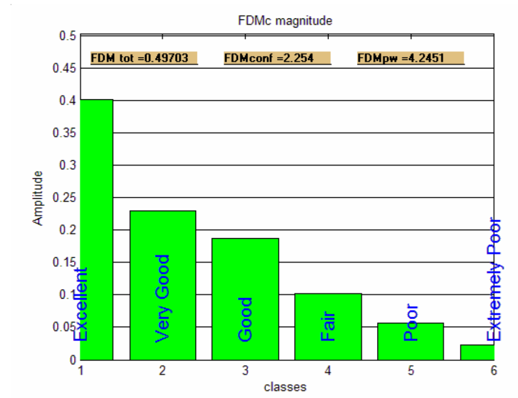

Figure 3 FDMc for Example #1.

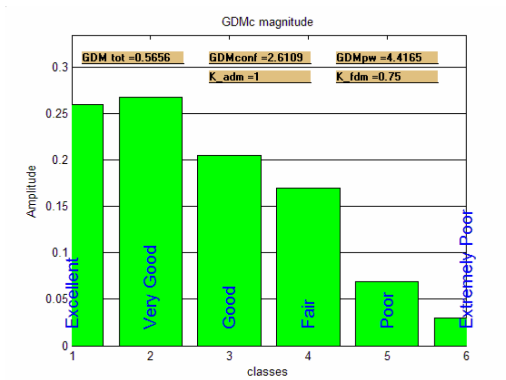

Figure 3 GDMc for Example #1.

Table 2 ADM/FDM/GDM Grade and Spread for Example #2.

	Grade	Grade Range	Spread	Spread Range
ADM	4	Excellent-Fair	4	Excellent-Fair
FDM	5	Excellent-Poor	5	Excellent-Poor
GDM	5	Excellent-Poor	4	Very Good- Poor

Summary

Validation of modeling and simulation results is extremely important. There are three different levels of validation, but the specific problem validation is the most important level to most engineers using simulation tool. A number of different ways to validate simulation results was discussed. Two examples of using the FSV technique were given to show how this technique can differentiate from good agreement and poorer agreement.

References

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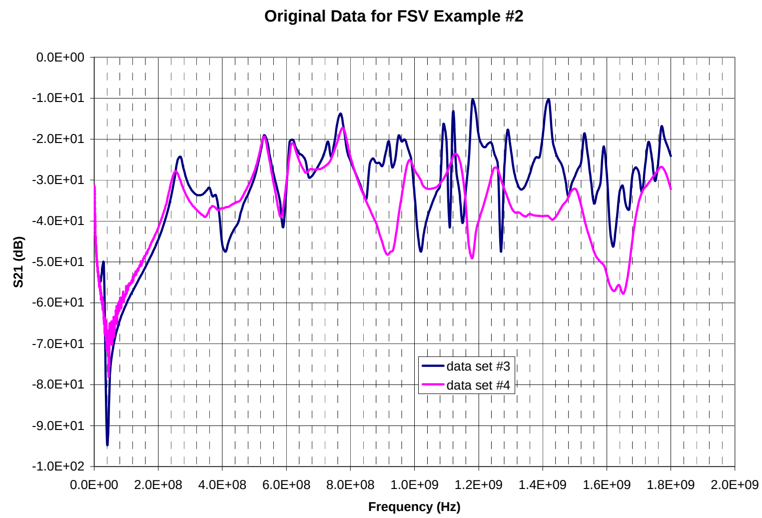

Figure 4 Example #2 Original Data.

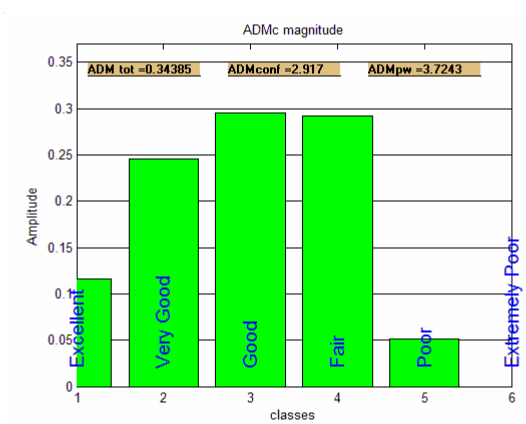

Figure 5 ADMc for Example #2.

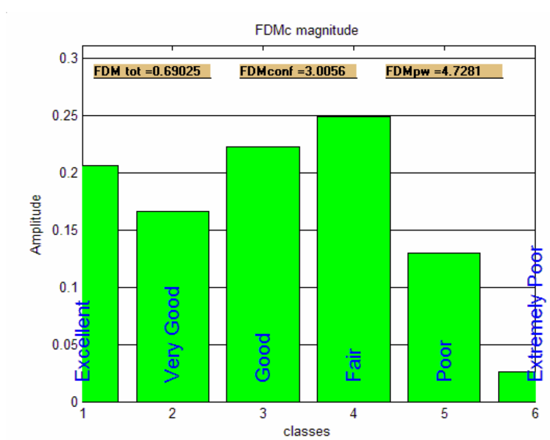

Figure 6 FDMc for Example #2.

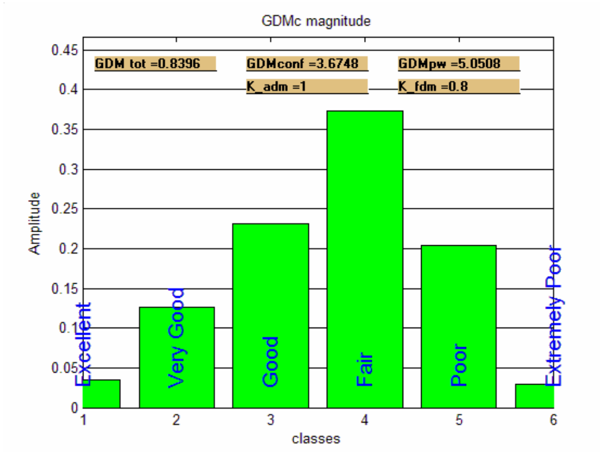

Figure 7 GDMc for Example #2.