NOISE CONTRIBUTIONS IN RECEIVE COIL ARRAYS

Matteo Pavan[1], Roger Lüchinger[1], and Klaas Paul Pruessmann[1]
[1]*ETH and University Zurich, Zurich, ZH, Switzerland*

Introduction: Receive coil arrays are used in MR to optimize Signal to Noise Ration (SNR) of measured signal. The engineer's goal is to build such arrays with high filling factor using electrical components with minimal losses, and decoupled coil elements such that elements noise and noise correlation are reduced. Theories for SNR maximization are always based on theoretical assumptions and a general theory does not exist, for this reason engineers use rules of thumb for optimal coil design. Such rules of thumb say to decouple different coil's elements either geometrically or by preamplifier decoupling, to avoid in general noise correlation and to perform noise matching to each individual channel's preamplifier such that the Noise Figure (NF) of each individual preamplifier is minimized.

However, recently it has been shown that noise decorrelation by signal processing can preserve SNR even in the case of an array with coupled elements [1], to maximize SNR in receive arrays the so-called active reflection coefficient should be used to perform noise matching [2] and Available Power Loss (APL) of the matching network should be considered [3].

These findings put the rules of thumb into question. The goal of this work was to elucidate this issue by studying the SNR achieved of single and coupled coils under controlled variation of matching conditions.

Materials and Methods: An automatic matching network system is a powerful tool to study noise contributions of receive-coil's elements. This system is modular and each channel consists of a PI matching network, were input and output capacitances are substituted with varicaps, a third varicap is placed in series with an inductance to have full control over all reactive components of the network (Figure 1). The varicaps are biased by three correspondent voltages that are produced by a digital to analog converter. The AMN system can measure impedance; the whole system is controlled by a microcontroller and sits in the bore to be able to keep the matching network as close as possible to its correspondent coil element. An external PC controls the state of matching network for a given coil impedance and it calculates the best matching condition for a given coil's load. The external PC queries spectrometer's log file and controls start of dynamic scans such that the impedance that the preamplifier sees is changed before the start of each dynamic scan in an automated way.

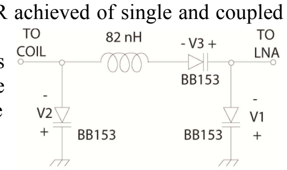


Figure 1: PI matching network

To fully characterize the matching network influence on image SNR, many dynamic scans were measured and for each of them a SNR map was calculated based on MR data. Three different experiments were performed, in the first one we used a single channel configuration, in the second one we used a two elements receive array with geometrically decoupled coils and in the third one we used a two elements coil array where the two coil's elements were positioned side by side in a heavily coupled coil configuration; in both last two experiments, matching setting of one coil element was kept fixed while the other coil element was adaptively matched with different configuration. All coil elements used were trapezoidal with an area of about 18.3cm^2 [4].

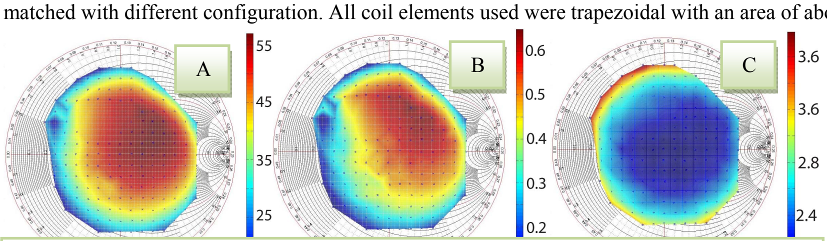
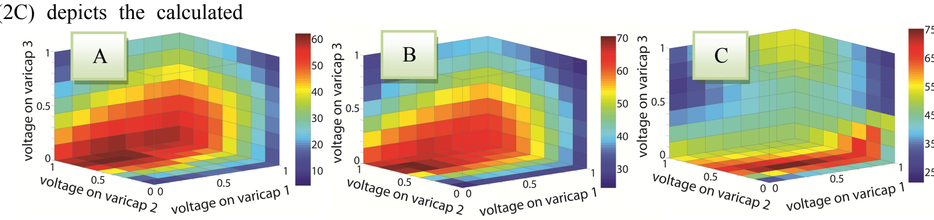


Figure 2: Single channel case. **(A)** Averaged SNR in SNR maps as a function of the impedance that LNA sees at its input. **(B)** Available Power Loss of the matching network as a function of the impedance that LNA sees at its input. **(C)** NF (in a logarithmic scale) of the LNA calculated from SNR maps, as point per point ratio of data in (B) over data in (A)

Result: SNR maps were acquired by means of a 3T MR system (Philips Achieva, Philips Healthcare, Best, NL) using as phantom a 10cm diameter water bottle. The sequence used was a gradient echo (TE=8.0msec, TR=11msec, FOV=120x120x220 mm^3, voxel size=0.94x0.94mm^2, slice thickness=10mm, flip angle=8°, reconstructed image 128x128 pixels). The excitation coil was the system body coil. All SNR displayed in figure 2 and 3 are SNR averaged over 20 pixels in a region close to the coil with variable matching conditions, before each SNR map is acquired, the matching network setting is changed.

Figure (2) shows the single channel experiment results; in (2A) is shown the SNR measured from SNR maps as a function of the impedance that the LNA was seeing at its input. In figure (2B) the Available Power Loss (APL) of the matching network is computed from interpolation from a look up table of the S matrix during different matching settings. The APL is the correspondent of the Available Power Gain defined for active devices and often used for preamplifiers characterization. It can be shown that the NF of a matching network is inversely proportional to its APL [5]. From definition of noise factor F of a two port device as ratio of SNR_{in} over SNR_{out} and using Friis formula for cascade of noisy devices, it is possible to calculate the NF of the preamplifier as $NF_{amplifier} = 10\log(APL^*(SNR_{in}/ SNR_{out}))$, where SNR_{in} is an unknown constant that represent the intrinsic SNR of the spin system. Figure (2C) depicts the calculated $NF_{amplifier}$, the scale is logarithmic and it has an unknown additive constant. Data shows that maximum SNR does occur neither for minimum $NF_{amplifier}$ nor for minimum APL.

Figure (3) shows data in the voltage space. Each point of this space is a triplet of voltages that are used to bias each of the three varicaps of the matching network. This space is introduced here because plots shown in figure (2) are missing one degree of freedom that we have when using a PI matching network; that is: each matching network's output impedance can be achieved with many different voltage settings that are sharing different APLs. Data shown in figure (3) indicates that SNR from a geometrically decupled array (3B) has a similar behavior as of SNR from a single channel (3A) and SNR behavior of heavily coupled array differs significantly (3C). It is interesting to notice that the heavily coupled array presents the highest SNR and anyway both SNR maximums in the two channels cases shown in (3B) and (3C) are located in an area where noise correlation coefficients of the coil elements (3D) and (3E) are high.



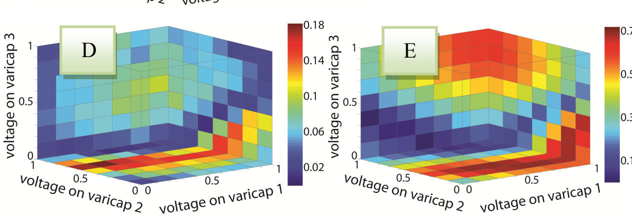


Figure 3: Data in voltage space. Voltage axes are normalized. **(A)** Single channel SNR **(B)** SNR from two geometrically decoupled coil elements **(C)** SNR from two heavily coupled coil elements **(D)** correlation coefficient from two geometrically decoupled coil elements **(E)** correlation coefficient from two heavily coupled coil elements

Discussion and Conclusion: An AMN system has been interfaced with an MR spectrometer allowing studies of noise behavior under different matching conditions of coil arrays. NF of a LNA can be measured when the LNA is in B_0 field by means of SNR map. Data show that was possible to achieve a higher SNR in the case of a heavily coupled two coils array compared to the case of geometrically decoupled array. In both arrays maximum SNR was obtained for matching configurations that lead to high noise correlation and in all cases noise matching was not an optimum matching condition since at least the Available Power Loss of the matching network has to be taken into account.

References: [1] Effects of inductive coupling on parallel MR image reconstructions, Ohliger MA et al. MRM 52: 628-639 (SEP 2004) [2] C. Findeklee, Proc ISMRM, 2009 [3]Fast Automatic Matching Control: Technical Advances and Initial Results of SNR Optimization, M. Pavan et al, Proc ISMRM, 2011 [4]Mechanically Adjustable Coil Array for Wrist MRI, J.A. Nordmeyer-Massner et al, MRM 61:429–438 (2009) [5] Microwave Engineering, David M. Pozar, Wiley, 2nd edition (1997)