MRI coil stability

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Introduction: MRI receiver chains that are carefully tuned and matched to operate at the Larmor frequency are often prone to oscillation – usually at other, nearby frequencies. Oscillations at any frequency are undesirable and will degrade image quality. This problem is exacerbated by the use of high-gain, low-input-impedance preamplifiers (used to assist in decoupling nearby coils [1]), which can be particularly unstable. Miniaturization and integration of coil arrays and components, such as moving preamps onto the coil [2], increases the likelihood of oscillations due to parasitic coupling. Isolating and eliminating oscillations can be a challenging task, especially in large arrays, and can add significantly to development time and cost.
In this work, we develop a model to analyze and predict the stability of coil arrays given preamp data, together with coil schematic and geometry. It should also be useful for evaluating candidate components, for example, different preamplifier designs. The method is used to predict the stability of a coil array at the Larmor and nearby frequencies, for varying conditions of coil loading and preamp termination, and is then compared with experimental results.

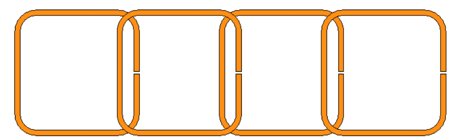

Fig. 1. Four coil linear array

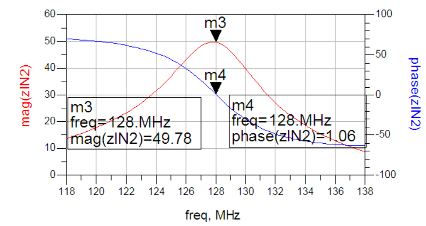

Fig. 2. Coil impedance after tuning and matching

Methods: For each coil in the array, the coil geometry was simulated (Ansoft Q3D, PA, USA) to estimate the inductance and resistance at 128MHz. These values, together with matching and tuning components were used to construct a circuit. The preamp data were then added to the circuit. The data are usually in the form of 2-port S parameters, measured over a 20MHz frequency span, centered at 128MHz. Then end-to-end (coil source to preamp termination) S parameters were obtained (ADS, Agilent, CA, USA). The effects of parasitic coupling and feedback were incorporated by assigning a mutual inductance *M* between each component (e.g. preamp, balun) and the coil. Each value of *M* was calculated using electromagnetic simulations to model leakage fields from the component and then determining flux linkage between the component and the coil.

The stability was evaluated by considering the Rollet k-factor and the stability measure [3].

$$k = \frac{1-|S11|^2 - |S22|^2 + |S11S22 - S12S21|^2}{2|S12S21|} \quad \cdots \quad (1)$$

$$b = 1 + |S11|^2 - |S22|^2 - |S11S22 - S12S21|^2 \quad \ldots \quad (2)$$

If $k > 1$ and $b > 0$ the receiver is unconditionally stable. If the conditions for unconditional stability are not met, the receiver may still operate in a stable manner under typical MRI loading and preamp termination conditions. Therefore, source and load stability circles were considered. These stability circles show coil loading (source) and preamp termination (load) conditions that will lead to instability. The stability circles are frequency dependent so a family of circles within the frequency band of interest is considered to understand the conditions and frequencies at which the coil may oscillate.

In extending this model to coil arrays, additional coupling terms that include coil to coil coupling were added to the circuit as mutual inductance terms. Then stability was again evaluated, one coil at a time, with other coils assumed to be nominally loaded.

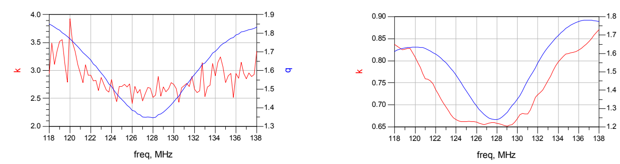

Fig. 3. Coil with preamp A is unconditionally stable (left), but same coil with preamp B does not meet unconditional stability (right)

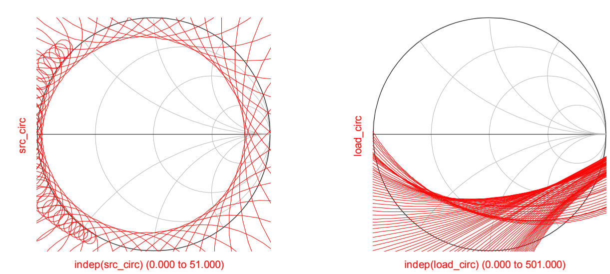

Fig. 4. Source stability circle (left) and load stability circle (right) for coil with preamp B

Results: The linear array of four coils considered in the stability analysis is shown in Fig. 1. The impedance (magnitude and phase) for an inner coil, following tuning and matching of the four coils is shown in Fig. 2. The stability of the coil is evaluated with two candidate preamplifiers, identified as A and B in this work. The k-factor and stability measure for an inner coil with each preamplifier are shown in Fig. 3. As seen in this figure, coil with preamp A is unconditionally stable. However, the coil with preamp B does not meet unconditional stability. Therefore, the source and load stability circles are evaluated. The source stability circles are shown in Fig. 4 (left). Each circle in red represents a single frequency in the range of 188-132.5 MHz, at 0.5 MHz step. For stability, the source impedance must be outside each of the red circle at the corresponding frequency. Careful examination of these circles show that typical source impedances due to coil loading are stable. However, under low loading conditions, the source impedance may move within the red circles and lead to oscillations. These frequencies are identified as 120.5MHz and 135MHz. The load stability circles, shown on Fig. 4 (right) show that typical preamp output impedance of 50 ohm seen at the mixer leads to stable operation.

In test coils built with preamps A and B, stable operation has been observed in coils with preamp A. However, coils with preamp B have shown unstable operations under various conditions. Additional investigations into unstable conditions and corroboration with model predictions are continuing.

Conclusions: The high gain preamplifiers in MRI coils, together with parasitic coupling can lead to unstable operation of coils. Circuit models, generated with coil schematic, layout and preamp data can predict the stability of receiver chain and if not unconditionally stable, under which conditions oscillations would result. Integrating such modeling in the coil development process has significant potential to eliminate troubleshooting and redesign required by instability.

References: [1] P. B. Roemer, et. al., Magnetic Resonance in Medicine, 16, 192-225, 1990 [2] R. O. Giaquinto, et. al., ISMRM, p2815, 2009 [3] R. Ludwig et. al., "RF circuit design: theory and applications", Prentice Hall