SPICE models of barrier compared to measured data

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Abstract: SPICE models of electromagnetic zone barrier are devised. The models are based on data from 2D and 3D Maxwell equation solvers. A transfer impedance approach modeled incident electromagnetic waves in SPICE. Test systems using D-sub connectors, passive surface mounted filters and encapsulation was designed. Test system verification measurements were made in a fully anechoic chamber. The coupling through the zone barriers was measured. Good agreement was found between simulated and measured data.

Introduction

The focus for electronic system designers is on product functionality. Here EMC aspects are hard to approach using for the electronic engineer well known tools such as SPICE. This work thus focuses on building SPICE models for electromagnetic zone barriers enabling SPICE simulations of radiated power and immunity to incoming disturbances. The datasheets from the manufacturer seldom gives a complete description of the electrical characteristics of a component. For instance for a filter the insertion loss is often the only given performance parameter. To be able to make accurate SPICE models for a component it is necessary to know the entire scattering parameter matrix. It is then desired to find a lumped component circuit with the behavior described by the S-parameters.

SPICE models has been developed for commercially available components that can be regarded as EMC barriers. Surface mounted filters and shielded connectors and cables are examples of such components. Models have also been developed for EMC barriers that appear in a circuit due to the layout of circuit. This includes separation of traces on a printed circuit.

The modeling approach for the different kinds of barriers have to be chosen with care to obtain useful data with a limited amount of effort put in. Here some a priori knowledge is necessary. A skilled RF designer can from the geometry of a barrier judge if it can be regarded as a multi-conductor transmission line (MTL), cascaded MTLs or if a more general approach has to be chosen.

SPICE model generation techniques

For barriers that can be viewed as multi-conductor transmission lines the cross-section is divided into small elements and the Laplace equation is solved [1]. An assumption is made that the cross-section is uniform. From the

solution the charges on each conductor can be computed and thereby the per-unit length inductance and capacitance matrices. When the matrices are known it is a straightforward task to construct a circuit representation that can be used in a standard circuit simulator, see fig. 1.

Figure 1 Circuit segment representing a multi conductor transmission line

Barriers with complex or unknown geometry, for instance commercial filters, cannot be viewed as transmission lines. Here another method has been used. The S-parameters of the component are measured using a vector network analyzer. The next step is to set up a discrete circuit and then compute the S-parameters. The computed S-parameters are then compared with measured data for the frequency range of interest. The weighted difference is minimized by adjusting component values in an iterative scheme, searching among component values in a given range [1]. To verify the generated SPICE models results from SPICE simulations were compared with measurements on the barriers. Good agreement was found [1].

Simulations

For further verification of the generated models a test system was designed involving several combined barriers and many connection ports. This made it possible to analyze the system in many configurations. The test system consists of a terminated coaxial cable (RG58), a shielded 9-pin D-sub connector, four parallel traces on a printed circuit board and a surface mounted filter, fig. 2. The traces on the printed circuit board were designed as 50Ω microstrips to minimize reflections and standing waves in the system causing unpredictable results in the measurements.

Figure 2 SPICE simulation model of the system (the models for the cable and connector shield is not included in this figure).

Two measurement ports on the PCB utilizing SMA connectors makes it possible to monitor both transmitted signals in a microstrip and signals in an adjacent microstrip due to crosstalk on the PCB. Moreover the unused measurement port can be left open or terminated with matched impedance which renders 16 different test configurations that has been used in the comparison.

Using the generated SPICE models of the EMC barriers to describe the essential electromagnetic behavior of the test system in a circuit simulation, the different configurations were analyzed in the frequency domain.

To model the coaxial cable shield leakage and D-sub connector shield leakage the transfer impedance for those components were used. For the cable the IEC 96-1A standard was used to obtain transfer impedance values and for the D-sub connector a method was used that is described in [2].

Figure 3 The test system consisting of a printed circuit board with parallel traces in a shielded enclosure. A surface mounted filter is included on one microstrip and a coaxial cable is via a 9-pin D-sub connected to the PCB.

Measurements

The simulated system was implemented on a PCB and shielded by a metallic box with the shield connected to the ground plane of the PCB microstrip lines. The SMA ports of the PCB were extended to the wall of the box (see fig. 3). A 1 meter RG58 coaxial cable was terminated in the far end in 50 Ω and in the near end connected to 4 different pins of the D-sub in sequence. The outer conductor (shield) of the cable was in good connection over 360° with the backshell of the shielded D-sub connector. The shell of the D-sub connector was then grounded in the shielded box.

Figure 4 Setup of the system inside the anechoic chamber

Measurements were performed inside a fully anechoic chamber where the excitation of the test system was done with an incident electromagnetic plane wave (fig. 4). The coupling from the radiating antenna through the cable and connector shield and through filters and crosstalk between parallel

microstrips was measured using a vector network analyzer. The electromagnetic field was generated with a bilog antenna at a distance of 3 meters from the system. The coupling for the test system was compared to the coupling for a single conductor that replaced the system in the same position.

The lower frequency limit of the antenna is 30 MHz and of course the corresponding 10 meter wavelength does not give good far field conditions at the 3 meter antenna distance. Therefore the lower end of the frequency range in this measurement should be regarded with some caution.

First the coupling between the antenna and the single conductor was measured as $S_{21\text{single}}$, then the coupling was measured with the system $S_{21\text{system}}$. Because the incident field is giving raise to a surface current on the cable shield the system transfer impedance was calculated by including the 50 Ω measurement system impedance:

$$Z_{T_system} = \frac{S_{21\text{system}} \cdot 50\Omega}{S_{21\text{single}}} \quad (1)$$

The system transfer impedance was obtained for 16 configurations of the system, with the center conductor of the coaxial cable connected to each of the 4 pins of the D-sub connected to the traces on the PCB, leaving unused pins open. For each of these measuring output on SMA 1 and SMA 2 leaving the unused connector open or with a matched load.

To have better control of the current distribution another measurement was made according to the sketch in fig. 5. The source port of the network analyzer connected to the cable termination causing a direct injection of current on the cable shield. The current (I_{probe}) was monitored using a calibrated current probe while the cable was positioned at a fix distance of 20 mm over a ground plane. After measuring the voltage level at the SMA ports (U_{SMA}), the system transfer impedance is easily calculated as:

$$Z_{T_system} = \frac{U_{\text{SMA}}}{I_{\text{probe}}} \quad (2)$$

Figure 5 Setup for measurement with direct injection of current onto the cable shield

Again this measurement was repeated for all 16 configurations. A problem with this method is however the poorly defined input impedance of the current injecting point.

To improve the method an EM clamp was used for injection of current on the cable shield outer surface, see fig. 6. The metallic box and the termination of the coaxial cable were in good contact with the ground plane making a closed loop for the current. A calibrated current probe was used to monitor the current and calculations were carried out as described above.

Figure 6 Measurement setup where the current injection was improved by the use of an EM clamp (the current probe is missing in this figure).

As a comparison measurement were made on the shielded box only, including the PCB inside and the D-sub and SMA connectors. The obtained coupling values were combined with the transfer function due to the transfer impedance data for the coaxial cable and D-sub connector shield. This offers another way to calculate the system transfer impedance.

Results

The measurement results obtained in the anechoic chamber shows a poor agreement with the SPICE simulations in the frequency range 30 MHz to 60 MHz where overlapping data is available. Differences between 10 and 40 dB in the two configurations are shown in fig. 7 and fig. 8. However when comparing with other measurements or by extrapolation of the simulation results a better agreement is found in the higher frequency range towards 100 MHz.

When analyzing the results from the method using direct current injection there seem to be a resonant behavior at about 25 MHz probably due to the uncertain input impedance at the current injection point (the far end of the coaxial cable). By the use of an EM clamp for the injection of current smoother frequency dependence is obtained.

System transfer impedance - Dsub pin 7 - SMA 2

Figure 7 Comparison of SPICE simulation results and measured data with input on D-sub pin 7 and output on SMA 2, SMA 1 terminated in 50 ohm

System transfer impedance - Dsub pin 8 - SMA 2

Figure 8 Comparison of SPICE simulation results and measured data with input on D-sub pin 8 and output on SMA 2, SMA 1 terminated in 50 ohm

With the EM clamp injection method a much better agreement is obtained between the measured system transfer impedance and the SPICE simulation, shown in fig. 7. In fig. 8 the same comparison is not so good but exhibits an almost constant offset.

By combining measurements for the parts of the system into a complete system transfer impedance good agreement is obtained with SPICE simulation in fig. 8 but a remaining offset is shown in fig. 7.

Conclusion

The measurements for the desired verification are hard to do with one single approach. For the measurements with incident plane wave in the anechoic chamber the problems at 30 MHz are likely to be caused by the short distance between the setup and the radiating antenna compared to the wavelength. It may also be affected by the poor performance of the antenna at this frequency.

The frequency range for the SPICE simulation was limited by the transfer impedance data obtained for the coaxial cable shield. It is reasonable to believe that better agreement would be found if the SPICE simulation could be done at 100 MHz.

The deviation between the obtained results seems to decrease when frequency increases in the frequency range of this study.

References

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