Low-loss adjustable networks for automated matching of transmit coils

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Introduction: While multi element coil arrays have long been used in parallel MR imaging, they lack a system to automatically match each element to arbitrary loads. A mismatched element caused by a change to the sample translates to reduced RF energy deposition in it and therefore reduced excitation performance. Moreover, an automated matching procedure would benefit patients by reducing pre-scanning processes. To achieve this, a custom in-house, high power, wide range, low loss capacitor was designed and fabricated as a building element of a matching network dedicated to the transmit system of an MRI scanner, controlled autonomously and remotely by a piezoelectric motor of proven operability in ultra-high field [1].

Methods: Under the assumption that inductors are comparatively lossy elements to capacitors, a small variable capacitor able to withstand the high power output of a Philips 7T system has been designed, built and tested. Apart from the electrical properties taken into account in the design, mechanical constrains were introduced by the inherent limitations of the piezoelectric motor (SQUIGGLE motor, New Scale Technologies) which is responsible to adjust the variable capacitor to the preferred value. Mechanical criteria include minimum friction of moving parts, due to the reduced maximum force (5N) of axis' translational movement, along with the desire for a fixed galvanic connection of the capacitor. To satisfy them both, a topology of two identical flat capacitors connected in series was chosen. The adjacent plates are merged in one body and constitute the moving part of the capacitor. The outer plates are fixed and delegated for the galvanic connection with the rest of the circuit (Figure 1a). The fixed plates are square (12mm) printed on double sided PCB with FR4 epoxy substrate (ε~4.4, tanδ<0.02), at a distance of 3mm. They are connected via impedance controlled striplines to SMA cable connectors. On the other side of the PCB, opposite to the plates, the copper is removed to avoid leakage of capacitance through the substrate. Capacitor's electric field is concentrated on a ceramic dielectric (K0140, Kyocera) with high dielectric constant (ε~142), high breakdown voltage (8.2KV/mm) and low losses (DF~1 @ 1MHz). The dielectric is square (12mm±0.1) with thickness of 1mm±0.01, polished per request in order to reduce friction. The inner plates consist of a rectangular (10mm x 27mm) piece of PCB of identical specifications as the one of the fixed plates. The inner plates' PCB is placed on top of the dielectric and is free to move in one direction.

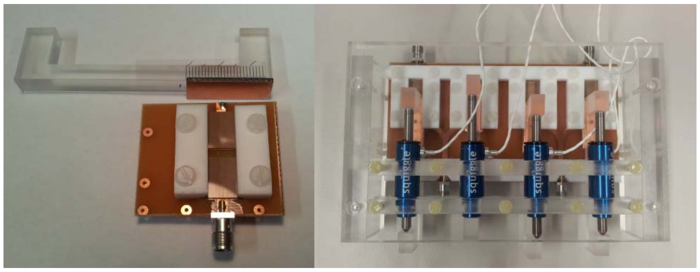

Figure 1. a) A single capacitor with its top plate disassembled, b) four capacitors, controlled by four motor, forming two distinct L-matching-networks.

The whole construction is fixated by hard Teflon walls (PTFE) in dimensions that allow the moving part to move smoothly, while keeping the rest in position. Teflon was chosen because of its excellent low friction property and its significant corona resistance. Since the edges of the capacitor are adjacent to the Teflon surface proper care needs to be taken to prevent breakdowns through the adjacent material.

The moving part of the capacitor is mechanically coupled to the piezoelectric motor with a glued PMMA piece which has one degree of freedom and is pushed back and forth by the tips of the motor's axis. The motor is hanging from the top cover of the box that contains two separate matching L-networks (Figure 1b).

The complete electrical characterization of each matching network by the 2-by-2 S-matrix for a combination of discrete positions is essential to automate the matching procedure. A sparse grid of 20-by-20 different positions of the moving part yields a pool of S-matrices with center frequency at 298MHz and span of 50MHz. Subsequently, the values of the S-matrices are interpolated linearly and result in a finer grid (153x153) of S-matrices which will serve as look-up data to solve for the matching problem. The one port matching problem for an element of a coil array [2] is solved analytically and the resulting S-matrix of the matching network is compared to the pool of interpolated S-matrices. The S-matrix with highest similarity is chosen and directly sets the appropriate positioning of the motors, which concludes the procedure.

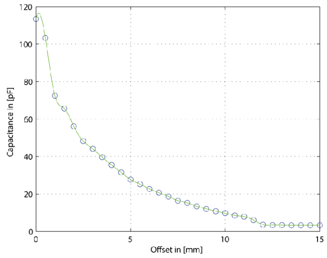

Figure 2. Capacitance range in relation to the offset.

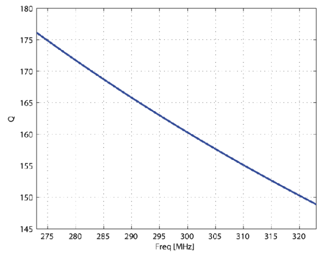

Figure 3. Measured Q in maximum capacitance.

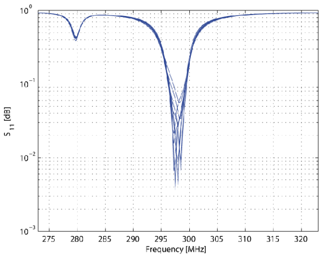

Figure 4. Arbitrary load matching at 298 MHz.

Results: Figure 2 demonstrates the full span (3.3-126pF) and Figure 3 the high Q characteristic (Q~150@298MHz) of the capacitor. The Q was modeled as an in series capacitor and the measured data have a standard deviation of 0.007 and 2.9 Ohm for the real and imaginary part of the impedance, accordingly. The reproducibility of a specific value was calculated over the 400 different combinations by repeating the measurement 4 times. There was no external intervention while the measurement was running instrumented by a computer responsible to acquire the data and control the motors. The average of the measurement standard deviation is 0.021 with minimum and maximum 0.0004 and 0.06, accordingly. The matching network was able to match the 50 Ohm line to the arbitrary load repeatedly with success (Figure 4).

Discussion: A low-loss, high power handling, extended range adjustable capacitor has been implemented as a block unit of distinct L-matching-networks. A fully automated procedure controlled by an external computer resulted in highly reproducible results. This suggests that the goal of per channel matching is achieved. Further investigation into different scenarios of loads and safety procedures needs to be taken before integration to a clinical system.

References: [1] Carl J. Snyder, et al. ISMRM 10:1523, [2] D. O. Brunner DO, et al. ISMRM 2007, p. 448