A MODULAR AUTOMATIC MATCHING NETWORK SYSTEM

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Introduction: A Matching network is a very important device for MR signal detection [1]. Since they are the first element in the chain between coils and the ADC (Analog to Digital Converter), their insertion loss cannot be compensate with preamplification and SNR (Signal to Noise Ratio) is directly affected. A matching network that presents the wrong impedance at the input of the first low noise preamplifier can deteriorate substantially its noise figure (NF). To keep the coil matched to the impedance that gives the best noise figure of the preamplifier it is a challenge when coil loading conditions are changing, when coils can be stretched to adapt to the anatomic region to be imaged [2]; even more difficulties come whenever we have to consider coupling between different elements in an coil array. It would be unthinkable in an clinical setup to adjust manually matching and tuning of a coils array depending on different patients or different measurement. In this work we present a modular Automatic Matching Method (AMN) system that can be easily extended to match the output impedance of many different channels at the same time. An underlying point of this system is the capability of matching impedances to any desired point of the complex plane.

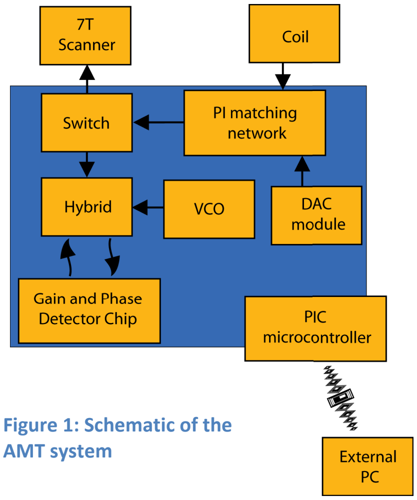

Figure 1: Schematic of the AMT system

Materials and Methods: Remote impedance matching can be achieved through the use of a matching network made of varicaps (BB153 *Philips*), a varicap is a diode that changes its capacitance depending on its reverse bias voltage (in our case the range is 65.1-6.9pF when the bias voltage is between 0 and 10 volts). The matching network we use is a PI network where the input and the output shunt capacitances are substitute with respectively two varicaps; another varicap is placed in series with the series inductance (37nH) to have fully control of all the reactive elements of the matching network. The AMN system consists of two main parts that are interfaced to an external PC through a microcontroller (PIC16F777, *Microchip*, with 14 analog to digital channels and internal oscillator clock). One main part of the system is the DAC (Digital to Analog Converter) module that is connected to the varicaps of the matching network and the second part is the RF circuitry capable of measuring the reflection coefficient seen by the preamplifier. A switch (controlled by the microcontroller) is determining whether the coil has to be connected to the reflection coefficient measurement circuit (since the characteristic impedance is set to 50Ohms, reflection coefficient measurement directly reflects the impedance we want to measure) or to the preamplifier of the MR reception chain. The switch is a SW-395 (*tyco electronics*) SPDT GaAs switch, insertion loss less than 0.5dB, typical isolation 28dB, maximum switching time 5 usec. Microcontroller and external PC are communicating to each other using a serial fiber optic connection (thought the use of a UM232 USB-Serial UART module, *ftdi chip*). The principle of operation is very simple, when the AMN system is the idle mode the switch connects the output of the matching network to the preamplifier, the reflection coefficient circuit is isolated and the scanner can be used to image. Whenever we want to match any special impedance we have just to type it in the external pc running Matlab©, this PC tells the microcontroller to isolate the scanner and connect to the matching network output the reflection coefficient measurement circuit, at this point a Matlab script iteratively changes remotely the output voltage of the DAC (changing in this way the reactive elements of the matching network) and reads the corresponding new output impedance value until the desired impedance is reached. The DAC module is an AD5361 chip (*Analog Devices*), it has 16 channels and a resolution of 16 bit over the maximum range output voltage range +/-10V. Varicaps have to be only reverse biased, so half of the DAC voltage range cannot be used, this allows anyway to have 2^{15} different capacitance value over the range 6.9-65.1pF and allows the matching network to reach 98304 different impedances almost all over the entire impedance complex plane. The DAC has already the capability of driving 5 different and independent matching networks but the chip is itself modular and more AD5361s can be connected together to extent the number of output channels. The major source of noise in the matching network is not actually *1/f* noise from the varicaps but very low frequency noise coming from the power modules of the DAC, this noise can be reduced with the use of big capacitance (50uF). The core of the reflection coefficient is an RF gain and phase detector chip (AD8302, *Analog Devices*). A fixed reference signal (same frequency as proton frequency) is generated (only when the impedance measurement is performed, to avoid RF artifacts in the image) with a Voltage Controlled Oscillator (VCO), this reference is fed into an double hybrid (directivity better than 40dB) and thanks to isolation between different ports of the hybrid is possible to separate the forward and the reflected, those two waves are fed into the gain and phase detector that gives at the output two constant voltages, one proportional to the phase difference between the forward and the reflected wave and the other proportional to the ratio of the magnitude of the forward and the reflected wave, no high speed digitizers are needed at all for reflection measurement. To have a very good directivity (this defines the sensitivity of the measurement to the reflection wave) we chose a tuned hybrid with the minimum number of reactive elements. The AD8302 chip is non linear when detecting phase differences close to zero and does not distinguish phases that differ to each other of 180°, these problems can be solved with a simple look up table for the linearization of its response function and with a variable delay line to detect whether two phases differ to each other of 180° or not. Since the microcontroller has 14 ADC, 7 magnitudes and 7 phase information can be read at the same time.

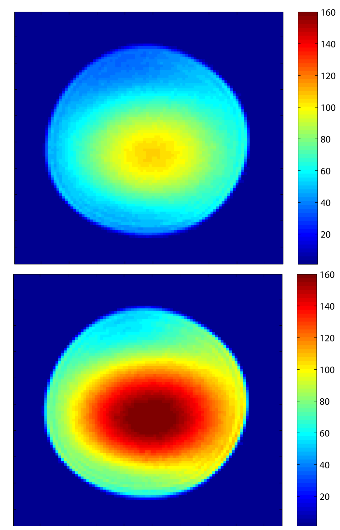

Figure 2: mineral oil phantom, SNR map when the impedance seen by the preamplifier is 11.0-9.3i Ohms, Below: SNR map when the impedance seen by the preamplifier is 46.2+11i Ohms, same scaling, changes in SNR are due to the different NF of the preamplifier.

Result: Phantom SNR measurements were performed in a 7T Philips Achieva system (Philips Healthcare, Best, NL) to the AMN in a single channel configuration, the coil (receive only) was a 3.5cm square loop with 4 splitting capacitor (to minimize current distribution changes when adapting the impedance and also to tune the coil). The sequence is a FFE (TE=shortest, TR=40msec. FOV=80x80x10 mm, voxel size=1.5x1.5 mm, flip angle=25°), the phantom is a 5cm diameter bottle filled with mineral oil. The excitation coil is a volume resonator. The average SNR in the phantom when the preamplifier sees an impedance equal to 46.2+11i Ohms is 64.0 (figure 2 below) and 41.1 if the preamplifier sees an impedance equal to 11.0-9.3i Ohms (figure 2 above). A Matlab script is optimizing the impedance, that means that the optimization algorithm can be change really fast and all the parameters (impedance, varicap voltages) can be plot if needed to follow up the optimization process, for instance it is useful when matching coil arrays with coupled elements. A typical impedance matching operation takes less than 3-4 minutes, but if needed this time can be speed up if the optimization algorithm would be implemented in the microcontroller itself. **Discussion and Conclusion:** An Automatic Matching system has been implemented and tested in 7T system. The advantage of this system is to be easily scalable to many independent channels suiting applications like receive array, notoriously hard to match due to elements coupling, mechanically adjustable coils and in general any coil that sees different load conditions. A good impedance measurement can be performed without high speed digitizers and impedances that minimize the noise figure of the preamplifier can be matched at any value of the complex plane. The matching network can work only for receive only coils since high power could direct bias the varicaps, attention has to be paid to have a good linearization of the gain phase detection chip. **References:** [1] Automatic Tuning of Flexible Interventional RF Receiver Coils, Ross D. Venook et al, MRM 54:983–993 (2005) [2] Mechanically Adjustable Coil Array for Wrist MRI, J.A. Nordmeyer-Massner et al, MRM 61:429–438 (2009)