LC-filter Simulation Using Multi-resonance Models of Components at Frequency Range up to 40 GHz

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Abstract—Relevance of simulation of electromagnetic compatibility tests for critical, in particular, military and space equipment is justified. To execute this for printed circuit boards, the models taking into account the parasitic parameters of components are required. Simulation results for frequency characteristics of the LC-filter consisting of surface mount components are shown. Comparison with results of measurements is executed. It is shown that in the range of 0.01–13.5 GHz the root-mean square error for reflection coefficient is 0.248.

Keywords—model synthesis, passive component, EMC, virtual testing, S-parameters, PCB

I. INTRODUCTION

One of the important manufacture stages of the critical radio-electronic equipment (power supply, life support, security and industrial control systems; military, space, aircraft and medical equipment; telecommunication, computing and financial high-loaded services; robotics) is carrying out comprehensive tests for ensuring high reliability. Mutual interference of equipment is increasing because of increase in the number of the simultaneously working electronic devices; spreading of wireless interfaces; micro- and nano- satellites, wearable devices and Internet of Things. It requires more careful tests for electromagnetic compatibility.

For example, military equipment needed to be tested in the frequencies up to 40 GHz and up to 100 GHz are recommended [1]. Requirements of the standard for the onboard equipment of spacecrafts are similar [2]. Signals at these frequencies are strongly influenced by the parasitic parameters of the components [3] and the inhomogeneities of printed-circuit boards (PCB) [4]. Unfortunately, detection of problems in the testing stage requires clarification of reasons, development of the solution and modification of design of board or circuit that takes a lot of time and demands changes of the project documentation. Therefore, it is proposed to transfer the test to the design stage, and to use the virtual tests [5]. However for this purpose the multi-resonance models, taking into account the parasitic parameters of components in a wide frequency range, are necessary.

A large number of methods of models synthesis from data of measured frequency dependence of parameters (for example, analytical approach [6], approximation by a rational function [7], structural-parametric optimization using genetic programming [8]) are developed. The main disadvantage of the known methods and the models provided by the vendors – the description of the components behavior in the first resonance region. During a number of studies [9] this problem was solved by the authors by developing and testing the techniques of multi-resonance models synthesis.

The following step, application of the synthesized models for the analysis of the frequency responses of the filter was discussed in [10]. However, it does not give a complete description of a measurement and simulation technique and the analysis of the results.

The aim of this study is to present a summary of the preliminary results for LC-filter simulation using multi-resonance models of components in the frequency range of 0.01–40 GHz.

II. MEASUREMENT AND SIMULATION TECHNIQUE

The filter was simulated using the following technique: 1 – measurement of S-parameters for the PCB with calibration standards and filter; 2 – calibration according to the TRL (Thru-Reflect-Line) algorithm; 3 – generating of filter model; 4 – calculation of the filter response; 5 – comparison of the simulation and measurement results.

The considered LC-filter consists of the GRM21BR71H224K capacitor and LQW2BHN33NJ03 inductance (Fig. 1). To measure the filter’s characteristics we manufactured two-layer PCB (Fig. 2) consisting of the FR-4 dielectric with thickness of 0.93 mm (microstrips with copper foil thickness of 35 µm and width of 1.85 mm).

![Fig. 1. Filter’s simulation circuit](image-url)
The model of each component was synthesized by the following technique [10]: 1 – development and manufacture of a set of test PCBs, processing of PCBs and soldering of components; 2 – measuring of calibration boards, computation of errors matrix and calibration of the instrument; 3 – assessment of calibration correctness; 4 – measurement of the S-parameter frequency dependence of a component soldered to the measuring board; 5 – verification of the measurement results; 6 – calculation of the impedance \( Z \) from reflection coefficient \( S_{11} \); 7 – subtracting the load resistance from \( Z \); 8 – approximating of the \( Z \) frequency dependence by rational function by vector fitting technique; 9 – expansion of a rational function on partial fractions; 10 – representing of partial fractions by the equivalent circuits via circuits synthesis methods; 11 – generating of total SPICE-model; 12 – verification of a model.

The model of the capacitor consists of the 22 circuits (Fig. 3), and inductance of 16. The filter is simulated in TALGAT system. The calculation of the \( S_{11} \) and transmission coefficient \( S_{21} \) was executed by the formulas

\[
S_{11} = 2 \cdot U_1 - 1, \quad (1)
\]

\[
S_{21} = 2 \cdot U_2. \quad (2)
\]

Formulas are obtained taking into account that \( V_{\text{SN}} = 1 \) V.

III. SIMULATION RESULTS

The results of simulation and measurements for \( S_{11} \) and \( S_{22} \) are shown in Fig. 4 and 5, and the values of the root-mean square error between the simulation results and measurements for the filter are shown in Table I.
TABLE I. ROOT-MEAN SQUARE ERROR BETWEEN THE SIMULATION AND MEASUREMENT DATA

<table>
<thead>
<tr>
<th>$f$, GHz</th>
<th>$S_{11}$</th>
<th>Arg($S_{11}$), °</th>
<th>$S_{21}$</th>
<th>Arg($S_{21}$), °</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.01–1.5</td>
<td>0.107</td>
<td>15.7</td>
<td>0.78</td>
<td>87.4</td>
</tr>
<tr>
<td>0.01–13.5</td>
<td>0.248</td>
<td>72.1</td>
<td>2.147</td>
<td>94.4</td>
</tr>
<tr>
<td>0.01–40</td>
<td>0.903</td>
<td>67</td>
<td>1.705</td>
<td>86.4</td>
</tr>
</tbody>
</table>

It can be seen from the figures and a table that the accuracy of the filter model for the $S_{11}$ is sufficient only in the range under 13.5 GHz. Taking into account the phase mismatch at frequencies above 1.5 GHz, we can suggest that it is necessary to take into account the effect of connecting of microstrips. Significant difference for $S_{21}$ is likely explained by the fact that the models of components are synthesized using only the $S_{11}$.

IV. CONCLUSION

LC-filter simulation taking into account parasitic parameters of components through multi-resonance models of components in the range of 0.01-40 GHz is executed. Models of components are obtained with respect to measurement results. Comparing of the simulation results with the measurement showed that the reflection coefficient acceptably matches in the frequency range up to 13.5 GHz. For more accurate results up to 40 GHz additional investigations are necessary.

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REFERENCES


