Application for Fast Determination of Inductor's Electrical Characteristics from S-parameters

Č. Žlebič, N. Blaž, A. Menićanin, Lj. Živanov, and M. Damnjanović

Abstract - This paper presents an application "IndCalc" for calculation of surface-mounted devices (SMD) inductor parameters, extracted from measured S-parameters. It simplifies characterization and provides reliable procedure for determining SMD inductor's parameters in a wide frequency range up to several GHz. In order to present developed application and its validity, commercially available components in their printed circuit board (PCB) environment are measured using Agilent vector network analyzer E5071B.

I. INTRODUCTION

RF chip inductors are an integral part of many tuning and filtering circuits and are mainly used in the RF circuits in electronics systems. With a small footprint and rugged construction, they provide a cost-effective solution for densely packed PC board designs that are found in RF and wireless communication, computers and automotive electronics applications. The operational frequencies of electronics products are constantly increasing, and the products that incorporate RF circuits into board-level designs are more and more popular, like cell phones, the application of RF chip inductors has seen a wide and rapid growth [1].

There is a natural tradeoff between performance, size, and cost that must be considered when selecting an inductor for a design. As a result, manufacturers produce many series of similar inductors, allowing engineers to select a component well suited for their applications. In the case of inductors, knowing the options enables an engineer to choose a component that not only satisfies a circuit electronically, but also improves its overall performance. In that manner, the aim of this work is to develop application that quickly and accurately converts the measured results into electrical parameters of interests.

The proposed application is named "IndCalc". It enables long extraction procedures to be avoided, and has additional options for saving calculated results in .xls format. That allows designer to easily and reliably characterize SMD components.

Č. Žlebič, N. Blaž, Lj. Živanov, and M. Damnjanović are with the Department of Electronics at the, Faculty of Technical Sciences, University of Novi Sad, Trg Dositeja Obradovića 6, 21000 Novi Sad, Serbia, E-mail: cedoz@uns.ac.rs

A. Menićanin is with the Institute for Multidisciplinary Research, University of Belgrade, Kneza Višeslava 1, 11000 Belgrade, Serbia, E-mail: aleksandar.menicanin@ieee.org

II. EQUIVALENT INDUCTOR'S MODEL

The "IndCalc" application is based on model of SMD component which can be presented as a two-port equivalent circuit. It consists of series resistance R (which includes SMD package and inductor losses), capacitance C (which represents the self-capacitance of inductor package), and equivalent inductance L (Fig. 1a). Extrinsic model includes parasitic effects (modeled with parasitic capacitance C_P and resistance R_P), which appear after mounting SMD component on the PCB (Fig. 1b) [2].

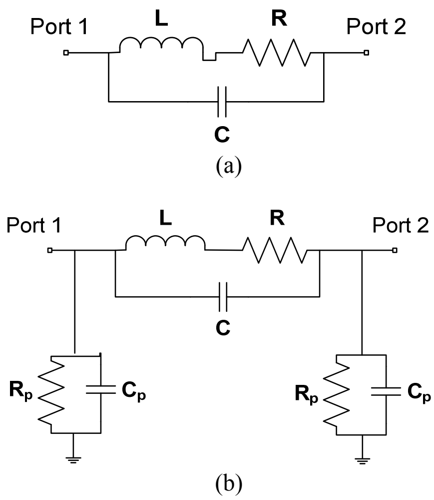

Fig. 1. The Equivalent model of inductor: (a) two-port intrinsic equivalent circuit. (b) two-port inductor model with intrinsic and extrinsic parameters.

Series impedance Z and shunt admittance Y_P of equivalent circuit (Fig. 1b) are determined as

$$Z = \frac{R + j\omega L}{1 - \omega^2 LC + j\omega RC}, \tag{1}$$

$$Y_P = G_P + j\omega C_P, \tag{2}$$

where $G_P = 1/R_P$ represent shunt conductance [3]. From (1), following expression can be derived:

$$Z(\omega) = \frac{R + j\omega L^2 C(\omega_0^2 - \omega^2)}{(1 - \omega^2 LC)^2 + (\omega RC)^2}, \tag{3}$$

where $\omega_0 = 2\pi f_0$, and f_0 is resonant frequency. Q factor is calculated from the 3 dB impedance bandwidth $\Delta\omega$, as

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$Q = \omega_0 / \Delta\omega$. After transformation, self-resonant frequency ω_0 and Q factor are calculated as

$$\omega_0 = \frac{1}{\sqrt{L_0 C}} \cdot \left(\frac{Q^2}{1+Q^2} \right)^{1/2}, \quad Q = \frac{\omega L}{R}. \tag{4}$$

Relationship between impedance Z, admittance Y_P and S-parameters is given by *ABCD* matrix

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} ZY_P & Z \\ Y_P(ZY_P+2) & ZY_P+1 \end{bmatrix}, \tag{5}$$

where *ABCD* matrix represents measured *S*-parameters through next transformations

$$A = \frac{(1+S_{11})(1-S_{22}) + S_{12}S_{21}}{2S_{21}}, \tag{6}$$

$$B = \frac{(1+S_{11})(1+S_{22}) - S_{12}S_{21}}{2S_{21}}. \tag{7}$$

There are two independent parameters in the chain matrix, because the model of inductor is presented with the reciprocal network ($S_{11} = S_{22}$ and $S_{12} = S_{21}$), and from this follows

$$Z(\omega) = B(\omega), \tag{8}$$

$$Y_P = \frac{A(\omega) - 1}{B(\omega)}. \tag{9}$$

Knowing Y_P from (9), the shunt conductance and capacitance using (2) can be calculated as

$$G_P = \mathrm{Re}(Y_p), \qquad C_P = \frac{\mathrm{Im}(Y_p)}{2\pi f}. \tag{10}$$

From (3), after calculation, the resistance and inductance are determined as

$$R(\omega) = \frac{Z_r(\omega)}{\left[1 + \omega C Z_i(\omega)\right]^2 + \left[\omega C Z_r(\omega)\right]^2}, \tag{11}$$

$$L(\omega) = \frac{Z_i(\omega) + \omega C \left|Z(\omega)\right|^2}{\omega\left[\left(1 + \omega C Z_i(\omega)\right)^2 + \left(\omega C Z_r(\omega)\right)^2\right]}, \tag{12}$$

where Zr and Z_i represent real and imaginary part of impedance Z.

III. Setup And Results of Measurement

Measurements are performed using Agilent vector network analyzer (VNA) E5071B and adaptation test fixture on PCB with attached SMD component which is characterized. Based on imported *S*-parameters and initiated special developed algorithm, by pressing "Import & Calculate" button at the left top of interface, application produce as final results, six diagrams with values of real and imaginary parts of impedance Z, inductance L, resistance R, Q factor and shunt conductance G_p and capacitance C_p in the relation to the frequency of the SMD inductor (Fig. 2).

Menu of application placed on the top left corner of interface, offers saving results in .xls format, pan around, searching the specific points and zoom in and zoom out of the obtained diagrams. To be sure that the correct file is imported, its name is also presented.

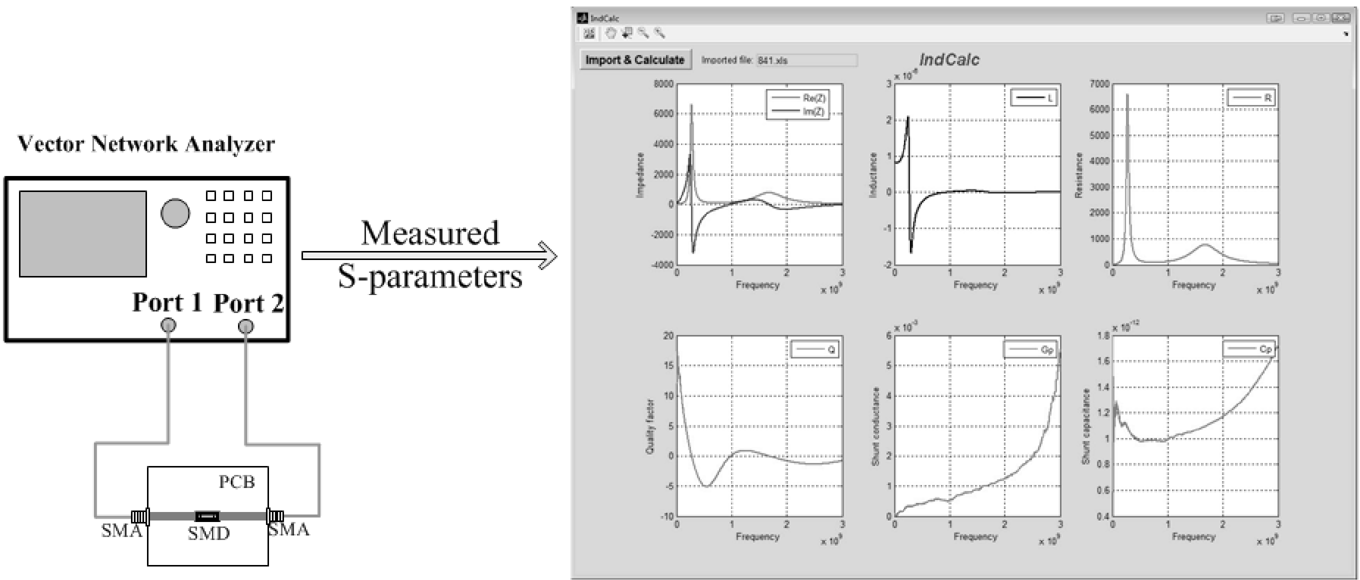

Fig. 2. Principle of determining SMD inductor parameters from measured *S*-parameters using VNA E5071B and developed interface of IndCalc application.

In order to present principle of simulation tool, two commercially available RF chip inductors produced by Coilcraft, are characterized (0603AF-241XJR_ and 0603AF-821XJR_) [4]. Because of clarity, and because this model of inductor is presented with the reciprocal network, in Fig. 3 are shown measured S_{11} and S_{21} parameters of 0603AF-821XJR_ component. Measured and calculated values of real and imaginary part of impedances of both characterized component are presented in Fig. 4, resistance *R*, *Q* factor and inductance *L* are presented in Figs 5 to 7. Shunt conductance and capacitance are shown in Fig. 8.

As it can be seen from Fig. 4, the real part of impedance of the 0603AF-241XJR_ inductor reaches 2.6 kΩ at the self-resonant frequency f_0 = 970 MHz, while the real part of impedance is approximately 6.65 kΩ at the self-resonant frequency which is 283 MHz.

The resistance of SMD inductors (Fig. 5) at resonant frequencies is nearly 2.6 kΩ for 0603AF-681XJR_ inductor and nearly 6.7 kΩ for 0603AF-471XJR_ inductor due to increased power dissipation in the ferrite core. The calculated *Q* factors of SMD inductors are shown in Fig. 6. The Coilcraft catalogue value of Q factor is 15 for 0603AF-241XJR_ inductor, and 16 for 0603AF-821XJR_ at 7.9 MHz. As it can be seen from these figures, calculated Q factor for the first inductor at 7.9 MHz is 14, and for the other is 12. Deviation from the values given by the manufacturer is greater for the second inductor, (12 instead of 16), compared to 6 % for the first inductor(14 instead of 15).

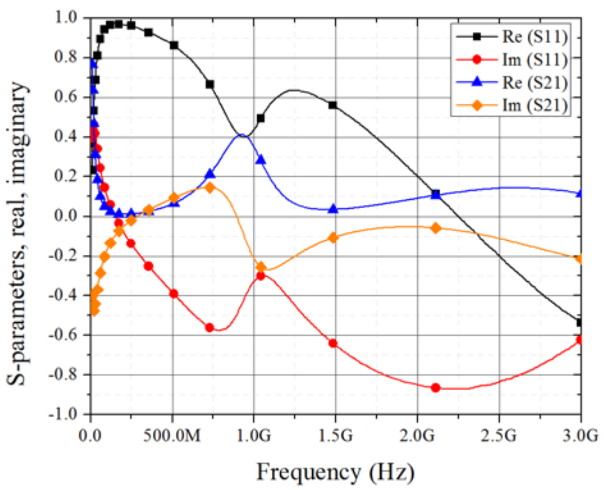

Fig. 3. Measured S-parameters of the SMD inductor 0603AF-821XJR_.

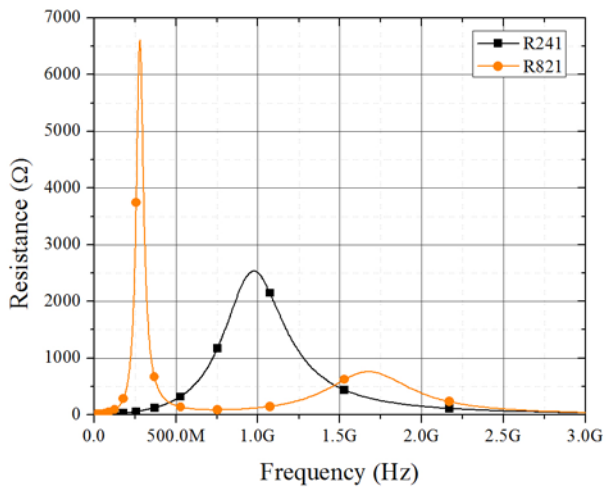

Fig. 5. Calculated resistance of the SMD inductors 0603AF-241XJR_ and 0603AF-821XJR_.

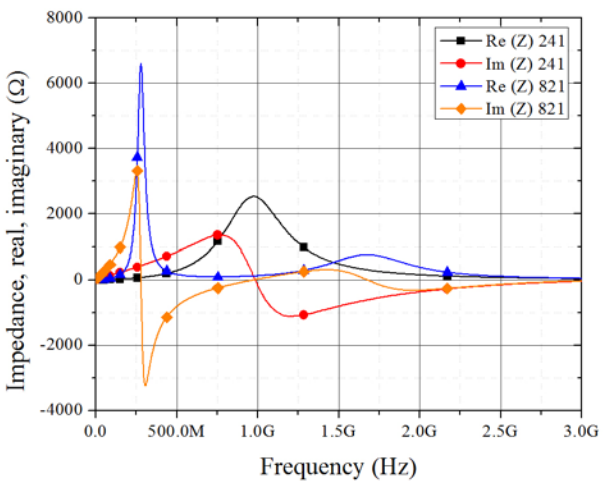

Fig. 4. Real and imaginary parts of the impedance of the SMD inductors 0603AF-241XJR_ and 0603AF-821XJR_.

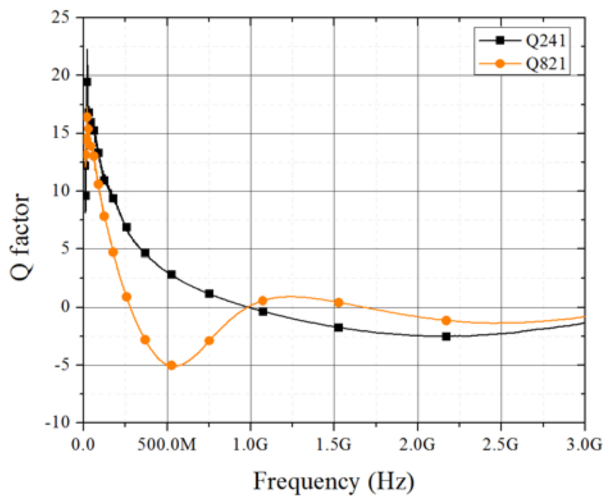

Fig. 6. Calculated Q factor of the SMD inductors 0603AF-241XJR_ and 0603AF-821XJR_.

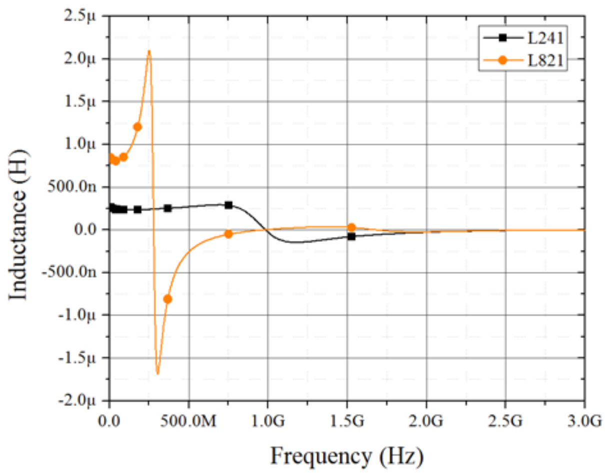

Fig. 7. Calculated inductance of the SMD inductors 0603AF-241XJR_ and 0603AF-821XJR_.

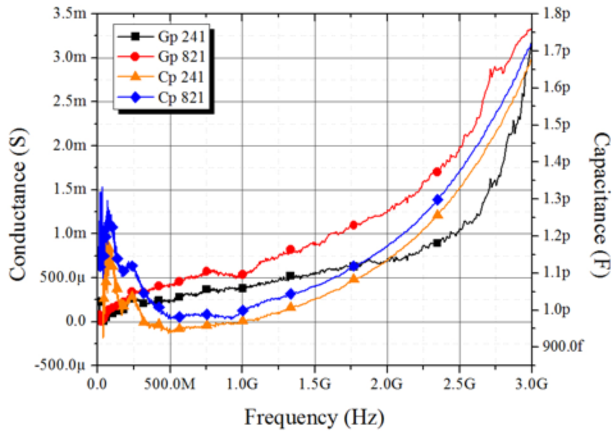

Fig. 8. Shunt conductance and capacitance of the SMD inductors 0603AF-241XJR_ and 0603AF-821XJR_.

Inductances of characterized inductors (shown in Fig. 7) are within the tolerance limit of ± 5 percent, given by the manufacturer. For example, for 0603AF-241XJR_ inductor, value of inductance given by Coilcraft is 240 nH at 7.9 MHz. The inductance determined by “IndCalc” is 235 nH. The datasheet inductance of 0603AF-821XJR_ inductor is 820 nH at 7.9 MHz, while calculated inductance is 833 nH.

The values of shunt conductance of characterized inductors are small, which means that the dielectric losses can be neglected. Values of shunt capacitance for both characterized components are in the range from 1.0 pF to 1.7 pF, over the 3 GHz bandwidth.

IV. Conclusion

In this paper, characterization of standard SMD inductor at RF frequencies based on intrinsic and extrinsic parameters is presented. The equivalent model includes losses occurred by mounting inductor onto the PCB board.

The model of inductor is derived from *S*-parameters measured on VNA using specially in-house developed application “IndCalc”. It is based on mathematical transformation of output signals of VNA (*S*-parameters). “IndCalc” transforms measured values into electrical parameters of SMD inductor.

Verification of proposed application is performed on the example of two commercially available SMD inductors, Coilcraft 0603AF-241XJR_ and 0603AF-821XJR_, since for these inductors the manufacturer did not provide appropriate graphical dependence of the electrical parameters as a function of frequency.

This application greatly facilitates the work of the designers, while selecting appropriate components for their design. In addition, the “IndCalc” application offers to save of the results in .xls format, so the data can be more easily processed. Also, it is possible to searching specific point on diagrams (i.e. pair of points on x and y axis).

Acknowledgement

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