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A standard procedure for implementation and automatic correction of LCC matching networks

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Abstract

A characteristic feature of most Magnetic Particle Imaging and Spectrometry systems is the field generator, an electromagnetic coil that produces the excitation field, which in turn forces the magnetic nanoparticles to produce their unique fingerprint used in imaging and spectrometry. Effective power transfer from the power source to the field generator usually demands for an impedance matching network. Due to component tolerances or environmental conditions, implementation of such an impedance matching can be tedious. Additionally, the impedance matching might change under working conditions caused by e.g. heating of the components and the resulting change in their electrical properties. This contribution aims to firstly present a standard procedure for implementation of an impedance matching network, addressing the difficulties arising from imprecise component values, and secondly a concept for automatic impedance correction if the electrical properties of system components change. To achieve those objectives, it is exploited that the conductance of the matching network is invariant under a change of the parallel capacitance.

I Introduction

Magnetic Particle Imaging (MPI) relies on the generation of alternating magnetic fields [1]. To effectively transfer power from the power source to a field generator MPI hardware typically includes an impedance matching network [2,3]. The field generator's impedance must be matched to the optimal load impedance Z_{src} of the amplifier. Due to imprecise components, the implementation can be tedious. Furthermore, during operation the impedance matching can detune, due to i.e. heating of the components. This contribution addresses both problems by introducing a standard procedure for implementation and automatic impedance correction.

II Material and methods

II.I LCC matching network

The topology of the matching network under consideration is shown in Fig. 1. It consists of the impedance that is to be matched, which in the case of a magnetic field generator is an inductance L_S in series to a resistor R_S. The matching is achieved using two capacitors, hence the name LCC matching network.

The reactance of the series capacitor C_S is given by

$$X_{CS} = \sqrt{R_S}\sqrt{Z_{src} - R_s} - X_{LS}, \qquad (1)$$

while the reactance of parallel capacitor C_P is given by

$$X_{CP} = -\sqrt{R_S}\frac{Z_{src}}{\sqrt{Z_{src} - R_s}} \qquad (2)$$

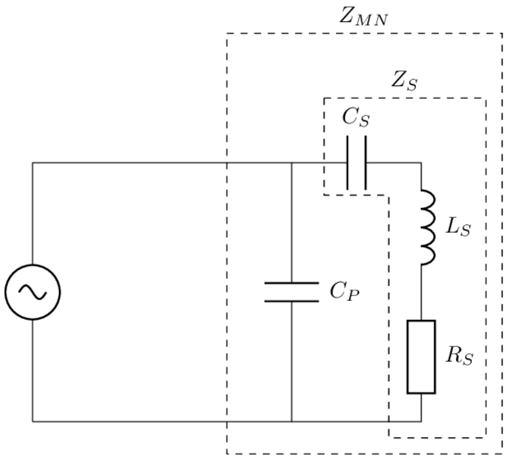

Figure 1: The matching network consists of inductance L_S and resistance R_S, representing the field generator. Adding the series capacitance C_S to the field generator forms the series circuit Z_S. Finally, adding the parallel capacitance C_P results in the matching network Z_{MN}.

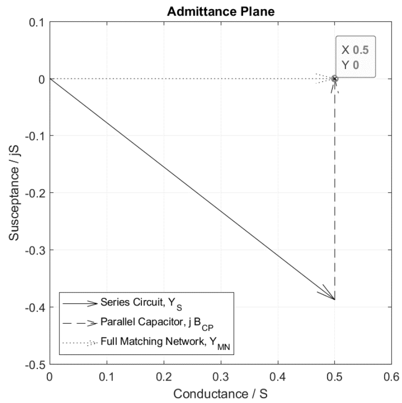

Figure 2: The admittance plane shows the purpose of the series capacitor is to adjust the conductance of the matching network correctly, whereas the parallel capacitor is supposed to eliminate all residual susceptances in the matching network. In this example, the field generator has a resistance of 1.25 Ω and a reactance of 1.25 Ω and is supposed to be matched to 2 Ω, therefore the conductance must be 0.5 S.

and the capacitance values can be obtained from

$$C = -\frac{1}{\omega X}. \tag{3}$$

Although those equations are mandatory in the initial design of an impedance matching network, they are inconvenient in further analyzing the impedance matching network and its components. Essential for understanding the purpose of the matching capacitors is the analysis of the admittances instead of the impedances of components and sub-circuits.

II.II Invariance of conductance

In this section, the purposes of the matching capacitors are discussed. Additionally, the invariance of the matching networks conductance under a change of the parallel capacitance becomes apparent.

In the following discussion, capacitors are assumed ideal and the optimal load for the power source is purely resistive.

In Fig. 2 the admittance plane is shown and it is evident that the series capacitor is adjusting the conductance of the matching network to its proper value given by

$$G_{MN} = \frac{1}{Z_{src}} = \frac{1}{R_{src}}. \tag{4}$$

Since parallel connections of admittances can be represented as vector sums in the admittance plane and C_P is assumed to be ideal and therefore has no conductance, it follows that the conductance can only be adjusted by the series capacitor C_S. The conductance G_{MN} is invariant under change of the parallel capacitor C_P and the parallel capacitor can only eliminate residual susceptance.

II.III Matching procedure

Following the discussions of section I it is straightforward to propose the following two-step standard procedure for impedance matching.

1. Change the series capacitor until the conductance of the matching network G_{MN} equals the reciprocal of the optimal load impedance of the power source Z_{src}, which is assumed to be purely resistive.
2. Change the parallel capacitor until the reactance B_{MN} of the matching network vanishes.

Note that this procedure does not rely on the knowledge of any component values, but only on properties of the whole matching network, which can be obtained by measuring voltage and current of the matching network. Thus, this procedure is suitable for automation when using variable capacitors. However, capacitance ranges of variable capacitors are typically quite small which prevents full automation of the process but are sufficient to correct small changes of electrical properties in the field generator due to e.g. heating. The capacitance range can be extended by using switched capacitor arrays as proposed in [4], however, huge efforts arise from such an extension. To verify the automatic impedance correction a testbed was implemented. Fig. 3 shows the testbed and its components. At its core a StemLab board (RedPitaya d.d.) is working as signal generator and data acquisition unit. Variable capacitors (Oren Elliot Products Inc.) are driven by a NEMA17 stepper motor and a “Silent Stepper Brick” (Tinkerforge GmbH). To extend the capacitance range a self-made switched capacitor array, switched by an “Industrial Dual Relay Bricklet” (Tinkerforge GmbH), is used. The field generator is a lab-made coil, which is

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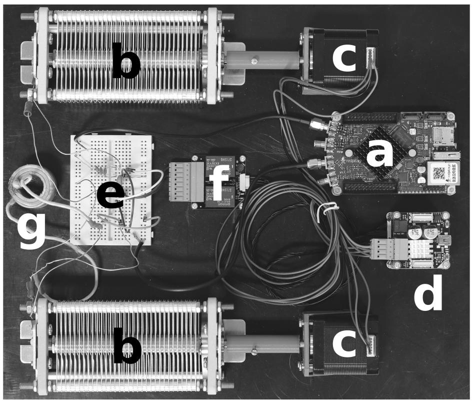

Figure 3: The testbed for evaluating the automatic impedance correction, consisting of StemLab board (a), variable capacitors (b), NEMA17 stepper motor (c), "Silent Stepper Brick" (d), switched capacitor array (e), "Industrial Dual Relay Bricklet" (f), field generator (g).

supposed to be matched to an impedance of 50 Ω at a frequency of 500 kHz.

III Results and discussion

First trials of the automatic impedance correction using the testbed have shown good results. Matching with an error of less than 2 Ω in magnitude (≈4 %) and less than 5 ° in phase could be achieved. However, this precision might dramatically increase in a more sophisticated setup including shielded lines and more reliable connections, since the current setup is susceptible to noise, electromagnetic interference and other signal degrading influences.

IV Conclusions

A standard procedure for impedance matching as well as automatic impedance correction have been proposed and its working principles discussed. The automatic impedance correction procedure has been evaluated in a testbed and yielded good results even though the current testbed was susceptible to signal degradation.

Acknowledgments

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References

[1] B. Gleich and J. Weizenecker, Tomographic imaging using the nonlinear response of magnetic particles. Nature 435, 1214-1217 (2005) doi: 10.1038/nature03808.

[2] S. Biederer, et al., Magnetization response spectroscopy of superparamagnetic nanoparticles for magnetic particle imaging. J. Phys. D: Appl. Phys. 42(20), 205007 (2009) doi: 10.1088/0022-3727/42/20/205007

[3] T. M. Buzug, et.al., Magnetic particle imaging: Introduction to imaging and hardware realization. Z. Med. Phys. 22, 323-334 (2012) doi: 10.1016/j.zemedi.2012.07.004

[4] A. Behrends and T.M. Buzug, Design of a Switched-Capacitor Array for High-Power Applications with Dense Coverage of Medium Frequency-Range. In: IWMPI 2018: Book of Abstracts, T. Knopp, T.M. Buzug, Ed. Infinite Science Publishing, 2018, pp. 171-172. ISBN: 978-3945954485.

