A Low Input Impedance MRI Preamplifier Using a Purely Capacitive Feedback Network

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Introduction:

MRI preamplifiers need to meet a number of technical requirements that are not easily to be achieved simultaneously. Major challenges are a low noise figure (e.g. <= 0.5 dB), a stable gain and a high dynamic range. In addition, the small signal input impedance, $z_{in} = v_{in} / i_{in}$, should be very low (≤ 5 Ω) so that a sufficient decoupling of adjacent and second neighbour loops in an MR-loop array is obtained. A low z_{in} is usually realized by means of a resonant step-up LC-network at the input (s. [1]). In order to keep the noise figure low, the inductor in this network must exhibit a high Q thus requiring a large volume. The novel amplifier type presented here no longer needs such a bulky inductor. Due to a lossless feedback network composed of only capacitors the amplifier exhibits a stable gain and a low z_{in} over a very wide frequency range while maintaining a high equivalent noise input resistance, r_n , and a low noise figure.

Principle of operation:

Fig. 1 shows the basic arrangement as described in [2]. In this example, the amplifier block is a state of the art high input impedance device with a low noise FET at the input. The output signal is fed back via a transconductor (e.g. an additional FET) to create a current flowing out of the capacitive feedback network. With a given voltage gain, $V = v_{out} / v_{in}$, of the amplifier block, a given transconductance, g , and a capacitance ratio, $\varsigma = C_2 / C_1$, it can be shown that the input impedance, z_{in} , is reduced from the original high value, z_0 , down to $z_{in} \approx (1+\varsigma)/(gV)$. This is true as long as $\omega C_2 << gV$ and $z_0 gV >> 1+\varsigma$ which is easy to achieve.

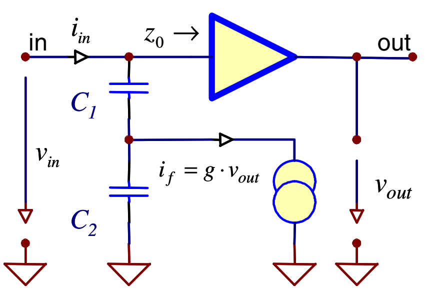

Fig. 1: Basic arrangement of the feedback amplifier

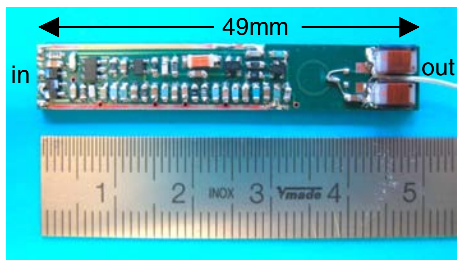

Fig. 2: Lab demonstrator of the feedback amplifier in SMD technology

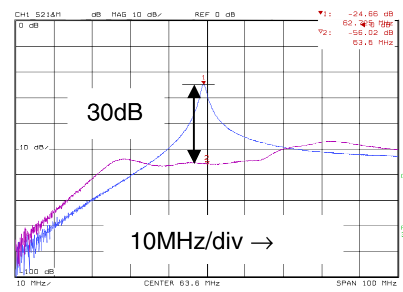

Fig. 3: Wide band decoupling of an MR-loop when the amplifier is switched on

Technical realization and operation:

The amplifier can be either directly connected to a concentrically arranged coupling loop or to one of the MR-loop capacitors with a decoupling choke connected between. This series choke may have a rather low Q. Thus, in both cases noise matching and decoupling is performed without a large volume input inductor. Fig. 2 shows a photograph of a 1.5 T (63.3 MHz) lab demonstrator occupying a volume of only 49 x 8.5 x 5 mm³. The board also includes an active pin-diode detuning circuit at the input and a sheath wave trap (common mode trap) at the output. Power supply and pin-diode control signal are both fed through the output coax line - the only wire to the environment. Since the feedback principle strongly suppresses any thermal gain settling, the amplifier can be switched off during transmit which reduces power dissipation and allows pin-diode biasing through a common single supply wire.

Results and conclusion:

The most impressive feature of the feedback amplifier is its wide band decoupling behaviour. Fig. 3 shows the resonance of a phantom loaded 1.5T-MR-loop measured with a double loop probe (blue trace). With the amplifier switched on the resonance peak collapses down by 30 dB over a more than 20 MHz bandwidth (magenta trace). No peaks arise on both sides of the center frequency as it is usually the case with an LC-input network. This simplifies tuning and prevents possible unwanted oscillations. The noise figure was determined to ≈0.4 dB and the 0.1 dB compression point at the output was >10 dBm. Future MRI-loop arrays with more but smaller loop elements require preamplifiers that provide easy handling (tuning) and a small size as well. The novel MRI-preamplifier presented above is such a useful “drop-in”-module for these arrays.

References:

[1] Roemer P. B. et al.: „The NMR Phased Array“, Magnetic Resonance in Medicine 16, 192 – 225 (1990), Fig. 6

[2] Oppelt R.: *Low-noise broadband amplifier device having negative feedback via a controlled current source, and use of the amplifier devicve*, US-patent 6,580,317, June 17, 2003 and 6,838,936 Jan. 4, 2005