

Selected Methods for Validating Computational Electromagnetic Modeling Techniques

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Abstract—Various methods exist for effectively comparing multiple sets of electromagnetic observable data on a given problem for validation and verification (V&V) purposes. Oftentimes, the goal is to cross-validate measurements with computer simulations or compare the results of multiple simulation runs in order to gain insight about error mechanisms and their control so as to ensure consistency, accuracy as well as repeatability. These methods are used to determine the degree of convergence (joint agreement) of such data and to investigate where and why disagreements may arise. Recent work has led to the development of robust cross-validation methods that can be applied to electromagnetic observables acquired through measurement or simulation and across any independent variable. This paper briefly discusses several of these methods as applied to cross-validating results derived from multiple simulation-based techniques in which alternative physics formalisms and numerical solutions may be employed.

Keywords—computational electromagnetics; computer model validation; error budgets; standardization

I. INTRODUCTION

Why should the EMC community be concerned with cross-validation? In practical terms, the answer lies in our need for reliable technologies and repeatable methods for assessing the EMC of complex systems or devices. This can be done through measurements and/or computer simulations; however, both involve the management of error budgets and associated uncertainties. Measurements alone can be quite expensive. Today we tend to rely on a more balanced approach to achieving EMC that involves both computer simulations along with performing selected measurements. It is generally more cost effective to utilize both approaches judiciously, especially in light of electrically-large complex systems (e.g., full size aircraft) EMC issues. Therefore, the importance of computer simulations has begun to be more widely recognized. But, how do we ensure that accurate models and appropriate simulation techniques are used? To answer this question, let us consider modeling and simulation first in the context of large-scale problems in computational electromagnetics (CEM) and the potential numerical errors that may arise in the process. It is the emergence of these errors that largely affects the utility, applicability, and accuracy of various CEM techniques.

An understanding of the error budgets and how these may affect simulation accuracy is needed in order for us to perform valid comparisons between different simulation techniques. Our objective is to gain confidence not only in applying the simulation techniques themselves, but also in comparing data sets on electromagnetic observables based on using multiple tech-

niques, including measurements, for V&V purposes. Furthermore, as one gains confidence in applying simulation techniques, the results of computer analysis can be used to guide measurements, thus reducing overall EMC program costs, which is the ultimate objective of this exercise. This boils down to being able to show how computer simulation techniques are effectively applied and where simulations agree with each other using alternative solutions as well as measurements for a given problem or application.

This is the impetus for the current work on behalf of IEEE Project 1597.1 towards the development of standards for CEM computer modeling and technique validation [1, 2]. This work is anticipated to result in a standard methodology in the near term for effectively comparing multiple sets of electromagnetic observable data on a given problem. The standard will provide a uniform method of comparing data acquired through measurements and/or computer simulations, but is aimed at the latter in particular, when multiple simulation techniques are applied in order to solve a given EMC problem. The standard and recommended practices also urge the use of canonical, standard validation, and benchmark problems to support cross-validation in a reliable and repeatable manner.

In order to better understand why some CEM simulation techniques may lead to differing results with respect to each other for a given problem (based on applying different physics formalisms and solution techniques), it is instructive to first gain insight into the potential sources of error in the overall computational scheme.

II. ERROR SOURCES

Modeling Complex Large-Scale Problems

Large-scale CEM problems require the application of the right tool for the right job in order to minimize the potential for error generation and propagation during each step of the process. The subtleties of this issue are associated with knowing where sources of error can arise, how to quantify them, and what methods can be used to control errors. Sources of error can be categorized as procedural, model-limited, technique-limited, problem dependent, numerical, and interpretive [3]. These by no means represent a complete taxonomy of error sources in CEM, but provide a means of better understanding error budgets and how these may be controlled. An overview of some of the sources of error to be mindful of and the potential pitfalls that may lead to computational uncertainty is given as follows.

Model-limited errors - This refers to the errors that arise because of limitations associated with the geometrical elements which are used to construct CEM models.

Sometimes the modeling elements are too gross or simplistic to faithfully represent the geometry at the frequency of interest. To overcome such difficulties, techniques have been developed to adapt detailed computer-aided design (CAD) models directly in order to derive high-fidelity CEM models. However, this results in a new source of error in that the CAD models themselves may contain subtle flaws that are not readily detected and which can result in other errors downstream of the modeling and simulation process.

Procedural errors - This refers to the step-by-step approach used in generating and analyzing a CEM model.

How one goes about modeling and analyzing a real-world problem is dependent on the type of problem to be solved and what electromagnetic phenomena and observables are of interest, among other considerations. For example, consider the problem of assembling a computational model, and integrating components and their individual electromagnetic contributions to compute a total budget solution—not to be confused with error budget. This problem is one of resolving a complex system into its parts, analyzing the electromagnetic interactions or relative contributions, and then integrating results in order to arrive at an accurate system analysis—a procedure called combinatorial modeling. First, this is an approximate idea. Linear superposition does not work. By solving a problem in components and later adding up the contributions, the total budget solution found this way is a lower bound to the true solution. The difference between the budget solution and the true solution is a function of how strongly the parts interact. The stronger they interact, the larger the difference between the budget solution compared to the true total solution.

An ill-posed problem can result in computational instabilities and numerical inaccuracies; for example, when an insufficient sampling criterion is used in an attempt to capture electromagnetic phenomena at resonance or about singularities or in the vicinity of near field caustic points.

The lesson to be learned here is this: building and analyzing a CEM model without some a priori understanding of the type of problem to be solved, the basic physics of the problem, and what observables are most appropriate based on the boundary conditions, frequency, and so forth, will likely lead to errors and lend to the uncertainty. In other words—one needs to properly define the problem and the desired “metrics.”

Technique-limited errors - This pertains to the approximations and potential errors that are introduced when Maxwell's equations are constrained to a particular subset of boundary conditions and modeling problems (also referred to as quadrature error), expressed either in differential or integral form.

As a result, the applied physics can exhibit certain inherent limitations. Some of the subtle issues here pertain to the applied mathematical algorithms and methods for truncating infinite series and controlling the number of second and higher order electromagnetic interactions (i.e., bounces) to be considered.

Problem-dependent errors – This pertains to errors that arise when the physical problem is not fully characterized and the solution approach does not match the problem to be solved.

For example, it is not necessarily prudent to use a full-matrix decomposition moment method (MoM) technique to solve a simple antenna coupling problem at 10 GHz. However, for scattering cross section problems at 10 GHz, moment method based techniques in conjunction with the use of fast solvers are

desirable in order to obtain highly accurate results. Similarly, a transmission line modeling (TLM) technique may be quite suitable to analyzing an internal cable coupling problem for a closed or bounded cavity, but may not be appropriate for calculating antenna radiation effects for exterior problems involving large, complex structures.

Again, it is imperative that one start by defining the problem to be solved. The most suitable physics formalism(s) and solution method(s) can then be determined with a greater degree of confidence. Generally, at a very high level, problems can be classified as one of the following types: EMI/C, scattering cross section, antenna radiation, signal integrity, shielded enclosure problems, and materials problems. These categories can be further subdivided as necessary. EMI/C, for instance, can apply to printed circuit boards (PCBs) or devices as well as to large-scale systems. Here, we are invoking the fundamental rule: *use the right tool for the right job!*

Simply put, some techniques may be more or less error prone than others, not because they contain inherent limitations as such, but because their application does not match the type of problem(s) to be solved very well.

Numerical errors – Here, solution error is closely tied to technique-limited error in that the physics and the numerical solvers work together to provide a total budget solution.

In ultra large scale computational electromagnetics, a variety of errors can arise. In fact, the effects of numerical noise tend to become more pronounced due to round off and phase velocity errors in ultra large scale computational electromagnetics. Solution errors are also attributed to the solver method employed. For example, banded matrix iteration involves approximations regarding the specification of the matrix band and the iterative convergence value, which sometimes can be a “best guess.” Full wave or lower-upper decomposition (LUD) of matrices can result in numerical noise propagation for dense matrices. Inconsistent use of block matrix partitioning schemes in conjunction with an inconsistent Green's function along with applying asymptotic methods or other approximations in computing a total solution can clearly promulgate numerical inaccuracies.

The enhancement of numerical noise and round off error propagation stems, for example, from the application of an inconsistent Green's function and the process of solving for a large number of current or field unknowns (N) for a dense matrix system. There are actually various numerical noise contributions at play in solving for the unknowns. These are product noise, subtraction noise, Gaussian elimination noise, matrix error noise (quadrature error in evaluating matrix coefficient terms), as well as phase velocity error where the phase velocity is incorrectly defined, which in turn can give rise to errors in the exponential function calculations [4]. This is related to the process of solving an integral equation which formulates a cooperative behavior among the current elements so as to produce a field that exactly cancels the incident field within a metallic scatterer, for instance. Reference [4] points out that this cooperative behavior requires that all the current elements “talk” to each other on the same “wavelength” or the same phase velocity. Hence, any inconsistency in the phase velocity will not allow the current elements to cooperate effectively with each other.

The sources of matrix error can be traced back to the problem of (i) geometrical modeling error; (ii) integral equation discretization (including basis function expansion error and quad-

ature error); (iii) matrix equation solution error (using iterative solvers, LUD, and banded matrices); (iv) matrix vector product error due to matrix equation factorization error (in the case of fast algorithms) and pre-corrected FFT errors; and (v) associated round off and numerical precision errors [3].

Interpretive errors - The human's attempt to interpret the computed observables can lead to erroneous conclusions about the data and detract from the real problem solution.

The process of modeling and analyzing problems that reveal singularities, caustics, and harmonic resonance behavior as well as situations where abrupt discontinuities of current or field point mismatches exist at/between multiple region (multilayer material) interfaces, can call into question the suitability of the technique as well as computational accuracy. Oftentimes, there is a balance of objective and subjective reasoning at play at this level of modeling and simulation. The proof comes in validating the results against ground truth or high-quality measurement benchmarks.

A standardized approach will most certainly be useful in performing a consistent, accurate, and repeatable V&V of multiple electromagnetic observable data sets. Research has been conducted to establish a standardized method of interpreting computed data results in a highly objective and consistent way using novel technique comparison and Feature Selective Validation (FSV) methods that are designed to reduce the associated uncertainty in interpreting data [5-7]. These methods are briefly described below.

III. SELECTED VALIDATION METHODS

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 [2]. The levels are:

- Computational technique validation
- Individual software code implementation validation
- Specific model validation.

The first level of model validation is the computational technique validation. This is usually unnecessary in most EMI/C 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 its limitations, strengths, and accuracy but, if a well known technique such as the finite difference time domain (FDTD), method of moments (MoM), uniform theory of diffraction (UTD), 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.

The second level of validation is to insure the software implementation of the modeling technique is correct, and generates correct results for the defined model. Naturally, everyone who creates software intends for 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 against which their software code has been tested, 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.

The third level of validation called 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 to begin with. 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 further subdivisions of this validation process, namely

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

A popular approach to validating simulation results is to model the same problem using two or more different modeling techniques. If the physics of the problem is correctly modeled with multiple simulation techniques, then the results should agree. As stated earlier, 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 weaknesses. Care must be taken to use the appropriate simulation techniques and to make sure they are different enough from one another to guarantee a valid comparison. 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 many 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 complete 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 or masking the 'real' data. Some techniques, such as FDTD, can simulate infinite planes (i.e., some FDTD tools allow metal plates to be placed against the absorbing boundary region, resulting in an apparent infinite plane). Other techniques allow infinite image planes, etc.

With regard to validation using convergence, there are a number of model parameters that must be decided upon before the actual simulation can be performed. The sizes of the grids/cells, etc. are often set to $\lambda/10$ to satisfy the assumption that the currents/fields/etc. (i.e., observables) do not vary within each grid/cell/etc. However, this size may not be small enough to correctly capture the desired observables if their amplitudes vary rapidly over the structure. Changing the size of the grid/cell is a good way to insure that the proper sampling was used. If the results change when the grid/cell size is changed, then the correct size was not used. Once the grid/cell 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 rerun until these parameters do not affect the final result from the simulation.

One important consideration when using grid/cell size convergence or computational domain size convergence is the amount of computer RAM memory required to run the simulation. Often, models are created that require most of the RAM available, and modifying the model for convergence testing may require more RAM memory than is available. This does not eliminate the need to validate the model. If convergence testing is not possible due to limited RAM memory, then a different validation approach must be used.

Volume based techniques (such as FDTD, FEM, TLM) should also vary the size of the computational domain. Effects from the computational boundaries should not influence the final results, and a different size computational domain will demonstrate if this is a problem.

There are yet several other methods that can assist in the model validation process. These include:

- Model validation using standard problems
- Model validation using known quantities
- Model validation using parameter variation.

Consider the parameter variation case for example. 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 results of 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 and to verify expected trends.

Perhaps one of the more novel validation/benchmarking methods that has emerged is based on an approach using a rating scale. This approach is used to aid the 'visual' comparisons made between experimental and simulated data (or any two

data sets). The technique simply aids the human comparisons, and so does not remove the opinion and experience of the analyst making the comparison. The technique also provides the analyst with an overall quantitative measure of similarity. The details of the development and improvements made to the modified scale are reported in [2], and the effectiveness of the improved technique with regards to its ability to reduce the variance between analysts is emphasized. This section concludes with highlighting the need for a "visual benchmark" and also emphasizes the usefulness and effectiveness of the technique.

A. Validation Rating Scale

Validation of electromagnetic modeling methods, particularly against experimental results, often involves structurally complex data sets. Quantification of these comparisons is usually made "by eye" to determine how similar the two traces appear. This method of validation has obvious limitations. First, the subjectivity of this approach makes expressing the degree of similarity very difficult. Second, there is no benchmark by which to make the comparisons, so rating the pairs of data depending on their similarity is a demanding task. It has been shown that a large variation in the similarity ratings can be given by a sample of experts, when comparing the same pairs of data.

The six-point rating scale, (derived from the Cooper-Harper rating scale used in aircraft assessment by pilots), is shown in Fig. 1. The technique removes the subjectivity when validating the data sets, by guiding the analyst through the comparison to be made. The rating scale therefore solves the problem of the users having no common yardstick with which to compare data sets. Careful design of the rating scale should, overall, leave the mean result from a group unchanged, but should reduce the spread of opinions i.e., the mean value should remain unaltered, but the variance (or standard deviation) should be reduced when the rating chart is used. The details of the design of the rating scales and their effectiveness are not presented here, but can be found in [2, 5-7].

It should be noted that only a binary decision is required at each node in the chart and this results in a six-point scale (rather than the more commonly used ten-point scale). Also, qualitative descriptors have been allocated to these values, which will help in individual skills enhancement and in the development of a shared tacit knowledge base ('genre').

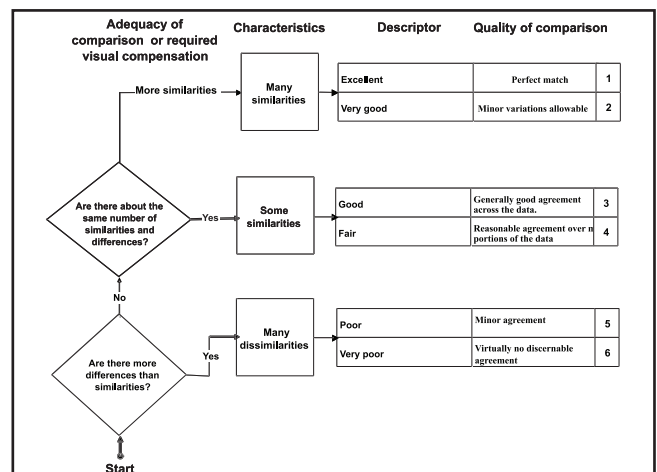


Figure 1. Modified Cooper-Harper rating scale for visual benchmarking [7].

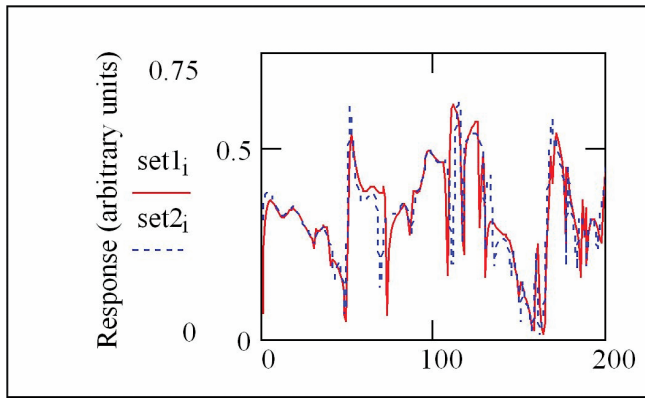


Figure 2. Example of two data sets for comparison.

B. Feature Selective Validation (FSV)

The experienced professional can look at the data in Fig. 2 and decide that the two plots have ‘good’ agreement, or ‘fair’ agreement, etc., mostly depending upon what their individual criteria are. The FSV allows a numerical calculation that gives a result that removes the ‘personality’ from the decision process. The FSV leads to a final result that is derived from the Modified Cooper-Harper Scale in Fig. 1.

The basis of the FSV technique is the decomposition of the results to be compared into only two ‘component’ measures and then the recombination of the results to provide a global goodness of fit measure. The components used are the Amplitude Difference Measure (ADM), which compares the amplitudes and ‘trends’ of the two data sets and the Feature Difference Measure (FDM), which compares the rapidly changing features (as a function of the independent variable). The ADM and FDM are then combined to form a global difference measure (GDM). In particular, the GDM value gives a single figure of merit representing the comparison of the modeled and measured data across the data points. All of the ADM, FDM and GDM components are usable as point-by-point analysis tools or as a single, overall measurement.

The benefit of the point-by-point results is that these can help to identify regions where attention needs to be focused during validation of the model or in the post-mortem phase.

Natural language descriptors are assigned to the output from this technique (ideal, excellent, very good, good, fair, poor, very poor).

Further, the probability density function (pdf) of the individual point-by-point analyses can be plotted to provide a confidence measure. Essentially, this density function provides a visual guide as to how well a comparison conforms to the

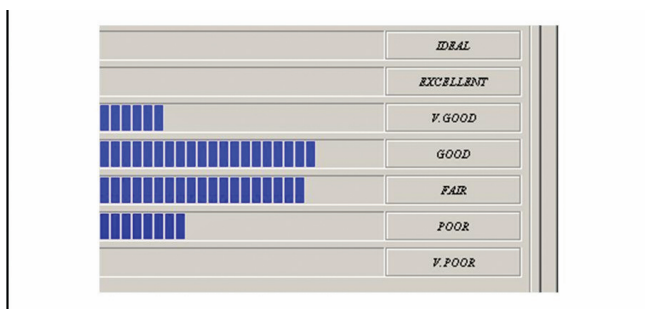


Figure 3. Example of a PDF histogram ‘confidence levels’ for a given GDM.

descriptor discussed above. An illustration of the probability density function for a given GDM value is shown in Fig. 3.

The results confirm the conclusions of a visual inspection of the source data; that is, the amplitude and general trends are in excellent agreement and while there are regions which are substantially different in terms of the location of features, the overall agreement is good.

This section has demonstrated the basis of the FSV method and described how it can compare data in a tiered manner, ranging from a point-by-point analysis to a single global figure providing an overview of the whole comparison. It has the advantages of breaking down the comparison into the two main aspects generally considered, namely amplitude/trends and features, and of having a natural language description. Previous tests have shown encouraging agreement with the perceptions of practicing engineers.

C. Conclusions

The current work towards developing a CEM technique validation standard describes the scale and the process to parameterize agreement between different data sets, whether the data represents modeled and measured data, data from two different modeling techniques, or other sets of data. A scale of 1 to 6 is used to quantify the agreement between the data sets using the FSV method. This method is used to find the final agreement level. Agreement levels of Excellent, Very Good, Good, Fair, Poor and Very Poor are allowed.

Other selected validation methods and techniques as described above are also covered in the draft standard [2].

IV. SUMMARY

This paper discussed EMI/C model and technique validation using several different methods, depending on which is most appropriate. Engineers should validate their models to ensure the model’s correctness, and to help understand the basic physics behind the model.

Measurements can be used to validate modeling results, but extreme care must be used to ensure that the model correctly simulates the measured situation. Omitting feed cables, shielding or ground reflections, or different measurement scan areas can dramatically change the results. An incorrect model result might be indicated when, in fact, the measured and modeled results are obtained for different situations, and should not be directly compared.

Multiple modeling techniques can be applied to the same problem. If the modeling techniques are different enough, then high confidence in the results can be obtained when the results agree.

Intermediate results can also be used to help increase the confidence in a model. Using the RF current distribution in a MoM model, or the animation in an FDTD model, can help ensure the overall results are correct by determining the intermediate results are correct. These intermediate results have the added benefit of increasing the engineer’s understanding of the underlying causes and effects of the overall problem.

Other validation methods, such as convergence and comparison against known quantities may be used when necessary.

This paper also highlighted the various sources of error in the overall CEM modeling and simulation process. An overview of some of the sources of error and the potential pitfalls that may

lead to computational uncertainty was provided. This is applicable to a broad range of problems ranging from the modeling of printed circuit board radiated and conducted emissions/immunity to analyzing large, complex system electromagnetic effects.

The modeling and solution of large-scale problems in CEM requires the application of the right tool for the right job in order to minimize the potential for error generation and propagation. This starts by knowing where sources of error can arise, how to quantify them, and what methods can be used to control errors. Sources of error were generally categorized as procedural, model-limited, technique-limited, problem dependent, numerical, and interpretive. These are by no means complete and inclusive, but these provide insights into better understanding error budgets and how these may be controlled.

The concerns raised over the lack of well-defined methodologies to achieve CEM technique validations within a consistent level of accuracy have led to new initiatives that are currently underway to develop standards and recommended practices for this very purpose. Also underscored is the need to identify and quantify the sources of errors and to employ controllable error schemes when and where feasible.

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REFERENCES

- [1] A. L. Drozd, "Progress on the development of standards and recommended practices for CEM computer modeling and code validation," Proc. of the 2003 IEEE Symposium on EMC, Boston, MA, pp. 313-316, 18-22 August 2003.
- [2] IEEE Project 1597.1: Standard for validation of computational electromagnetics (CEM) computer modeling and simulation (IEEE P1597.1 DraftTM/D1.2), 20 January 2005 (unpublished to date).
- [3] A. L. Drozd, "Some sources of error in CEM modeling and simulation," Technical Feature Article of the Applied Computational Electromagnetics Society (ACES) Newsletter, pp. 12-17, vol:19, no:2 July 2004.
- [4] M. L. Hastriter and W. C. Chew, "Role of numerical noise in ultra large-scale computing," Proc. of the Annual Meeting of the Electromagnetic Code Consortium

(EMCC), Seattle, WA, 18 May 2004 (CD-ROM).

- [5] A. P. Duffy, M. S. Woolfson and T. M. Benson, "Use of correlation functions to assist the experimental validation of numerical modelling techniques," Microwave and Optical Technology Letters, 17, pp. 361-364, 1994.
- [6] A. Martin, "Feature selective validation", Thesis for Doctor of Philosophy. De Montfort University, Leicester, 1999.
- [7] A. Duffy, A. Drozd, B. Archambeault and D. Colby, "Measuring similarity for validation of computational electromagnetic modelling," Proc. of the 2004 IEEE International Symposium on EMC, Santa Clara, CA, pp. 697-702, 9-13 August 2004.

Biography



Andrew Drozd is President and Chief Scientist of ANDRO Computational Solutions, LLC, a certified DoD small business located in Rome, NY. One of ANDRO's key business areas is in the advancement of computational electromagnetics (CEM) technology, which centers on research to develop new computer modeling and simulation toolkits for analyzing electromagnetic environmental effects (E3), including system-level electromagnetic interference/compatibility (EMI/C).

Mr. Drozd is a Fellow of the IEEE for the development of knowledge-based codes for modeling and simulation of complex systems for EMC. He has been an active EMC Society Member for nearly 20 years. He is a member of the EMC Society Board of Directors and is his term as President of the Society began January 2006. He is the Chair of the EMC Society Standards Development Committee (SDCom) sponsored P1597 Working Group on the development of standards and recommended practices for the validation of CEM computer modeling and simulation codes and applications. He is also a member of the TC-9 Committee on CEM, the Applied Computational Electromagnetics Society (ACES), and the Electromagnetic Code Consortium (EMCC).

Mr. Drozd's background is in systems engineering, and EMC computer modeling and simulation. He has over 29 years of technical and program experience in these areas, and more recently, has been working on applying expert systems to CEM modeling, E3 analysis of complex systems, autonomous spectrum management, and automatic target recognition (ATR) problems. Mr. Drozd has authored over 140 technical publications and conference journal papers on topics related to EMC computer modeling and analysis. **EMC**

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