

CREATING ACCURATE SIMULATION MODELS FOR ARTIFICIAL NETWORKS FROM MEASUREMENT DATA

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Abstract. A method for modeling an artificial network for automotive applications or a similar device in the frequency range from DC to 1 GHz is proposed. A passive equivalent circuit model, valid in the low frequency range, is combined with a high frequency model. The high frequency circuit model is determined by the deviation in impedance between low frequency circuit model and measurement data. The difference is approximated by vector fitting and an equivalent circuit model is created. The developed model is valid for both frequency and time domain simulations.

Introduction

Nowadays in automotive electronics the complexity of electronics systems rapidly increases. System reliability has especially high priority. Designed components are tested in many possible application environments. In automotive electronics external electromagnetic interference is one critical factor for reliability of ICs.

In order to characterize the behavior of ICs under external electromagnetic interference, several test methods have been standardized. Widely used are the Direct Power Injection (DPI) method [1] for ICs and Bulk Current Injection method for ICs [2] and systems [3]. Virtual RF immunity tests could predict the immunity of the designed IC during the early design stage. Thus possible design problems can be found on early design stages, and the costly redesign procedures can be avoided. Several approaches for virtual RF immunity tests were introduced [5-6].

In many test and measurement configurations an artificial network (according to standard CISPR 25 [4]) is used as a laboratory representation of the vehicle cable network. The artificial network (AN) is used for several purposes. Termination of the cable harness with a standardized load and supplying a measurement port for the RF signals at the cable harness are the most important ones. The device properties are specified in automotive EMC standards up to 108 MHz. Practically the immunity tests and measurements are often performed up to much higher frequencies, e.g. 1 GHz, and the available artificial networks are used in these tests. To obtain accurate results of the virtual test or measurement a simulation model of this device is necessary.

The paper proposes a fast and accurate modeling approach for artificial networks and similar devices. A passive equivalent circuit model is combined with numerical approximation in order to provide good accuracy in the entire range from DC to 1 GHz.

Artificial Network

The artificial network is a laboratory representation of the vehicle cable network. According to the standard it has the circuit as shown in fig. 1.

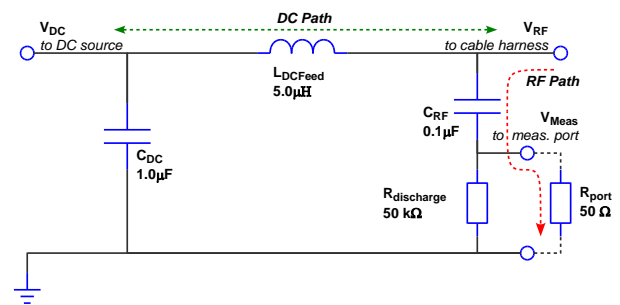


Fig. 1 Common circuit of an Artificial Network

The DC current is supplied into the cable harness through an inductance of min. 5 μ H. A capacitance of 0.1 μ F couples the RF port (V_{RF}) to the measurement port (V_{meas}). This assures the input impedance seen by cable harness to be 50 Ω in the RF range. Thus the artificial network works as a DC feed, an RF termination and a measurement unit simultaneously.

In many applications two artificial networks are used in parallel to provide a defined supply voltage and ground connection to the DUT (see fig. 2). In these cases it is quite common, that two artificial networks are combined together in a single 6-port package. In current investigation a similar artificial network is analyzed.

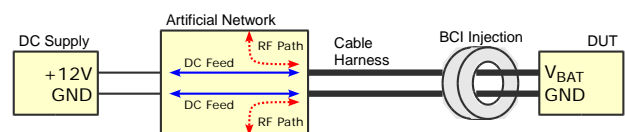


Fig. 2 Common application of an artificial network

VNA Measurements

The artificial network was characterized with an Agilent Vector Network Analyzer in the range of 300 kHz to 1 GHz. Two S-parameter sets, each of 3 ports, were measured for "left" and "right" channels correspondingly. The measurements have not shown significant difference between the two channels, thus they were assumed to be equal.

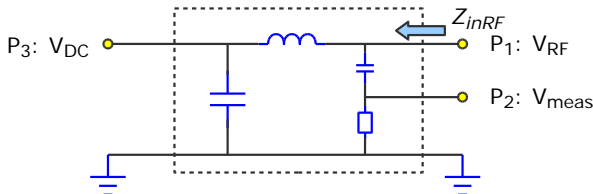


Fig. 3 VNA measurement port assignment

The measured input impedance of the RF side is shown in fig. 5. The expected 50 Ω value was observed up to 108 MHz, as specified in the standard. As expected, the characteristics above 108 MHz were exceeding the specified limits due to the internal resonances. Similar problems were observed for the transfer functions (e.g. S21 or S31).

Passive equivalent circuit model

The first step to create the model of the device is to update the ideal circuit model with most possible parasitic elements and to optimize their values.

The ferrites in the inductors usually show the decrease of the magnetic permeability above frequencies of approx. 10 MHz. The resulting impedance of such an inductance can be efficiently modeled with a parallel RLC circuit. The capacitors usually have an equivalent serial resistance and inductance (ESL and ESR). Moreover, each port adds its own parasitic inductance and capacitance to the AN model.

All these properties are added to the circuit as passive elements (see fig. 4). Manual optimization of the parameters is performed to obtain the best fitting in terms of S-parameters. With passive circuit approach the accurate fitting can be easily obtained up to the frequencies of 100 MHz (see fig. 5).

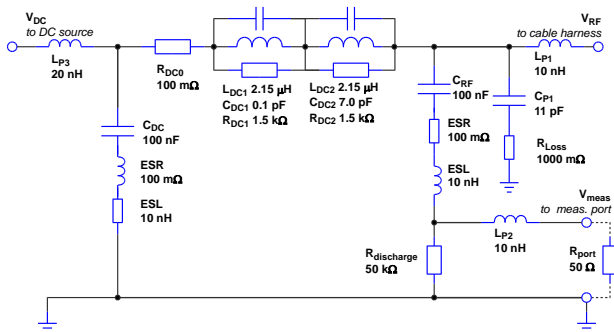


Fig. 4 Passive equivalent circuit model

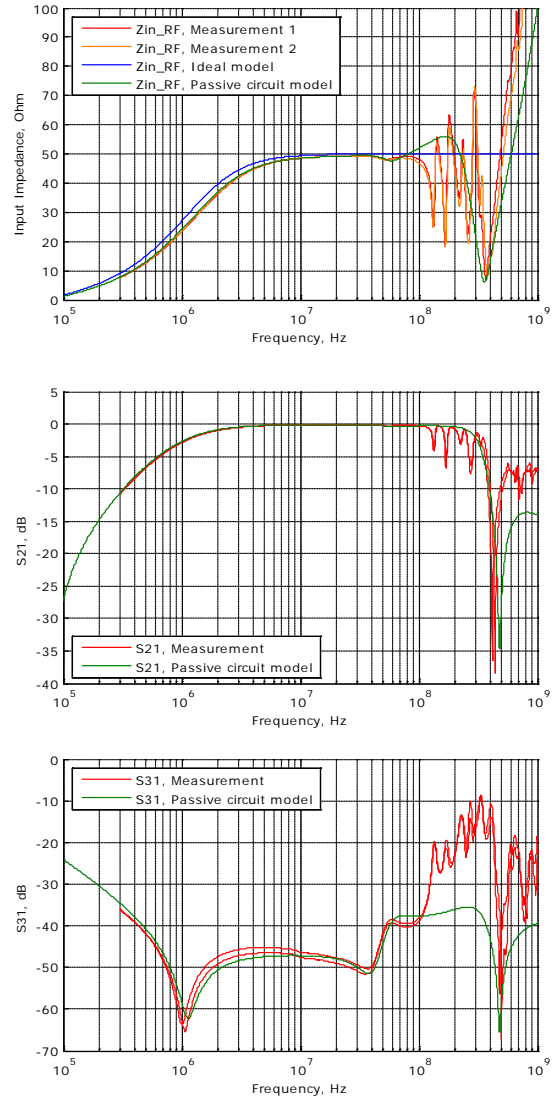


Fig. 5 Input impedance and transfer functions, measurement vs passive circuit simulation model

The passive equivalent circuit model is extremely simple and fast in simulation. However, direct extension of the model up to 1 GHz is not possible, since the amount of circuit elements and parameters will grow significantly. To extend the passive circuit model to higher frequencies the following approach is proposed.

Model Deviation

The simulation and measurement results are converted into Y-parameters and the deviation dY between the model and measurement is calculated directly as

$$dY = Y_{MEAS} - Y_{SIM}$$

Physically, this deviation represents the lacking part of the currents in the model for any voltages at the ports. If we introduce these additional currents into the circuit by e.g. connecting the behavioral Y-parameter black-box in parallel to the main passive circuit, we would obtain ideal fitting to the measurements.

This can be easily done with some circuit simulation software which can handle behavioral models directly. Not all of the circuit solvers can handle the Y-parameter black-boxes models directly. Thus, the data must first be converted into another representation.

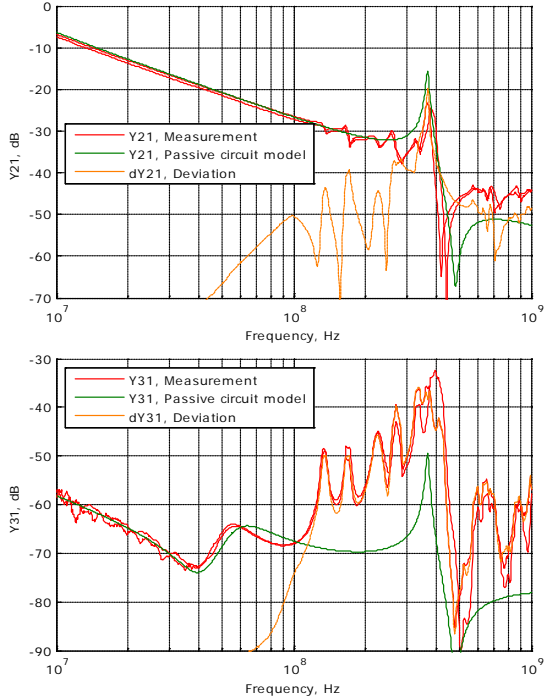


Fig. 6 Model deviation above 100 MHz as Y-parameters

Vector Fitting and State-Space Modeling

The rational approximation of the Y-parameter dataset can be performed with Vector Fitting algorithm [7] implemented in Matlab. The resulting approximation is a State-Space model of the following type:

$$x' = A \cdot x + B \cdot v;$$

$$i = C \cdot x + D \cdot v;$$

where v is the vector of port voltages (input quantities), i is the vector of port currents (output quantities), x is the vector of internal states, and A , B , C , D are the coefficients matrices, which are obtained as the result of vector fitting approximation.

The State-Space model can be implemented as an equivalent circuit solution, where the internal x -states are modeled with voltages v_{xi} at the x_i nodes, and the quantities v_i , x_i and i_i interact through the R , C and G SPICE devices.

The sample circuit implementation of a second order model (two internal states, x_1 and x_2) for a two-port device (two ports, v_1 , v_2 , i_1 , and i_2) is shown in fig. 7. For devices with more ports or higher model orders the amount of the components will increase proportionally.

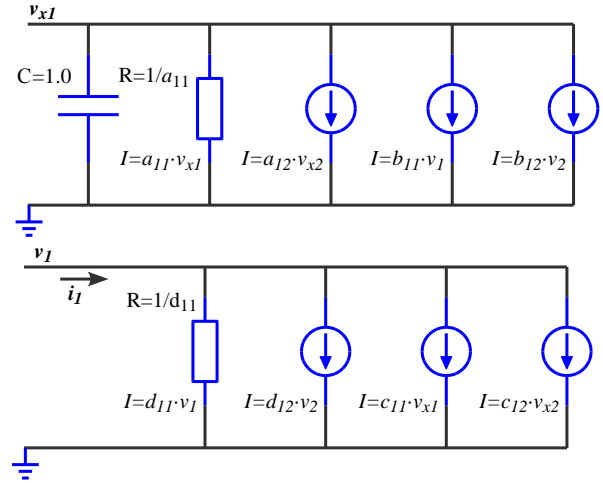


Fig. 7 Equivalent circuit implementation of a State-Space representation
a) state x_1 implemented as voltage v_{x1}
b) current i_1 and voltage v_1

This equivalent circuit representation can then be included as a netlist into the simulation models in any circuit simulation software. The implementation is valid for both frequency- and time-domain, assuming that the approximation fitting to the initial data is accurate in the specified range.

Now, the Y-parameter deviation (dY) between initial passive model and measurement is approximated with vector fitting and implemented in a circuit solution.

The discussed dY dataset was explicitly controlled before the approximation so, that the Y-parameter curves tend to zero below 100 MHz. This assures that the resulting circuit solution with the vector fitting approximation will have no influence on the external circuits at frequencies below 100 MHz.

For the verification purposes the circuit solution with the approximated Y-parameter dataset is simulated separately. The results are shown in fig. 8.

The passivity of the vector fitting approximation is a significant question, and is discussed in multiple researches. Here the passivity of the developed model is verified with an additional S-parameter simulation.

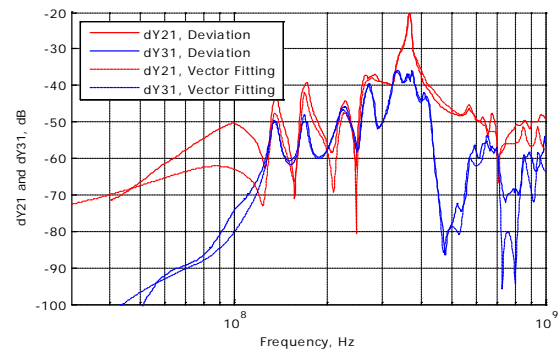


Fig. 8 Vector Fitting results

Final Equivalent Circuit Model

The developed circuit with approximated block for model deviations is connected in parallel to the initial passive circuit model. Thus the lacking part of impedances in the range above 100 MHz is provided and high modeling accuracy is obtained up to 1 GHz.

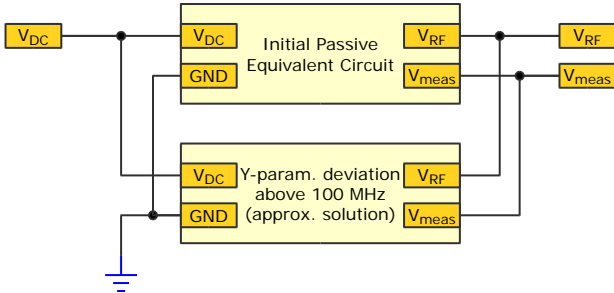


Fig. 9 Final model consisting of passive circuit model and approximated solution for Y-parameter deviation

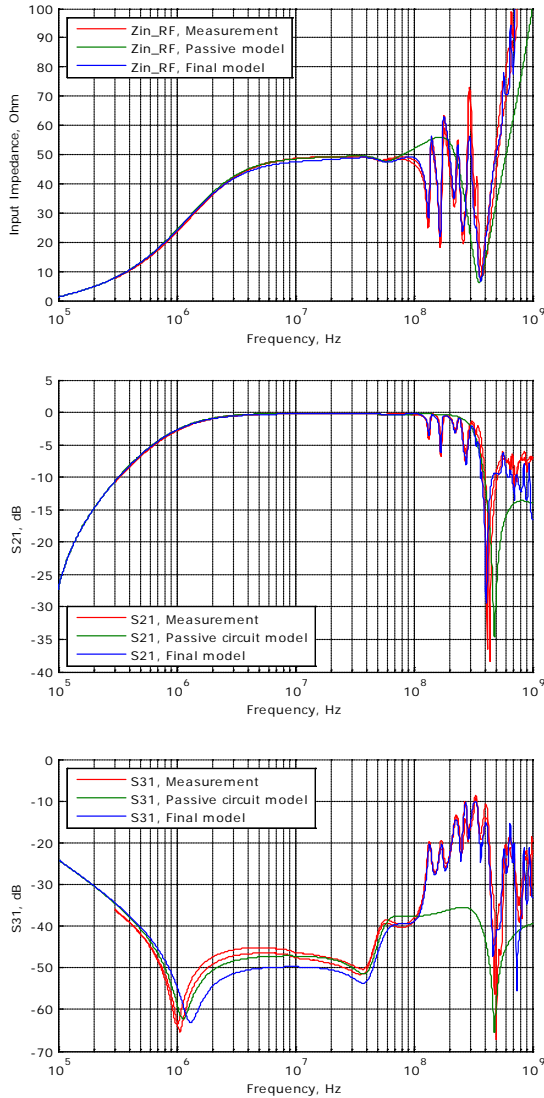


Fig. 10 Final modeling results: S_{21} , S_{31} and Z_{inRF}

Since the Y-parameters of the approximation tend to zero below 100 MHz, the functionality of the main passive circuit below 100 MHz is not affected. The proposed approach shows good accuracy in the entire frequency range from DC to 1 GHz, both in Y-parameter and S-parameter representation.

The developed model can be used in any virtual EMC test and measurement configuration. Accurate modeling of the transfer functions and input impedance of the artificial network up to 1 GHz ensures the accuracy of virtual test results and thus significantly increases the virtual test reliability.

Conclusions

A method for modeling an artificial network in the frequency range from DC to 1 GHz is proposed. A passive equivalent circuit model valid in the low frequency range is combined with a circuit implementation of a numerical approximation. The model is valid for frequency- and time domain simulations. The simulations show good agreement with the measurements in the range from DC to 1 GHz.

Literature

1. IEC 62132-4: Integrated circuits - Measurement of EM immunity, part 4: Direct RF power injection.
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