Convergence of Simulation and Measurement Worlds in the Modern Era

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Abstract

In today's era, EM simulation is now part and parcel of the product lifecycle management for many manufactured electrical/electronic goods. For most application requirements, regardless of electrical size, there exists a numerical technique that aids in the development, design and certification. In some cases a single solver is not adequate and a combination of different numerical techniques can be employed to a problem to obtain an optimised goal. However the key question is still the same after more than 25 years of simulation development regardless of the design at hand:

Will my simulation be accurate enough and have good correlation with the expected measurements/ outcome?

This paper looks at a couple of diverse examples where simulation and measurements have converged in an increasingly complex and sophisticated world, and some of the considerations required. It also looks at how the ethos of the simulation models has adapted to modern management.

Introduction

The last 25 years has seen a significant technological advancement in many areas and as we enter into the age of the ‘Internet of Things’. An engineer’s life seems destined to become even more challenging. Electromagnetic modelling is just one of many areas where growth has been essential and key to the technological advancements.

This growth has seen an increase in the number of numerical techniques and packages now available to help solve the electromagnetic problem at hand. There have also been changes in the techniques certain EM problems are modelled. In more recent years the design engineer has had to deal with changes brought about by austerity. Regardless of the changes seen throughout the years the end goal is always to achieve accurate simulations that conform to the measurements.

This paper looks into two modern day test cases where recent modelling techniques have been applied to the problem to achieve good to exceptional results. Some common problems are highlighted to try and explain where some engineers need a little more caution. The significant aspect in both examples is the interaction of simulations and measurements at early stages to obtain the intended results.

Example 1 – SMD High Frequency Modelling

The first test case to be taken into consideration is the modelling of Surface Mount Devices (SMD). SMD’s have gained an attraction over the decades and successfully used in many communication and RF sensing/control systems. For instance the low noise block for satellite broadcasting is widely used in households in a frequency band of 10 - 12GHz. However with higher operating frequency bands, increased accuracy of the models is required.

Modelling of SMDs is common practise and highlights a number of pitfalls encountered that has often ended in heated discussions between Engineers and their colleagues. Regardless of using the exact components stated in their designs, the discrepancy between the modelled and simulated results can be significant. This can be the case for even ‘simplistic’ boards and can end in costly re-spins or missing tight deadlines. A good resource for helping with circuit modelling is Swanson’s book [1].

With this in mind, how can the Design Engineer achieve a result that meets the system requirements first time, and have confidence in their modelling? For this case study it is important to contemplate all aspects of the design including OEM manufactured parts and data.

The Problem

A narrow band Amplifier Design circuit and low pass filter design are considered for this example. With an Amplifier you can often download the layout, substrate and expected S-parameters. But quite often a different substrate is required when taking into account system requirements like obsolescence, material availability and budgetary constraints.

An amplifier was designed on FR4 and a calibration kit manufactured for obtaining measured data at well-defined reference planes in the centre of the test boards. The aim is to just measure the amplifier and compare this with the Manufacturers data sheet. It is expected to see some discrepancy between the measured and specified performance due various reasons e.g. different substrates or layout for the monolithic amplifier IC. Given the comparisons in Figure 1, a Design Engineer may feel the difference isn't too critical at this stage and proceed with their amplifier circuit.

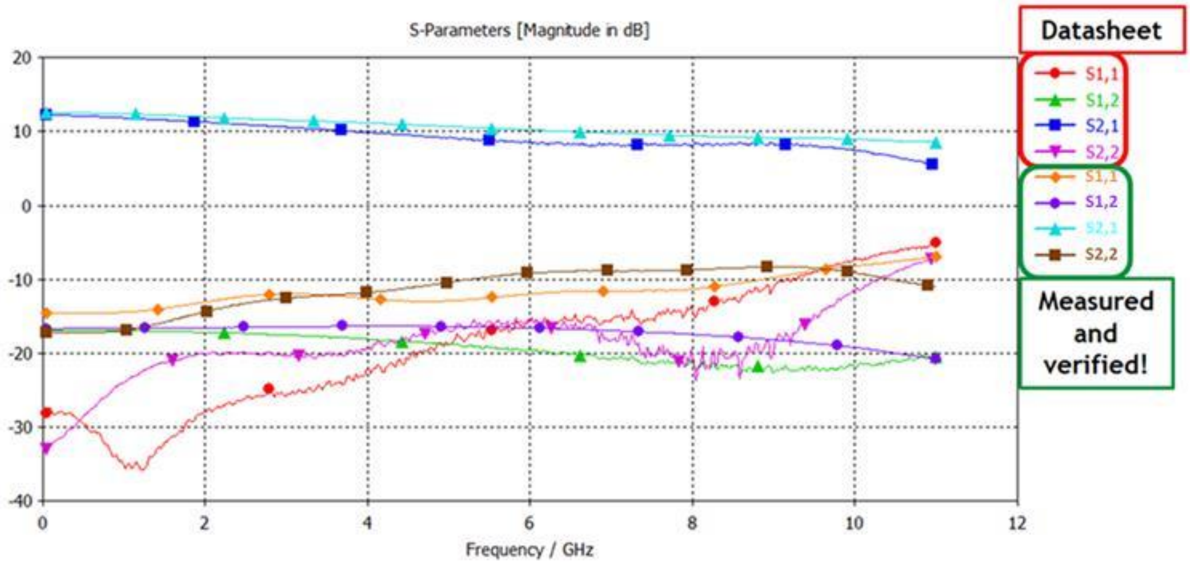

Figure 1 Early design S Parameters for an amplifier

With a simplistic narrow band amplifier design a 2 component matching network is required on both the input and output of the amplifier to complete the circuit. By using the OEM data, matching networks can simply be generated for the amplifier circuit to optimise for 10.7 GHz; the frequency of interest in this example. If the same matching networks are then applied to our measured data model on the FR4 substrate, the problem becomes critically clear.

Although the predicted reflection coefficient based on the vendor data sheets is around -40dB (red, solid circle), shown in Figure 2 , the reflection coefficient based on the measured data is predicted to be -5dB (black, dotted circle). This is not acceptable in terms of the discrepancy or, more importantly, in terms of systems performance. But this may not have been identified until after fabrication of the board!

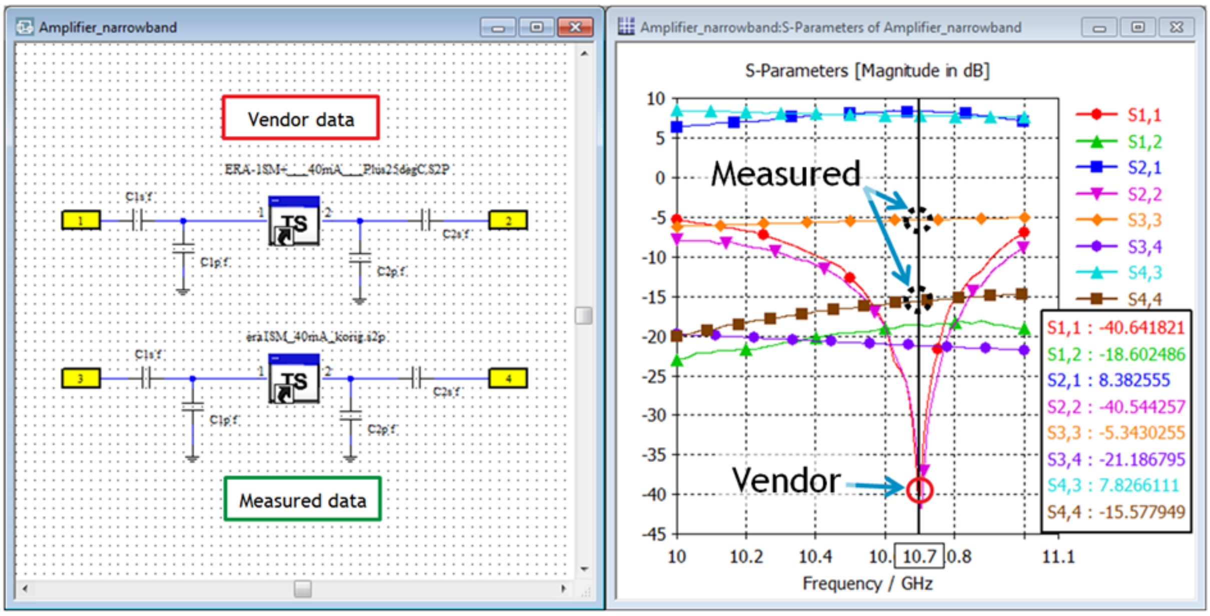

Figure 2 Discrepancy of simulation to measured result in final design

The reason for the large discrepancy is found mainly in the phase of the S-parameters. Matching networks work only where the electrical distance to the amplifier is known. As the datasheets have not supplied the reference plane at which the amplifier was measured, the phase shift experienced can completely destroy the matching effect. This is what is seen within this example. Naturally there exist other sources for the discrepancy, like layout, substrate permittivity and thickness.

However some problems can be found at a more primitive component level (passive SMD components). Many vendors supply SPICE or Touchstone files to aid with the design of the boards, and these can often be mistakenly accepted as the given performance for that particular device. When the SPICE model is reviewed carefully, it may be found the model has been derived under different conditions to those of the user, and interaction with the layout may be insufficient. Figure 3, shows the comparison of using SPICE (Mauve, Black curves) or Touchstone files (Green, yellow Curves) compared to a measured (blue, red curve) result for a SMD low pass filter design.

The low frequency response seems reasonable, when soldering and manufacturing tolerances are taken into account, with a discrepancy of 20MHz around 700MHz. The higher frequency response, around 3GHz, within the stop band region predicted resonances with an error of around 500MHz, and this is not so acceptable.

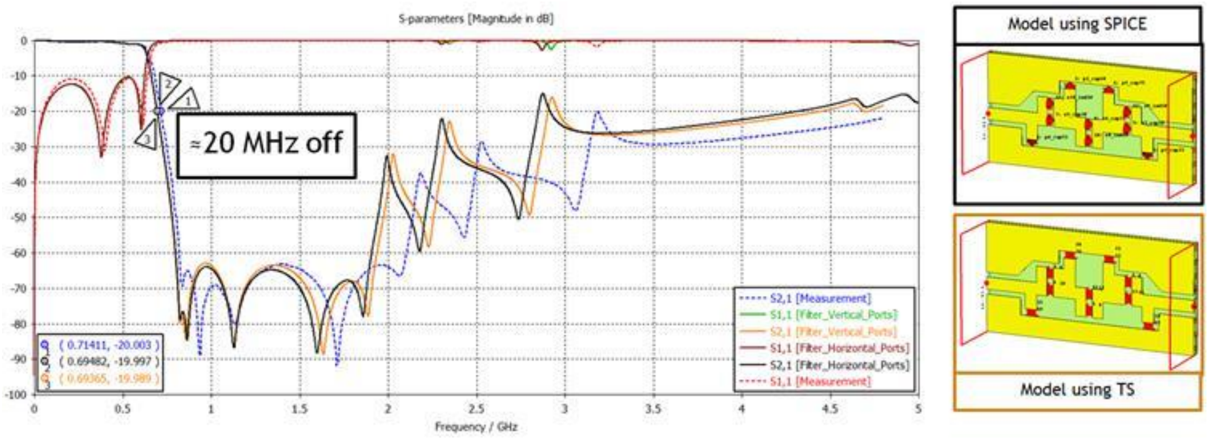

Figure 3 Discrepancy when using vendor Spice or TS models

So what can be done to accurately predict the response of a PCB? Is it possible to get better quality simulation models for SMD components?

The Solution

In response to the previous question, the answer is a definitive ‘Yes’. However, as can be surmised from the previous section, the problem is deserving of additional work from the engineer. If we consider the case of the Filter Layout seen in Figure 3, fixtures are made for each of the components and the final filter design. Each component is then measured using an appropriate calibration kit. By having a whole set of fixtures as shown in Figure 4, averaging of random errors like Soldering and SMD displacement etc. can be taken into consideration. The substrate’s complex permittivity can be extracted from the measured data as a side product of the calibration procedure [2] using simulation tool sets [3].

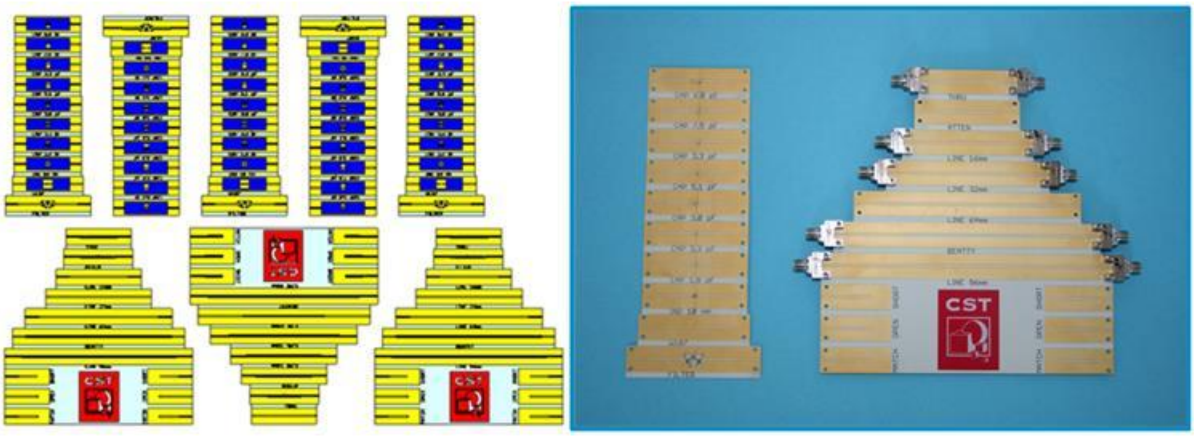

Figure 4 Fixtures for measuring components in design

After measuring each individual component in the correct configuration, hybrid models can then be defined. In this hybrid modelling approach the 3D body of the SMD is also included. The internal structures of the components are modelled at circuit level using discrete port interfaces. The advantage of this hybrid approach is that the interaction of the SMD with the layout is also taken into consideration at 3D EM level; therefore the models are robust and accurate. However the computational effort has increased slightly.

The simulation model can then be optimised to achieve a good correlation between the measurement and the model. Figure 5 highlights the measured and simulated S-parameter results, amplitude and phase, for a 10nH inductor using these techniques. To achieve the very good correlation is seen, a simple RLC equivalent circuit is used for the circuit portion of the inductors hybrid model.

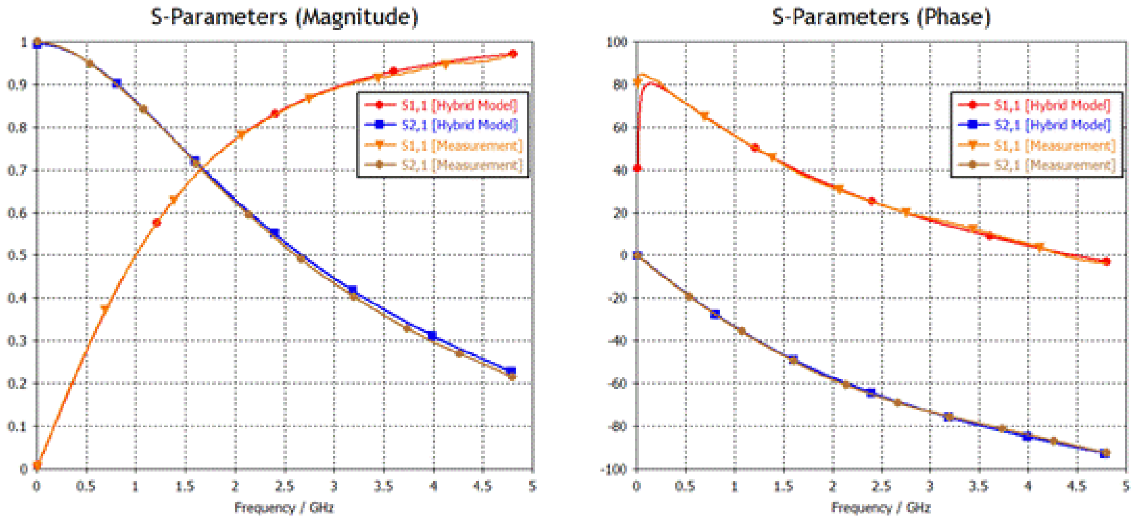

Figure 5 Measured and simulated amplitude and phase for 10nH inductor

These same techniques are applied to all the components to be placed on the board. The complete filter can be then assembled, re-simulated using the hybrid components and compared with the original measurement. The final simulation model, measured board and comparison are shown in Figure 6 and 7. The results predicted not only the cut off frequency very accurately, but also the resonances in the stop band.

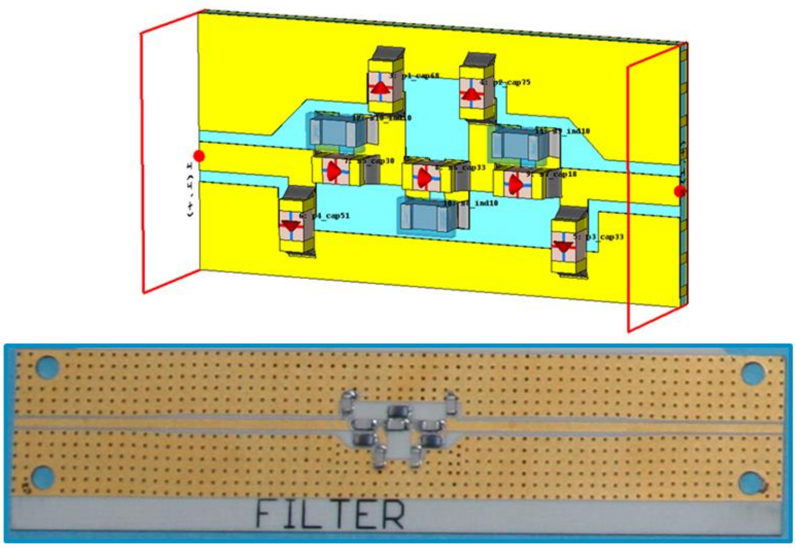

Figure 6 Final simulation and measured board

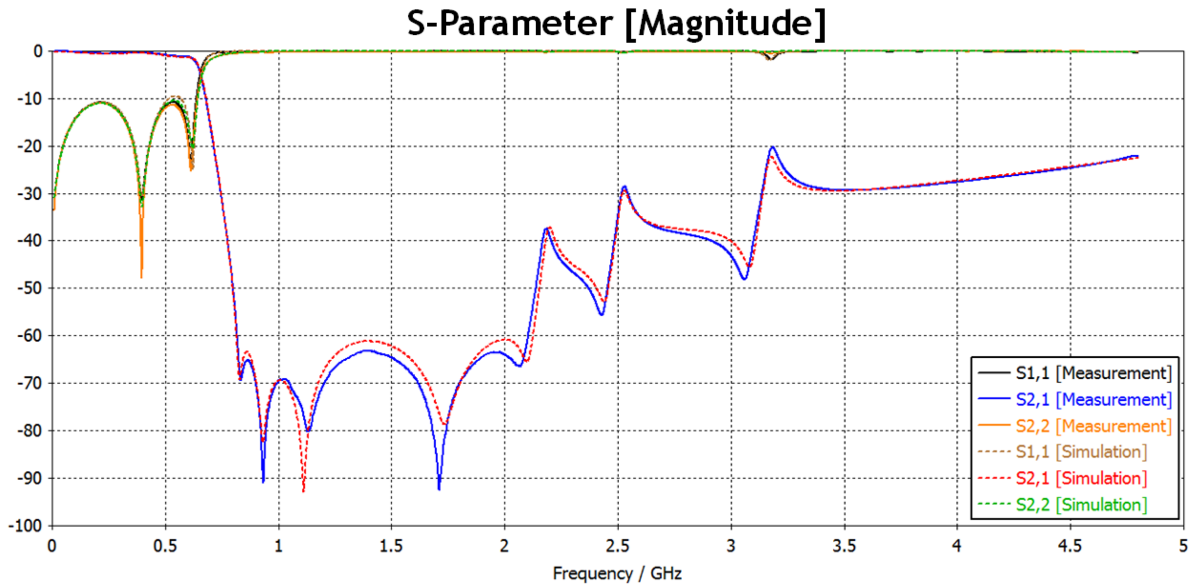

Figure 7 Measured versus simulated results for filter design

To demonstrate the accuracy of the hybrid model, the mutual inductance of the three inductors on the board layout were also accurately predicted. This corresponded to the three troughs located around 1GHz.

With this approach the hybrid model can be used in arbitrary layouts whilst maintaining very high accuracy. It also provides accurate modelling without the requirement for detailed knowledge of the internal topologies. Therefore to answer the original question of: 'Is it possible to get better quality simulation models for SMD components?' the answer is very much based on the Engineers effort. This is summarised in Figure 8;

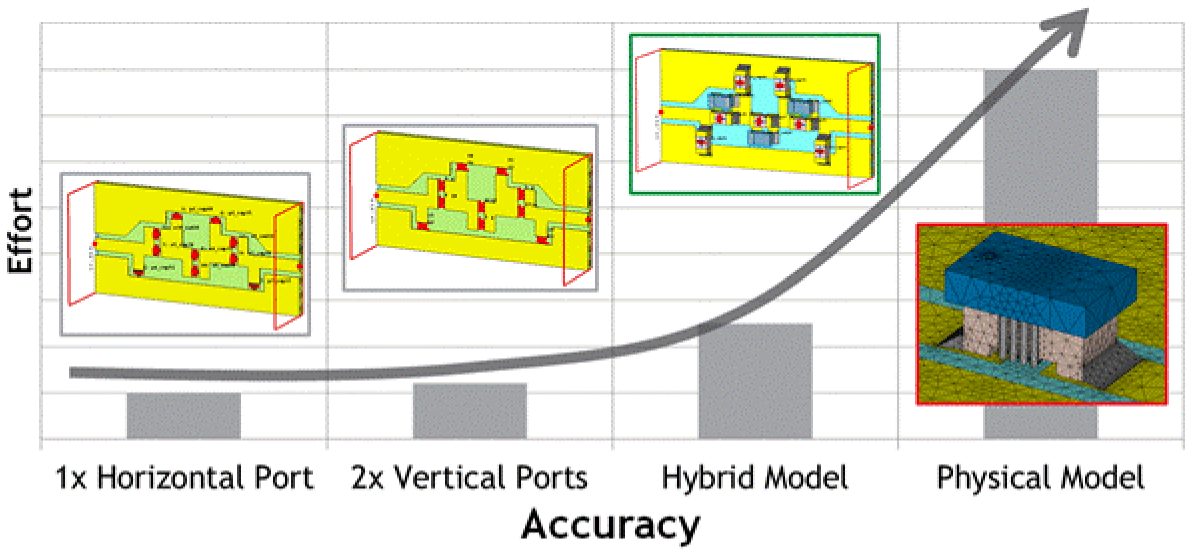

Figure 8 Chart displaying accuracy versus effort

The graph shows the effort and accuracy achieved firstly with the SPICE model approach, then the touchstone model with 2 ports for each component. The very accurate hybrid approach comes next, that has been presented within this paper. After the hybrid model you can go even more brute force in the approach and achieve very accurate results by modelling the physical models. This can be demanding on CPU time, RAM and engineering effort, but can be essential for looking into manufacturing tolerances of components or when good results are required without the need for vast measurements. So the hybrid model, although requiring a little more effort, is an ideal approach for most applications of this type.

Example 2 – Electrically Small to Large Structures Modular Modelling

The second and final simulation example addresses simulation and measurement worlds in a different context. In recent years the headline topics have been based around austerity and making monetary cuts. These cuts have often been managed in different ways within the engineering world. Whether focusing on the bill of materials level, involving changes to the substrates or components, or to top level planning. This often involves using or modifying existing designs to suit the needs of new system requirements or platforms.

This modular approach to engineering has been quite popular, where you can take an existing design and place it in a new environment to achieve the required system levels. It may involve making slight modifications to achieve the desired results. Alternatively this could be installing antennas with different pre-existing black boxes on different platforms in a plug and play configuration to achieve the desired outcome.

The Problem

Considering the modular approach there are instances where an electrically small problem (Module A) is placed within an environment where the complete problem is deemed as electrically large (Module B). This then has other modules added to it or placed on difference platforms to complete the system requirements.

Based on the electrical size of the simulation, a suitable numerical technique would be chosen. If an antenna is simulated fine discretization of the problem may be required. However if the antenna is placed on a very electrically large structure the same discretization would not be practical and therefore a different numerical technique would be applicable. What started as a volumetric mesh problem may now have become a surface mesh problem.

With many businesses, different opportunities are sort and the final platform may vary from application to application. The final installed antenna performance can be highly dependent on the final platform, not just in terms of form but also in terms of specialist materials being introduced. This could involve materials that are frequency and angular dependent. Therefore does the engineer need to start from scratch for each new design application? How does the Engineer cope efficiently with the different numerical techniques required for the vastly different electrically sized problems? Then add to this conundrum the change in platforms?

The Solution

Although a number of years ago, such a task would be near impossible to solve. These days modular modelling, which almost replicates top level business project planning, is increasingly common. The system can be built up and modelled using smaller building blocks. Each of the building blocks concentrates on a specific part of the design and has a dedicated numerical solver applicable to the electrical size problem at hand. This is sometimes referred to as the System Assembly and Modelling (SAM) Framework. In some cases, within this framework bi-directional coupling is required between the solvers to ensure accurate results are obtained.

Once again the simulation and measurement worlds are required combine to provide optimal solutions. A good example to emphasise the importance of the SAM framework as well as the combination of these two worlds is a phased array. A Phased Array can often be thought of as multiple radiators in close proximity to one another, which when fed appropriately can achieve a required specification.

In some instances a good prediction of the overall phased array performance can be made from a single element and applying periodic boundaries. This is done using a numerical technique suited for electrically small problems and often provides the engineer with confidence in his design before proceeding to the full array.

When modelling the full array a numerical technique for a mid-ranged electrical problem is more appropriate, i.e. the Finite Integral Technique. The engineer can then make comparisons with their specifications as well as take into account non periodic effects from edge radiating elements or passive elements and actual scanning behaviour. At this stage the engineer may wish to take into account protective coverings like Radomes, as this can cause lensing effects or incur further systems loses.

The Array may be placed next to other arrays or directly onto a given platform. This now makes the problem electrically very large and therefore a different numerical technique like a Shooting Bouncing Rays approach would be advisable. This is because discretising an electrically large problem using a volumetric mesh would not be a practical approach in terms of computational resource. The three stages of electrical problem are highlighted in Figure 9 with stage 1 being electrically small, leading up in size to stage 3 electrically very large.

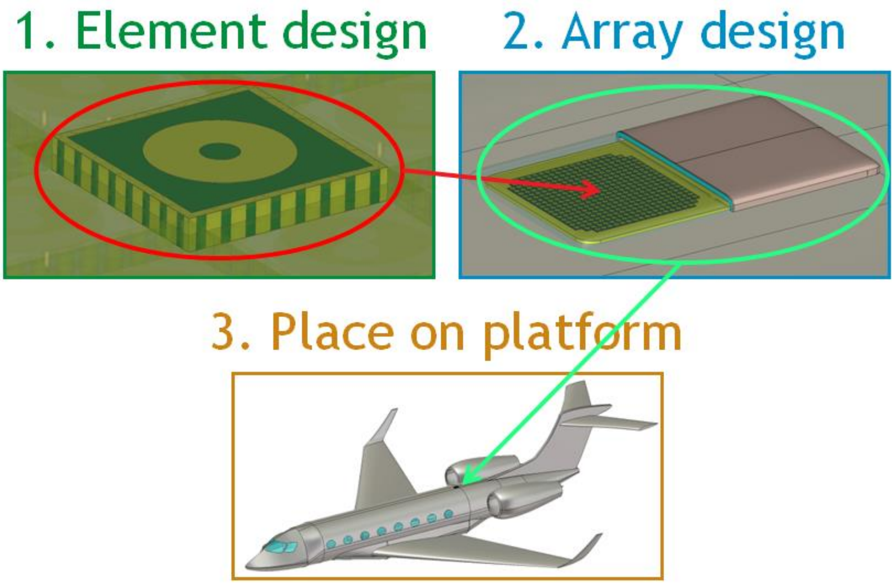

Figure 9 Problem becoming increasingly electrically large

As previously suggested this can now be coordinated in a methodical and modular fashion for optimal processing of the simulation problem. A typical framework for the System and Assembly modelling environment, seen in Figure 10, shows the modular approach taken to ensure the most appropriate numerical techniques are used for a given problem. So if a helicopter platform is then preferred to an aeroplane, this is easily adapted by importing the appropriate CAD file and setting the location of the Antenna module. For the measurement phase of such a project, large platforms can be quite expensive and difficult logistically to organise, therefore the running of simulations to assess performance is paramount of importance.

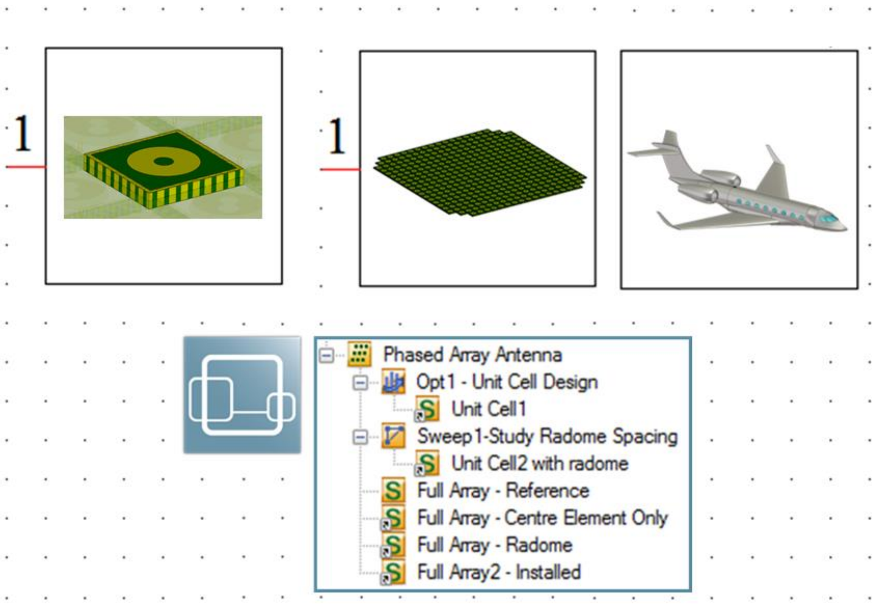

Figure 10 Example of a system assembly framework

Occasionally simulations in such an environment still necessitate vital input from the measurement world and not only for the final verification of system performance. With the introduction of more sophisticated materials, whether for Radomes or for other application areas, the development and emergence of angular and frequency dependent materials are becoming more prevalent. The properties of these materials are not always known or well documented but are still needed to be simulated so the overall expected system performance can be evaluated.

Modern day aircraft often have a variety of materials making up their airframe these days rather than metallic shells. Composites in some cases may be as high as 80% in their proportion of the airframe. Therefore it is important this is accurately derived within the simulation environment and included within the modular framework for calculation with the correct numerical technique.

The procedure often employed to simulate unknown materials properties or occasionally for composite materials, firstly involves the measurement of the material over a suitable frequency range and at multiple angles. By knowing the full transmission and reflection characteristics for the unknown materials via measurement, this information can be applied as a coating to thin panels within the simulation.

Diverse application fields such as Lightning Strike certification and Radar Cross Section are just two examples of where this kind of simulation-measurement hybrid technology is extremely important. Prior to the addition of advanced materials, good simulation measurement agreement of the basic structure is important and this has been shown by Pienaar et al [4] for a large model airframe. Good agreement has also been seen with well documented RCS examples of a small arrow head or a 9 inch Nasa Almond as shown in Figure 11. The simulations involving more advanced material models will not be shown at this time due to confidentiality.

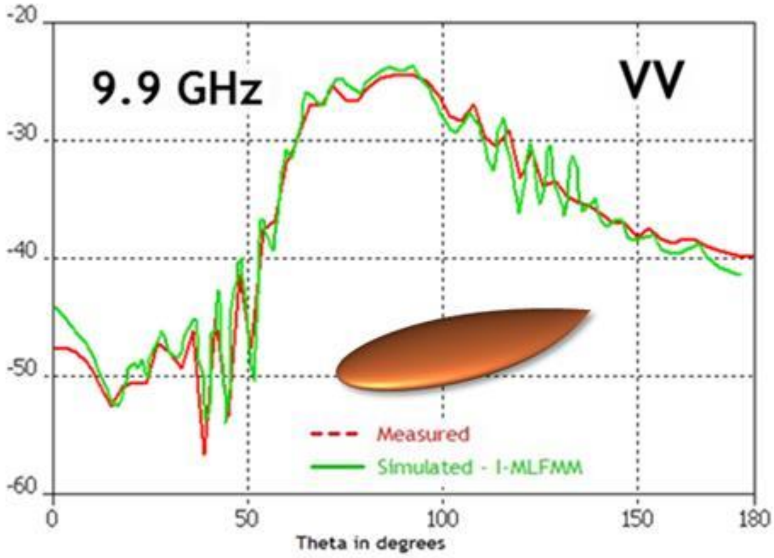

Figure 11 Good Correlation between simulation and measured result for NASA Almond

Conclusions

The perception of electromagnetic simulation has changed noticeably in the last 20 years. Engineers tend to be more accepting of the numerical techniques behind the software and the results achieved. More sophisticated simulations and accuracy are achievable through the development of computers and numerical techniques. Run times have significantly reduced from weeks to minutes, and reliability of the software has increased compared to 20 years ago.

It has been shown how modern day packages can emulate current management techniques in times of austerity. This paper has shown regardless of electrically size and the development of increasingly complex simulation software; the synergy between Simulation and Measurement is potentially stronger and more important than ever. Whether this is looking at increasingly complex materials or taking into account manufacturing tolerances. This is increasingly important with the rapid emergence of 3D printing.

The modern design engineer, rather than blaming the measurement or the simulation for being wrong, now needs to think more carefully about what is being simulated. How much time and effort is required to achieve practical results, and the accuracy that is needed. They may need to consider the simulation problem in a different way.

For PCB's a hybridised approach, although slightly more time consuming, is potentially a good approach to achieve good accuracy in a reasonable time scale as recalled in Figure 12. This is also beneficial to companies re-using existing technology, albeit slight optimisation for system requirements may be required.

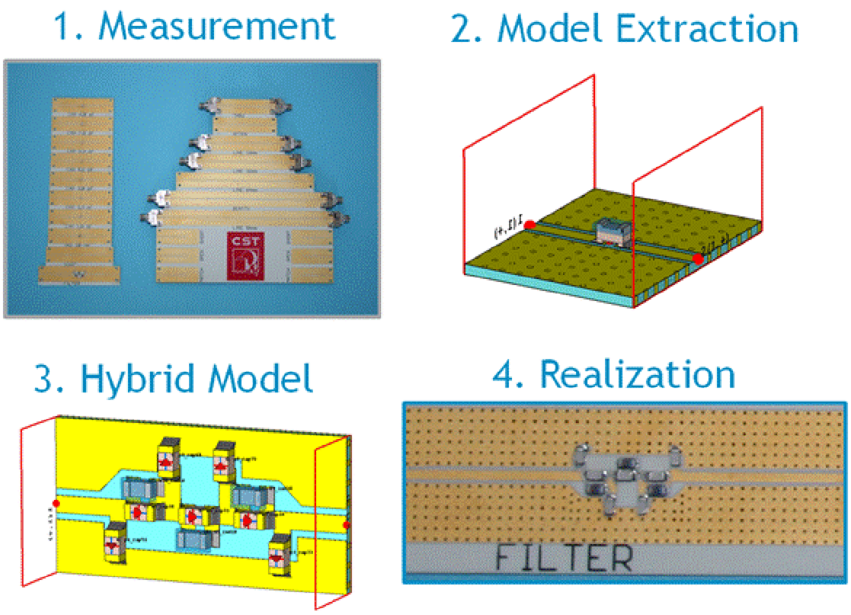

Figure 12 Combination of measured and simulated results to achieve optimal end goal

Given the advancement of technology in the last 20 years the coming years will be interesting for Electromagnetic and Multiphysics Simulation packages. A refocusing of the lens for capabilities of simulation providers may be necessary. However, measurements will always be critical.

The Next Era of Simulations Packages

So what is the next step in the rapidly changing world of simulation software packages? This paper merely touched on some of the features available in today's market. But the reality is cross functional engineering packages are becoming more widespread, these include numerical solvers to account not only for electromagnetic applications but also for mechanical and thermal constraints. Therefore in the authors opinion in the near future one package could be suited for all Engineering disciplines, whether EM, Environmental, structural, mechanical, safety etc.

The continued and increased fusion of Measurement and Simulation worlds will play a critical role in the present and future. The modelling of 3D problems will become even more lifelike, with predictive diagnostics becoming more common place. For example making sure all electronic functions will still be operational in the event of an accident, or push button manufacturing solutions for some applications. The possibilities seem endless, but without a doubt the emergence of super hybrid simulation packages and advanced 3D imagery will have a significant say in the technological advancement.

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