

Preamp Decoupling - Eigenvalue Solution Approach

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Introduction

Over the last 30 years of MRI clinical usage, almost all subparts of the system have been redesigned or improved. In the early days of the MRI transmission and receiving have been performed with the same volume body coil. Starting with the late eighties several groups proposed taking advantage of multiple coils during receive cycle of the MR sequence [1,2]. Utilization of the multiple channel coils allows improved SNR, which can be fructified into increased resolution or reduced scan time. One of the major problems an RF engineer encounters when designing a multi-channel RF coil is the element-from-element decoupling. There are three techniques, with some sub-varieties, habituated in achieving acceptable decoupling: inductive decoupling, capacitive decoupling and so called “preamp decoupling”. Inductive decoupling, consisting in partial overlap of the coils so that cancellation of magnetic fluxes between neighboring coils occurs, is the most often been used because it is geometrically fixed, does not need tuning and permits decoupling of the coils in a large broadband. Capacitive decoupling is used when topology and position of the element cannot be changed [3]. It consists in an introduction of a decoupling capacitor in series with the mutual inductance of the two elements, allowing narrow band decoupling of the two imaging channels centered at system frequency. The most modern decoupling method is the so-called “preamp decoupling”[2], which consists in bringing a low impedance preamp as close as possible to the coil element and inserting it into a parallel resonance trap which itself is in series with the coils element. This method allows decoupling of the coil elements placed far from each other (next nearest of more distant neighbors), which exhibits weak coupling and cannot be decoupled by other means. Although there are many interpretation of this techniques based on transmission line theory [1,4], we consider that an eigenvalue interpretation [5] is closer to the multiple-degree-of-freedom electrical oscillator, which the MR phased array RF coil represents par excellence.

Theory

The mathematical model used to demonstrate our point is applied to the system of the two neighboring elements with inserted preamps (Figure 1). The

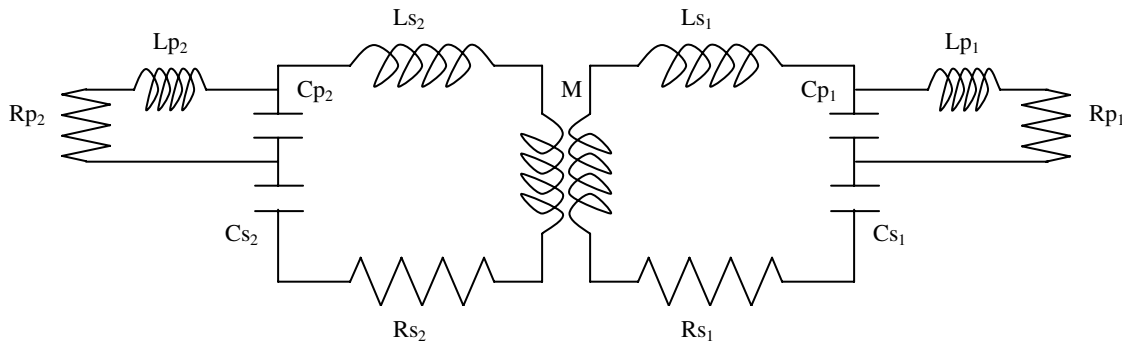


Figure 1. Lumped circuit elements of the two coil elements with preamp decoupling circuits.

inductances of the coil elements are denoted by L_{s1} and L_{s2} , resistances including the load effect of the lossy phantom R_{s1} and R_{s2} , mutual inductance by M , series capacitance of the coil elements by C_{s1} and C_{s2} , parallel capacitances by C_{p1} and C_{p2} and preamp impedance by R_{p1} and R_{p2} . Lagrangean of the system is derived and Euler-Lagrange equations are written for the unknown currents through the elements I_{s1} and I_{s2} and the currents through the preamps I_{p1} and

I_{p2} with source voltages V_{s1} and V_{s2} (1). This system of equations can be generalized for any number of elements in a multi channel array coil ($2N$ equations for N channels).

$$\begin{bmatrix} i\omega L_{s1} + \left(\frac{1}{i\omega C_{s1}} + \frac{1}{i\omega C_{p1}} \right) + R_{s1} & \frac{1}{i\omega C_{p1}} & i\omega M & 0 \\ \frac{1}{i\omega C_{p1}} & i\omega L_{p1} + \frac{1}{i\omega C_{p1}} + R_{p1} & 0 & 0 \\ i\omega M & 0 & i\omega L_{s2} + \left(\frac{1}{i\omega C_{s2}} + \frac{1}{i\omega C_{p2}} \right) + R_{s2} & \frac{1}{i\omega C_{p2}} \\ 0 & 0 & \frac{1}{i\omega C_{p2}} & i\omega L_{p2} + \frac{1}{i\omega C_{p2}} + R_{p2} \end{bmatrix} \begin{bmatrix} I_{s1} \\ I_{p1} \\ I_{s2} \\ I_{p2} \end{bmatrix} = \begin{bmatrix} V_{s1} \\ 0 \\ V_{s2} \\ 0 \end{bmatrix} \quad (1)$$

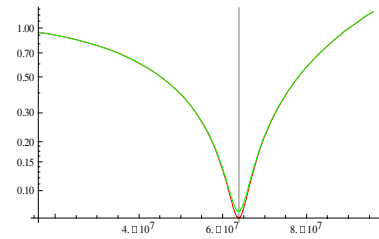


Figure 2. Ratio between loop current and preamp current for 2-channel coil.

Results

The solutions of the system (1) depend on particular values of the capacitors, inductors and resistances. The requirement of the preamp decoupling is to have minimal current in the receiving loops (i.e. I_{s1} and I_{s2} minimal)[6]. However through the preamp the current flow should be maximized (i.e. I_{p1} and I_{p2} maximal). So the pertinent goal is to seek the minimization of the ratios $|I_{s1}|/|I_{p1}|$ and $|I_{s2}|/|I_{p2}|$ which are represented in Figure 2 for experimental values of the lumped circuit components.

Conclusion

The approach described above allows accurate description of the phenomena in the multi-channel RF receive coil and allows quantitative estimation of the level of decoupling, been given all lumped circuit component values. The original Lagrangean can take into account also mutual capacitance between channels.

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References

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