A self-built two stage stable preamplifier for small coils

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Introduction: Coil arrays for signal reception are widely used in MRI to obtain high local SNR [1] and for improved imaging speed [2]. Increasing the channel number in the coil array, the single coil element in every channel becomes smaller, respectively. Thus, higher gain is required for preamplifiers to improve low signal level to acceptable values. However, high gain is a conflicting goal with the stability [3] and the possibilities of oscillation in the preamplifier [4] and coils [5] increase. Additionally, the unstable performance may even be induced in a conditional stable preamplifier [3] because of different body noise resistance of the coils, supplying different source impedance to their preamplifiers. So, besides high gain and other parameters (low noise and low input impedance), unconditional stability should be considered in preamplifier design. Here, we present methods to stabilize an unstable two-stage preamplifier, while the high gain and other parameters are kept.

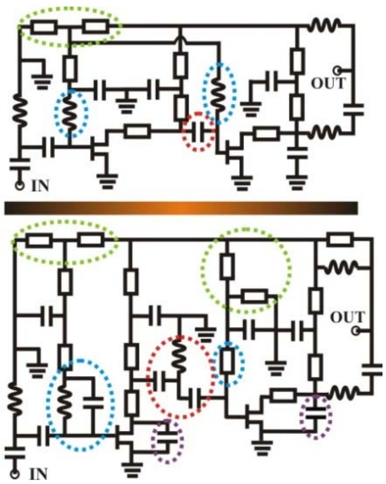

Fig 1: Comparison between the unstable preamplifier (top) and stable preamplifier (bottom).

Method: A representative circuit diagram for an unstable preamplifier is displayed in Fig 1 (top). Due to the Miller effect [6], the distributed capacitance between the gate and drain of the transistor is amplified and can possibly lead to oscillations. It was observed that with a preamplifier according to this unstable design, the capacitor highlighted in the red circle can change the DC bias. Oscillations need to be avoided to exclude device damage. Some methods to suppress oscillations and ensure unconditional stability are presented here. The new stable preamplifier has a representative circuit diagram that is shown in Fig 1 (bottom). For easier comparison, unstable factors and subsequent changes are marked by circles of identical color. Improvements are the following:

1) Instead of one voltage divider circuit for two stages, two voltage divider circuits are used for two stages separately in the new preamplifier design (green circles in Fig 1). Thus, higher resistance is added to the unstable loops brought by the Miller effect. Oscillations at all frequencies are reduced.

2) Large inductors were used to block RF and pass DC for the gates of the two stages in the old design (blue circles in Fig 1(top)). In the new design, for the first stage, the large inductor is replaced by one inductor and one capacitor whose resonant frequency is 123MHz. However, a large resistor is used for the second stage. Besides performing the same task as the large inductors in the unstable design, the new design reduces the inductance factor which may be resonant with Miller capacitance. Also, resistance is increased to stabilize the preamplifier. Anyway, noise from the large resistor in the second stage cannot be avoided completely. But according to Friis formula [3], its noise contribution for the total noise figure of the preamplifier can be neglected.

3) One capacitor that was applied for RF pass and DC block between two stages was replaced in the new design by a filter comprised of two capacitors and one inductor (red circles). The filter is supposed to remove low frequencies that may induce oscillations.

4) There is no feedback circuit present, but some feedback will always be present on the PCB due to parasitic coupling. If the feedback's phase is higher than 180° with magnitude larger than zero, the preamplifier could still oscillate. Two capacitors are used in the new design to adjust the phase of the feedback signal. They are marked in the purple circles in the new design. Additionally, they can filter unstable factors at high frequencies.

Preamplifier stability is evaluated by considering the parameter μ [7], which measures the distance from the unstable region to unit smith chart. In case the preamplifier is unconditional stable, $\mu_{source} > 1$ and $\mu_{load} > 1$, meaning that the preamplifier's source and load could be of any impedance termination, respectively.

Parameter μ and input impedance of the preamplifier were obtained from a network analyzer (Vector Network Analyzer, ZVB4, ROHDE&SCHWARZ, Munich, Germany), while noise figure and gain were obtained using a signal analyzer, together with noise source (both from Agilent Technologies, Boeblingen, Germany).

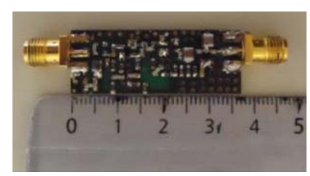

Fig 2: Fabricated preamplifier

Results: The new preamplifier was fabricated (see Fig 2) and characterized on the RF bench. Its measured parameter μ is depicted in Fig 3. Other parameters of the new preamplifier were characterized in comparison to a commercial preamplifier (Siemens Healthcare, Erlangen, Germany). With our equipment we found for the commercial preamplifier a gain of 27 dB, a noise figure of 0.75 dB and input impedance of 2.8+25j (Ohm). For our stable preamplifier gain= 32 dB, noise figure = 1dB and input impedance = 4.1-8.8j (Ohm) were measured. A copper conductor loop ($\emptyset = 2.5cm$) was built for MRI measurements in a 3T scanner (MAGNETOM Trio, Siemens Healthcare, Germany) by which the performance of commercial and our stable preamplifier could be tested (GRE, TR=100ms, TE=10ms, flip angle=25^{0}). Obtained image SNR values turned out to be comparable, 540 for our new preamplifier and 570 for the commercial preamplifier. The stability of the new preamplifiers was verified during long term use.

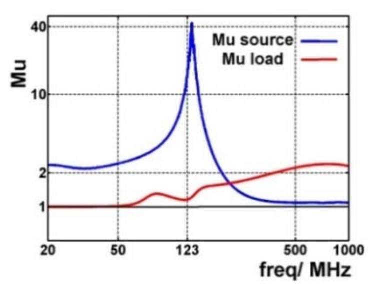

Fig 3: Pparameter μ from stability measurement

Discussion and Conclusion: Seen from measurements displayed in Fig 3, the preamplifier is found in unconditionally stable since its μ_{source} and μ_{load} were larger than one at all frequencies. (μ_{load} is close to but still larger than one at low frequencies). $\mu_{source} > 1$ leads to the conclusion, that the preamplifier also does not oscillate with different source impedance, thus allowing a variation in body noise resistance in a much larger range. Besides low noise figure and low input impedance, the high gain (32dB) of the preamplifier was kept during the stability improvement.

Consequently, the newly developed preamplifier is of advantages especially for small coils. Our applied improvements may also be helpful to stabilize other unstable two-stage preamplifiers used for small receive coils.

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Reference: [1] Keil, Boris, and Lawrence L. Wald. "Massively parallel MRI detector arrays."Journal of Magnetic Resonance (2013). [2] Pruessmann, Klaas P., et al. "SENSE: sensitivity encoding for fast MRI."Magnetic resonance in medicine 42.5 (1999): 952-962. [3] Frank Ellinger, Radio frequency integrated circuits and technologies, Springer-Verlag Berlin Heidelberg, Germany, 2007. [4] A.Peter et al., Optimised LNAs for 3 T, 7 T and 9.4 T, Proc. ISMRM 2011, p2607. [5] S. B. Bulumulla et al., MRI coil stability, Proc. ISMRM 2010, p3919. [6] Norman Dye, Radio frequency transistors-principles and practical applications (second edition), Butterworth–Heinemann,2001, USA, [7] Edwards. ML and Jeffrey H. Sinsky. A new criterion for linear 2-port stability using a single geometrically derived parameter, Microwave Theory and Techniques, IEEE Transactions on 40.12 (1992): 2303-2311.