Frequency Selective Negative Feedback to Avoid Preamplifier Oscillation in Multi-Channel Arrays

T. Grafendorfer[1,2], G. Scott[2], P. Calderon[3], F. Robb[4], and S. Vasanawala[5]

[1]RX & ATD Coils, GE Healthcare, Stanford, CA, United States, [2]Electrical Engineering, Stanford University, Stanford, CA, United States, [3]MR Hardware Engineering, GE Healthcare, Fremont, CA, United States, [4]Advanced Technology, GEHC Coils, Aurora, OH, United States, [5]Radiology, Stanford University, Stanford, CA, United States

Introduction: In recent years we have seen a trend among coil manufacturers to replace system preamplifiers with on-coil preamplifiers. This increases preamplifier-decoupling performance [1] in multi-channel arrays, which leads to better SNR and better acceleration performance. Unfortunately, placing the preamplifiers in the vicinity of the coil elements opens a new feedback path that can easily lead to oscillation. We developed a new strategy by applying frequency selective negative feedback that suppresses the gain at the match split peaks outside the frequency band relevant for MRI. This greatly reduces the possibility for oscillation, and the gain within the signal band stays more or less unaffected.

Theory: Figure 1 shows the model of a low input impedance 3T preamplifier connected to a 3-inch surface coil (unloaded). All capacitors are considered lossless, whereas the inductors are modeled with a series resistance. The unloaded coil resistance is 0.6 Ω, the preamplifier input impedance equals 1.2 Ω at resonance frequency and s_{21} equals 28 dB with a phase shift of 180°. Also shown is the coil transfer function V_s/V_{out} with and without the feedback network Z_f. The model for a traditional coil-preamplifier setup does not include Z_f, and by looking at the transfer function it becomes immediately evident why this configuration is prone to oscillation. Two coupled resonators, built by the coil and preamplifier decoupling cause a very high gain at the so-called match split peaks. These peaks appear approximately 10 MHz above and below resonance frequency and these are the frequencies where oscillation usually occurs. According to the Nyquist Stability Criterion [2] it only takes little feedback at the right phase shift for this system to oscillate. And since there is a phase shift of 180° between both peaks (not shown here) it is likely to "hit" one of the peaks with unwanted feedback. The low input impedance of the preamplifier is responsible for the high gain at the match split peaks. Increasing the preamplifier input impedance would increase stability but compromises preamplifier decoupling performance. Loading the coil also damps the system and reduces the gain at the match split peaks, but a well designed system should be stable under all loading conditions.

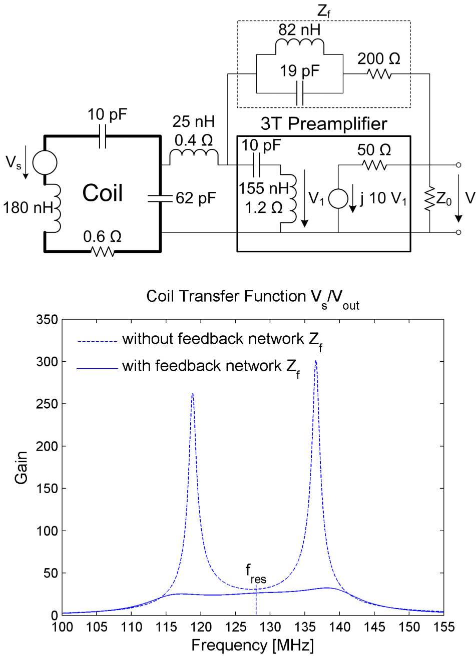

Figure 1: Model of a low input impedance 3T preamplifier connected to a 3-inch surface coil (unloaded) and the coil transfer function V_s/V_{out} with and without Z_f. The feedback network Z_f completely suppresses the gain at the match split peaks, which mitigates system oscillation.

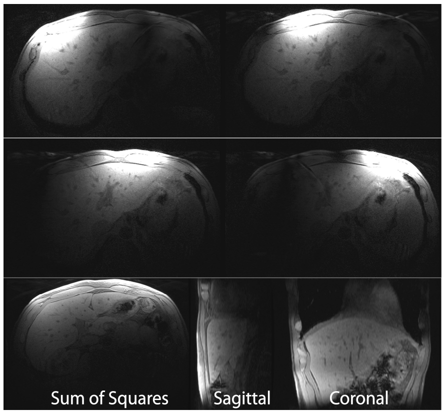

Figure 2: Pre-contrast LAVA (fat-suppressed SPGR) in a volunteer liver (416 x 416 matrix over 32 cm FOV, 84 slices at 3 mm thickness, 4x outer acceleration, TR 5.4 ms, TE 2.4 ms, 15 degree flip angle). Top two rows show representative images from four of the 16 elements, indicating excellent coil decoupling. Bottom images are composite sum of squares images from all 16 elements, as well as coronal and sagittal reformats. Note excellent detail of hepatic vessels despite absence of gadolinium. When combined with a posterior array, we expect good signal throughout the abdomen.

Methods: A feedback network Z_f, consisting of a parallel resonator tuned to the resonance frequency applies frequency selective negative feedback and completely suppresses the gain at the match split peaks. A conventional 82 nH chip inductor (Q-factor about 50) in parallel with a 19 pF ceramic chip capacitor provides about 3 kΩ peak resistance, which creates little feedback within the signal band and also has very little impact on the noise figure (0.05 dB). A 200 Ω resistor in series is necessary to prevent oscillation at higher frequencies. A T-network was added to the output of the preamplifier (GEHC Coils) to complete the preamplifiers s_{21} to a total phase shift of 180°. Depending on how dynamic disabling is implemented precautions must be taken to prevent oscillation during transmit. Here a pin-diode was placed in parallel with the feeding capacitor of the coil (not shown).

Results: A 4 by 4, 16-channel anterior cardiac/torso coil, total size 26 cm by 26 cm with overlapped coil elements in both dimensions was constructed. All 16 channels showed their match split peaks nicely suppressed. With 62 pF feeding capacitors a blocking impedance of about 250 Ω was achieved and sensitivity maps revealed adequate sensitivity variations for parallel imaging and no significant coupling between channels. Figure 2 demonstrates the excellent SNR of the coil and shows excellent detail of hepatic vessels despite the absence of gadolinium.

Discussion: A 16-channel coil that applies frequency selective negative feedback has been developed and tested. Despite a very low preamplifier input impedance (between 0.8 and 1.2 Ω) the coil shows a very stable behavior, and no additional measures like input baluns are necessary to prevent oscillation. Furthermore frequency selective negative feedback might allow even lower preamplifier input impedances without driving the system into instability. Future work will focus on increased preamplifier-decoupling performance achievable with substantially zero input impedance preamplifiers that reflect negative resistance into the matching network [3].

References:

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3. X. Lou, US Patent #6,369,550 B1