# Analysis of Industrial Cable Harnesses

**Modern EMC methods and simulation processes provide design assistance for automotive and aerospace applications.**

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The most frequently used keywords in cable harness development are optimization of development processes, variant design, introduction of new technologies, signal integrity, EMC instructions, and cost reduction. Whether in the automotive industry, aerospace industry, telecommunications, industrial plant, or consumer electronics, the most important design consideration assistance for engineers are suitable tools which make investigations in pre- and post-layout phases are possible. Specialized software can provide the engineer with fast solutions for given tasks and enhancements.

## INTRODUCTION

Only a few years ago, engineers' opinions of results regarding the simulation of complex cable harnesses fell into differing "camps." One group did not believe in simulation and relied on the quality of hardware measurements and the experience of design engineers. The other group accepted simulation, but did not believe that software investigations could compare to industrial enhancements. Finally, some optimists believed that simulation results would eventually prove the disbelievers wrong.

As in so many other cases, the truth lies somewhere between these two extremes. Certainly, experience can provide many solutions for given questions, but experience is of limited use when designing the next generation cable harness based on new materials or technologies. How else could a standard for a virtual cable harness, usually existing only on a CAD system, be properly integrated into a car chassis or housing without creating any electromagnetic compatibility problems? How could investigations into the behavior of production tolerances on signal integrity or interference with other cables and their components be carried out? How should a cable harness with a length of more than 3 km, as typically used in the automotive industry, be analyzed? Also, how would the aerospace industry handle dozens of kilometers of cable?

Still, simulation cannot fully substitute for measurements. There are too many parameters that would have to be considered, and these considerations would result in an immense increase in complexity and calculation time.

## DEMANDS ON SIMULATION TOOLS

Initially, and in principle, we must distinguish between the mechanical and the electrical requirements, although both influence design decisions. The mechanical questions are, for example, where to place components and their corresponding interconnections. A key question is to see whether the placement can be optimized in such a way so that the electromagnetic effect on other systems and the entire cable harness can be reduced to a minimum (Figure 1).

A possible design restriction might be that a cable bundle must not exceed a defined size so as to pass through a special housing or chassis. In other cases, a distinct placement could lead to an immense increase in cable length, a very undesirable result, adding weight and cost. Finally, such investigations must be done with respect to different variants within the cable harness, particularly when a "customer-specific cable harness" has become a standard in the automotive industry (Figure 2).

An investigation of the electrical behavior of a cable harness is slightly more difficult. While modifications on the mechanical side such as changes in the car design or a shifting of components is still possible, the EMC engineer must already have made decisions regarding signal integrity, susceptibility and alternating effects between the system components. In this situation, the engineer must refer to an existing mechanical environment to judge a given design so as to derive general rules from the electrical investigations that influence the harness design. In this respect, the surrounding metal sheets play an important role as they influence the signal behavior of the cable harness significantly (Figure 3).

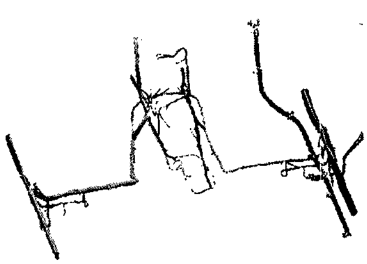

***Figure 1. Part of a cable harness in the CAD tool CATIA.***

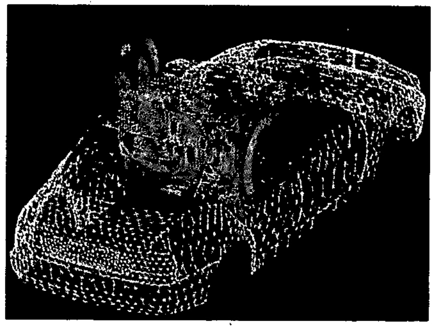

***Figure 2. Radiation calculation with respect to chassis.***

In short, it is not possible to separate the mechanical and electrical investigations; instead there must be efficient data exchange between both of these areas. Ideally, the problems of data exchange should be solved before any prototype exists. Thus, effective simulation requires:

- Interfaces to commonly used CAD tools (*e.g.*, CATIA E3D, Unigraphics UG Harness, SDRC Ideas3D, etc.) to guarantee a mechanical data exchange
- Automatic and statistical placement of cables and lines in the cable harness for evaluating chance or repeated simulations of the entire cable bundle
- Series investigations (parameter variation) to evaluate the mechanical and electrical production tolerances
- Monte Carlo analysis to analyze the mutual influence of several parameters and to drive behavioral models of complex systems
- Analysis in both the time and frequency domains to offer the most suitable simulation methods in a given situation
- Import and export of SPICE/ Saber equivalent circuits to investigate the influence of components on the cable harness and vice-versa
- Information on current density and voltage distributions as well as the influence of radiation and irradiation on system behaviors
- Determination of input impedances, S-Parameters (Touchstone format) and creation of equivalent circuits to receive a system description relevant for comparison with measurements (Figure 4).

For a typical cable harness simulation, first the 3-D cable harness (bundling) is subdivided into equivalent 2-D cross section geometries. These cross sections include many variations of cable wires and cable bundles. Next, the cable cross sections are subdivided into single segments (partitioning), whereby a transmission line analysis is completed, resulting in L, C, R, and G matrices. These are then compiled into a model for an equivalent circuit current calculation. Different types of simulations with variations in both the mechanical and the electrical aspects of the cable result in the process starting over (variation). The final analysis is a 3-D, full wave analysis, with one, many, or all of the results from the previous steps.

## TYPICAL APPLICATIONS

Most of the points listed above are already incorporated into the simulation program. In addition, the program also contains further functions that are important for cable harness studies. These points will be explained with the following application examples.

### CASE A

In order to reduce cost and weight, a cable harness supplier wishes to integrate different and separately

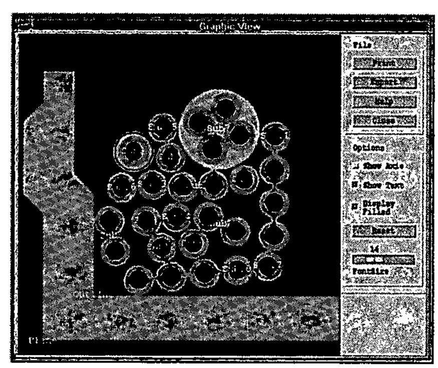

***Figure 3. Cross section of a typical cable bundle.***

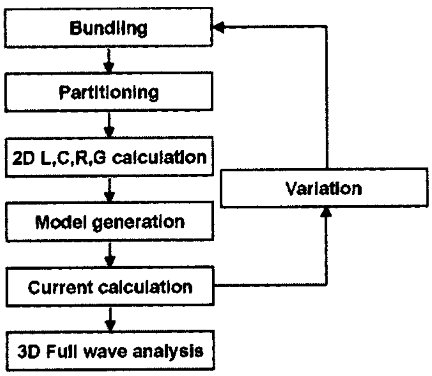


***Figure 4. Flowchart of a typical cable harness simulation.***

laid cables into one single ribbon cable. The position of the single cable wires within the ribbon cable must be optimized first with respect to crosstalk and second, with the influence of different materials on radiation behavior. To complete this task, a current/voltage analysis is done with a typical input signal in both the time and frequency domains in order to expose the mutual disturbances. Finally, a radiation simulation of the cable prototype is analyzed with virtual stripline measurement as used in the automotive industry. By comparing the results with the given threshold values, a decision can be made as to which cable variant is the most suitable for production.

### Case B

There are several possibilities for cable laying within a housing. In this case, an investigation is done to determine which route fits the requirements regarding susceptibility. For this purpose, the housing geometry is imported by means of an interface to a mechanical CAD system in the Nastran format. Finally, the different laying paths of interest are created manually with the software or by import of a Nastran file. With a current/voltage analysis completed, and consideration of the external radiation sources included within the simulation, the cable path in the housing can now be optimized.

### Case C

The board voltage in the automotive industry will be increased from 12 V to 42 V, in order to shrink cable cross sections, space, and other production costs. As a consequence, the current can be reduced while keeping the power the same. By varying the thickness of the insulators, the diameter of the conductors or the conductivity, as well as the permittivity, the corresponding parameters can now be correctly adopted by the cable manufacturer for the reduced physical dimensions.

### Case D

The overwhelming variants in cable manufacturing make it impossible to systematically analyze all relevant parameters. Besides production tolerances for materials, there are additional tolerances regarding cable bundle cross sections and variances regarding distance to neighboring ground planes. Nobody can estimate the exact cross section of a cable bundle exactly with respect to its position in a housing or a chassis; but a suitable procedure exists (the Monte Carlo analysis) to approximate the signal behavior of a complex cable harness with respect to production tolerances. At the same time, other parameters can be varied, both in defined ranges and randomly, resulting in a characteristic histogram (probability distribution) that allows, for example, the analysis of voltage crosstalk between selected conducting lines. By simply using a mouse click, the underlying system arrangement, belonging to a specific simulation, can be viewed, which allows the user to uncover system configurations that must be avoided with respect to EMC requirements (Figure 5).

### Case E

In order for industry to reduce the time-to-market of a new product, the prototype and testing phases are continually being shortened. The solution to this reduction, therefore, focuses more and more on the pre-development phase in which the cooperation between different system components must be defined and proved. In contrast to earlier production techniques, a parallel development process is now replacing a serial production process. This means that data exchange must be obtained via software analysis since prototypes or measurements are increasingly scarce. By utilizing different interfaces, it is possible to import geometrical and electrical data into a simulation tool and to react quickly with potential modifications. Behavioral models of electronic components (*e.g.*, in IBIS format) are of special interest because they enable investigations and verifications in the development process, beginning with IC development and culminating in the integration of complex systems

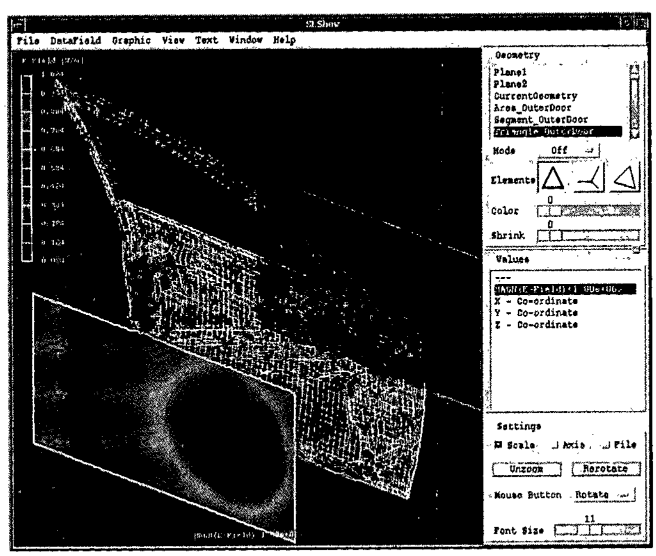


***Figure 5. Radiation of a cable bundle in a car door.***

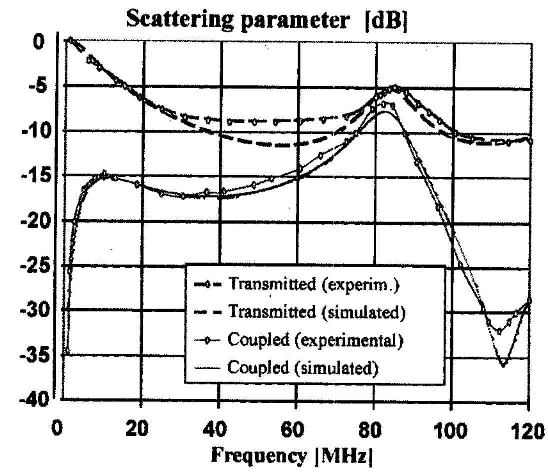


*Figure 6. Comparison measurement/simulation.*

(*e.g.*, complete vehicles). Another possibility is to create an equivalent circuit of the cable harness in SPICE or Saber syntax that can be used, *e.g.*, for PCB simulations.

In the final analysis, the use of simulation tools enables early investigations during the process phases of development, without the need for prototypes. This investigation early in the design process leads to both an enormous increase in product development and also to an optimization of these new products. These processes reduce development time and costly redesigns (Figure 6).

## OUTLOOK

The ongoing trend in industry—especially in the automotive industry—is a full integration of simulation during the design and development processes. The needed data (geometry, materials, etc.) can be stored in customer specific databases, for the other departments' disposal. In addition, suppliers are often asked to offer alternatives to existing designs and to prove them with measurements and simulation. The industry expects that these new designs will have both scalability and upgradability for future enhancements. With these design methods, the industry can react faster to new technologies (ribbon cables in the automotive industry), functionality (multimedia) and concepts (bus systems for data transfer).


***Matthias Troescher** received the Diploma in physics from the Technical University, Munich and a Ph.D. degree in Engineering Sciences from the Johannes Kepler University, Linz, Austria. He has been responsible for publications, technical support and product development for SimLab Software GmbH in Munich, Germany since 1999.* ■


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