What Actually Limits the Sensitivity of NMR Antenna–Receiver Chain?

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One of the less-known applications of a small loop antenna is in the NMR (Nuclear Magnetic Resonance) systems in experimental physics. The NMR makes use of the interaction of atomic nuclei with its surroundings, which are of electrical and magnetic nature, using the nucleus as a highly sensitive sensor at an atomic level (C. P. Slichter, *Principles of Magnetic Resonance*, Springer-Verlag, 1990). From an antenna engineer point of a view, the NMR system comprises the transmitting and receiving chains that are (via T/R switch) connected to the same antenna (cryogenically cooled small loop, equipped with an LC matching network). One of the difficult engineering problems in NMR spectroscopy is achieving a good sensitivity of the receiving chain. Recently (P. Kolar, S. Hrabar, M. S. Grbić, *Proc. on EuCAP 2017*, 2017), it has been shown that the noise properties of a receiving chain are not always dictated just by the proper resonant matching of the antenna and the use of high-quality pre-amplifier (as it is usually believed). This study analyzed the overall noise figure assuming ideal matching of all the chain elements. The main conclusion was that the minimization of losses in front-end components (T/R switch, coupler, and connecting cables) can increase sensitivity substantially.

Here, we update the previous efforts with development of the numerical model that allows accurate prediction and optimization of the system sensitivity. The model is fed by data obtained from *a priori* experimental characterization of all the system components. In this way, the model takes into account all the imperfections, such as impedance mismatch and non-linearity. The results show that (for the case of typical NMR system used in experimental physics community) the overall noise figure can hardly be lower than 1 dB. Of course, the detection post-processing (i.e, averaging) can increase an effective S/N at the cost of the measurement time. It is commonly believed that the use of low-noise cryogenically cooled amplifier (instead of the preamplifier that operates at the room temperature) makes the averaging time significantly shorter. However, our results indicate that this approach decreases measurement time only around 12%. Thus, if further enhancement is needed, one should either improve S/N at the antenna or decrease the losses in T/R switch. Practically speaking, this would lead to the construction of a multi-turn loop antenna and/or a low-loss, cryogenically cooled T/R switch.

In order to select the best cost-effective solution, the S/N characterization of the probe loop is under progress and preliminary measurement results will be presented at the conference.