A Generalized Concept for Preamplifier Decoupling

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Purpose: Preamplifier decoupling is a valuable technique in the development of multi-channel receiver array coils. Generally, it reduces the magnetic coupling by current suppression. Although well established, there is currently no simple rule available to design a proper network with desired properties. In this work, a concept is presented to obtain the required parameters for preamplifier-decoupled arbitrary networks. In addition, the robustness of the coil against varying loading conditions of the coil was investigated as a further property of the circuit.

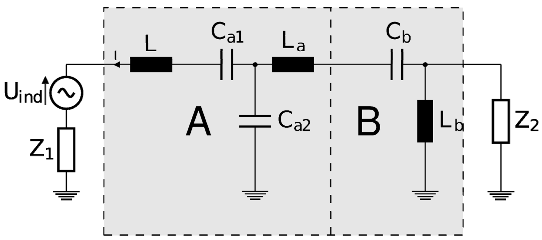

Fig. 1. *Network I adapted from Ref. [1].*

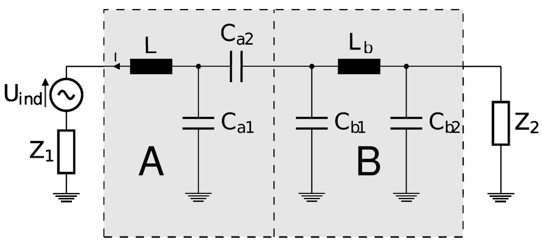

Fig. 2. *Alternative network II.*

Theory: Roemer et al. [1] have described the functionality of a decoupling network in terms of resonances in detail. The basic elements of a typical receiver coil network are shown in Fig. 1. A high impedance of Z_2 causes C_b and L_b to form a series resonance pulling L_a to ground when properly tuned. For this condition, L_a and C_{a2} form a parallel resonance, which in turn suppresses the current in the coil.

However, the decoupling effect may also be explained by impedance transformations. The starting point of this alternative concept is rearrangement of the network. Using the lumped equivalent of a transmission line, which is composed of reactive elements, the network is described by the input and output reflection coefficients, Γ_1 and Γ_2, respectively. The reflection coefficient is defined as the ratio of the backward and forward traveling current waves. At each point in the network, the current is then given by $I = (U_q/Z_0)\cdot(\Gamma^{+} - \Gamma_1\ \Gamma)$. To minimize the current in the loop, a reflection coefficient $\Gamma_1 = 1$ is required at this port. The network analysis of parts A and B thus results in the following conditions:

(A) $S_{A11} = S_{A22} = 0$ and $S_{A12} = S_{A21} = e^{j\,\pi/2}$,

(B) $S_{B11} = S_{B22} = 0$ and $S_{B12} = S_{B21} = e^{j\,\pi/2}$.

Applying the general equation for the transformation of a reflection coefficient by an arbitrary network, Γ_1 is therefore given by $\Gamma_1 = S_{A12}\ S_{B12}\ \Gamma_2\ S_{B21}\ S_{A21} = 1$ and Γ_2 is given by $\Gamma_2 = (Z_2 - Z_0^{+})/(Z_2 + Z_0^{+})$, where Z_0^{+} is the right-sided characteristic impedance of the network and is given by the noise match of the preamplifier.

For achieving preamplifier decoupling, the general network condition between coil and preamplifier must be $\Gamma_1 = S_{12}\ \Gamma_2\ S_{21} = 1$. If the transfer function of the network is written as $S_{12} = e^{j\alpha}$, a more handy expression is obtained according to $\alpha = (\beta_2 - j \ln|\Gamma_2|)/2$. Based on this result, conditions for minimal current can be derived for any given reflection coefficient. Further analyses based on this concept revealed robustness of the network against changing loading conditions as another useful property.

Simulation results: To validate the derived expression, a circuit simulation was used (Qucs)[2]. The network in Fig. 2 was compared to a network designed according to the equation for α as derived above. For both designs we assumed an input impedance of Z_2 = 5 MΩ for the preamplifier. The results are presented in Fig. 3. In Fig. 4, the current for the second design is shown for different input impedances of the preamplifier (5 MΩ, 50 kΩ, 5 kΩ). The imaginary part of α is also shown. Figure 5 summarizes findings for varying loading conditions of the coil. For a real and reactive change of the coil impedance, the current minimum remains stable at the target frequency.

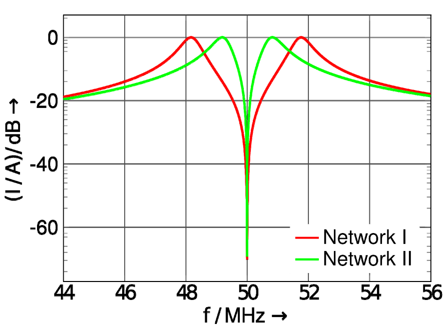

Fig. 3. *Current I for Network I and II.*

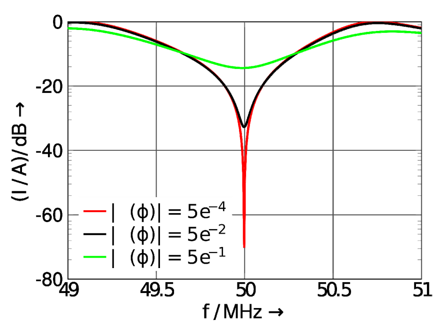

Fig. 4. *Current I for different Z_2.*

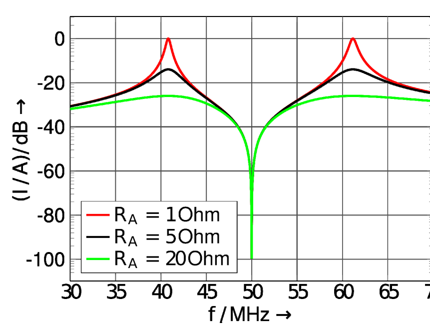

Fig. 5. *Current I for $Z_1 = R_A$.*

Discussion: With regards to the complex nature of α, the real part is the phase shift introduced by the network to achieve preamplifier decoupling, whereas the imaginary part is negative and corresponds to an amplification, which is not realistic with only passive elements in the circuitry. Nevertheless, the imaginary part is of some value in evaluation of the network. If its value is small, the current suppression will be nearly ideal, but it will degrade with increasing values. A further advantage of our approach is that it highlights important design aspects. In particular, two properties are important for preamplifier decoupling: *(1)* a mismatch and *(2)* a suitable network for proper transformation of the resulting reflection coefficient. Theoretically, only one network is required between coil and preamplifier. However, due to the constrain that the inductance of the coil is part of this network and is defined by the geometrical design of the loop, it is advantageous to replace the single network by two cascading networks as shown in Figs. 1 and 2.

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Reference: [1] P.B. Roemer et al., Magn. Reson. Med. 16:192-225 (1990). [2] S. Jahn, Int. Jour. of Num. Model.(21),5: 335-349 (2008)