FAST AUTOMATIC MATCHING CONTROL: TECHNICAL ADVANCES AND INITIAL RESULTS OF SNR OPTIMIZATION

M. Pavan[1], R. Lüchinger[1], and K. P. Pruessmann[1]
[1]Institute for Biomedical Engineering, University and ETH Zurich, Zurich, Switzerland

Introduction: Noise reduction is an important issue for SNR (Signal to Noise Ratio) maximization in MR measurements, therefore a low-noise amplifier should be used as first element in the spectrometer's receive chain. Since the Noise Figure (NF) of an amplifier changes depending on the impedance seen by the amplifier at its input port, a matching network is commonly placed between this low-noise amplifier and the coil to assure minimum noise injection by the amplifier (i.e. minimum NF) in the receive channel. Noise caused by the insertion loss of the matching network cannot be compensated with pre-amplification, so matching network design and settings are as critical as the choice of a proper amplifier with minimal NF. Automatic Matching Networks (AMN) have been introduced by [1] and [2]; they are a great tool to overcome notoriously difficult matching situation such as coil arrays [3], mechanically adjustable coils [4] and in general coils that see different loading conditions.

In this work it is presented how a matching network can be remotely and rapidly controlled with an AMN system and what is its influence on the noise injection through the means of equally automated SNR measurement in a 3T MR system.

Materials and Methods: Figure 1 depicts the block schematic of the new AMN system. The first element of this system is a trapezoidal receive loop-coil. To prevent ground currents between the loop and the rest of the system, the coil is coarsely matched and tuned then connected to the next block by means of a coaxial cable with cable traps. The next block is a remotely controlled PI-matching-network that performs fine matching. The PI-matching-network is made of 3 varicaps and 1 inductance as in [1] but now the varicaps are biased by means of a new DAC (AD5724R, *Analog Devices*). This DAC is fully compatible with the supply voltages available in the 3T MR system; thereby 50Hz noise coming from ground current generated by external power supplies is completely removed. In the schematic, the PI-network is followed by a RF switch that connects it in turn either to a low-noise pre-amplifier or to an impedance-measurement circuit. By default the PI-network is connected to the low-noise pre-amplifier and the impedance-measurement circuit is isolated, only when the impedance that the amplifier sees needs to be adjusted, new voltage values are written in the DAC, then the switch connects the PI-network to the impedance-measurement block and the new impedance value is measured as a feedback.

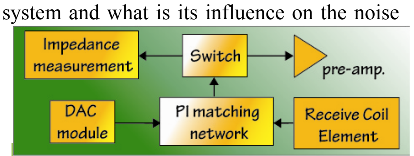

Figure 1 – single channel AMN

All components of the circuit are jointly controlled by a microcontroller (PIC24HJ64GP206, *Microchip*) and the entire circuit sits in the bore to minimize cable losses. Some of the features of the microcontroller are: it tunes and detunes the coil, programs the DAC voltages and given these voltages it interpolates from a look-up table the entire S-matrix of the PI-matching-network, it measures the impedance at the output of the PI-matching-network and calculates the impedance at the input of the network (i.e. the impedance of the coil), it shifts the impedance reference plane and calculates the impedance that the amplifier sees at its input.

The PIC is connected via a fiber optic to an external PC running Matlab© that processes and visualizes all the information from the PIC; this PC performs basic control of the MR system (3T Philips Achieva system, Philips Healthcare, Best, NL) such as starting scans by means of a chip that emulates a second keyboard (HT82K629A, *Holtek*). The external pc can also query the spectrometer's log-file to understand when the scan is completed after which it calculates automatically the corresponding SNR map. In this way thousands of scans can be run automatically under continuous dynamic control of coil matching.

Result: The new system compared with the one in [1] performs faster, it changes voltages on the DAC in about 10uSec, it reads an impedance value in about 450uSec and it optimizes the impedance that the pre-amplifier sees to a desired value in average in 200mSec instead of several minutes. The PI-network can match a wide range of coil impedances, for example it can match a coil to 50Ohms with S11 less than -20dB as a press of a button, with any loading condition, even if the coil is heavily loaded by a piece of metal or if the coil is detuned (data not shown).

Phantom SNR measurements were performed in a 3T system, single channel receive only the coil (gradient echo TE=3.5ms, TR=13msec. FOV=120x120x220 mm, voxel size=1x1 mm, slice thickness 10mm flip angle=15°), the phantom was a 10cm diameter water bottle. The excitation coil was the system body coil. 1000 scans were acquired automatically in about 50 minutes while changing the PI-matching network settings prior the start of each measurement. To cover the full range of matching conditions reachable by the PI-network the voltage of each varicap was set to 10 different points linearly distributed over output voltage range of the DAC, leading to 10x10x10 different matching conditions. Figure 2 depicts the SNR map acquired with the highest SNR value and ROI (40 pixels) where the SNR is averaged. Figure 3 shows the averaged SNR over the 1000 different impedances that the amplifier saw during the corresponding scan.

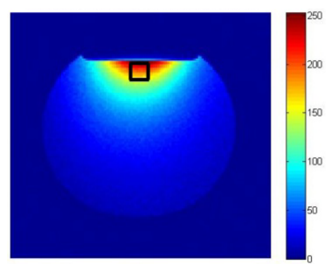
Fig 2 – SNR image with highlighted ROI

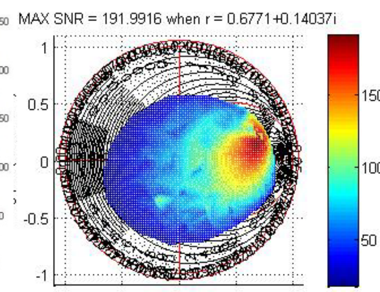

Figure 3 – SNR over impedance

The aim of the study is to show the impact of a matching network on the overall SNR. By means of Friis's formula for NF calculation of cascade of noisy devices we can separate from the total noise, the noise contribution of the amplifier and the noise contribution of the matching network. First, we calculated the available power gain (in this case available attenuation) of the PI-matching-network for the corresponding impedance that the amplifier sees. In figure 4 is shown the absolute value of PI-network gain over the corresponding impedance seen by the amplifier. Despite the S-matrix of the PI-network was measured while the DAC was in the field, the somewhat jittered structure in figure 4 and 5 is due to residual interpolation errors of the PI-network's S-matrix due to the fact that the DAC voltages slightly change when exposed to a strong magnetic field. Second, we estimate from the measured SNR maps the NF of the pre-amp.

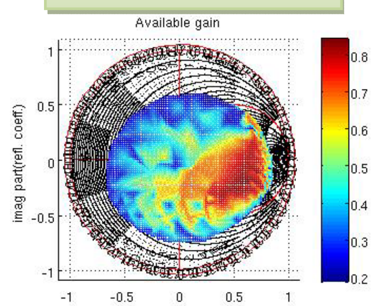

Figure 4 – PI network's available gain

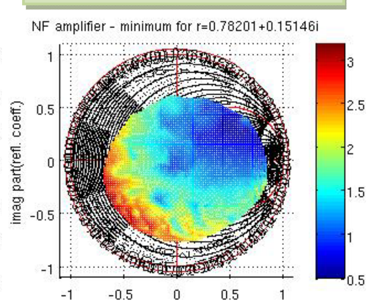

Figure 5 – NF of the amplifier

The result of the study proves that the maximum SNR does not occur for the same impedance that gives the minimum amplifier's NF (cf. figure 3 and 5). This is because the total NF is the cascade combination of amplifier's NF plus the NF of the matching network.

Discussion and Conclusion: A fast, more robust and to the MR system interfaced automatic matching network has been implemented and tested in a 3T system. SNR measurements over many different matching conditions are now feasible and can be performed in a short time, in a repeatable and robust way. The initial study performed shows that maximum SNR is achieved not when the pre-amplifier's NF is minimum but when the cascade combination of the amplifier's NF plus the NF of the matching network is minimum. This increases the complexities of the matching problem and makes the use of an AMN system mandatory. The system is modular and four channels have in fact already been implemented, enabling studies of matching issues in coil arrays.

References: [1]A Modular Automatic Matching Network System, Matteo Pavan et all,, Proc ISMRM, 2010 [2]An Automatic Impedance Matching System for Multiple Frequency Coils, S. Wu et all, Proc ISMRM, 2010 [3]Improving SNR by Generalizing Noise Matching for Array Coils, C. Findeklee, Proc ISMRM, 2009 [4]Mechanically Adjustable Coil Array for Wrist MRI, J.A. Nordmeyer-Massner et al, MRM 61:429–438 (2009)