On the coil noise contribution to SNR versus coil diameter, temperature, frequency and load distance.

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INTRODUCTION

Recent years have seen a trend towards RF coil arrays with a very large number of elements to accommodate parallel imaging techniques (1) with bigger acceleration factors. If this large number of elements is applied towards the same region of interest, then necessarily the size of the array elements will have to shrink (2) and there will come a point where the elements' noise will be dominated by coil losses rather than patient losses (3), and therefore going to more even smaller elements does not pay off. For many years it has been shown that super-conductive coils can dramatically increase the unloaded Q of an RF coil (4) and therefore the point where coil losses become a significant part of the total noise is shifted towards much smaller coil sizes. The HTS material that is needed for such coils is however hard to work with, and cannot be bent into arbitrary shapes. It is easier to work with normal copper coils and cool them with Liquid Nitrogen. Significant improvements in unloaded Q are seen here as well, although not as good as with the super-conductive coils (5). A complete study of SNR benefits, including measurements at many different coil radii, frequencies, temperatures, and distances to the load has not been done before. It is the goal of this study to determine exactly when the coil noise becomes dominant: what is the smallest coil diameter and how close does it have to be to the load? The latter is of particular importance, since in practical coils there is an air gap between the elements and the patient, e.g. a head coil needs to accommodate 98% of all head sizes.

METHOD

Six sets of circular RF coils were made out of regular 2 ounce copper 1.4 mm FR4 printed circuit board. The coils were 2, 4, 6, 8 and 10 cm in diameter (center to center). The width of the trace was 6 mm. These sets of different diameters were then tuned to the proton frequencies at 0.2, 0.35, 0.7, 1.5, 3, and 7 Tesla i.e. 8.5, 14.9, 29.8, 63.8, 127.7 and 298 MHz. In total there were 30 circular coils. The number of capacitive junctions in the coils was chosen to keep all capacitor values well above 20 pF to reduce the possibility of energy leaking away via parasitic capacitance. Ceramic capacitors (ATC100B) were used that had a Q of 2000. A PVC container in the form of a cylinder was machined to contain liquid nitrogen for cooled experiments. The internal diameter was 11 cm. The outside surface was covered with foam for insulation. The load for our experiments was a large rectangular phantom, dimensions 15.2 by 15.2 by 38 cm, containing water plus 3.36 g/l $NiCl.6H_2O$, plus 2.4 g/l NaCl.. The phantom represented a similar load as a real person. When the PVC container with the RF coil was placed directly on the load, the distance between the coil and the phantom liquid was exactly 7 mm. Pieces of foam were used to vary the distance to the phantom. Small 50 ohm flux-probes (self resonance frequency >>300MHz) were used to measure the room temperature and LN_2 temperature Q of the unloaded coils in the PVC container. Subsequently the Q was measured at different temperatures and coil to load distances for all possible combinations of coil diameter and frequency. Baluns in the flux probe cables to the network analyzer prevented energy dissipation in the coax shields, and weak coupling to the RF coils under test, by means of probe-coil distance guaranteed that there was no loading effect on the RF coil from the probes themselves. Obtainable SNR improvements from cooling were calculated from the square root of the Q ratio.

RESULTS

Many data were obtained, with the most significant set of data shown here (the entire spreadsheet being too big for this abstract). Fig 1 shows the obtainable SNR improvement by cooling the coil from 295 K down to 77K, for all 5 diameters and all 6 frequencies, where the distance between the phantom and the coil was kept at 7 mm. Fig 2 shows similar data, but now for a coil to phantom distance of 25 mm. Repeating the same measurement several times revealed an accuracy of about 3%. It was furthermore found that at room temperature and a coil to load distance of 7mm,

the coil noise becomes significant (>10% impact) below a diameter of 4 cm at 298 and 128 MHz, below 6 cm at 64 MHz, below 8 cm at 30 MHz, below 12 cm at 15 MHz and below 18 cm at 8 MHz. These diameters will get larger with increasing distance to the load: 4, 6, 8, 12, 14, 18 cm respectively for the frequencies above at a coil to load distance of 25 mm.

Fig 1: SNR improvement with LN_2 , load distance is 7 mm

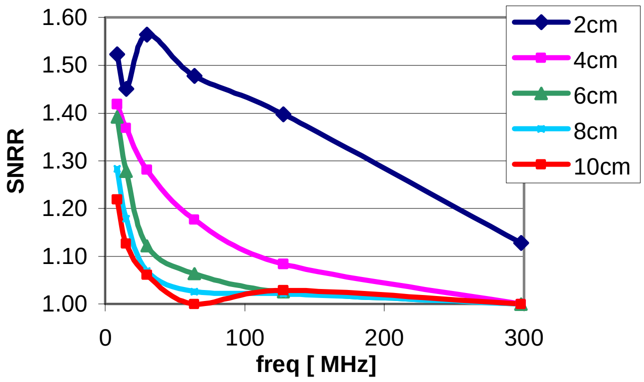
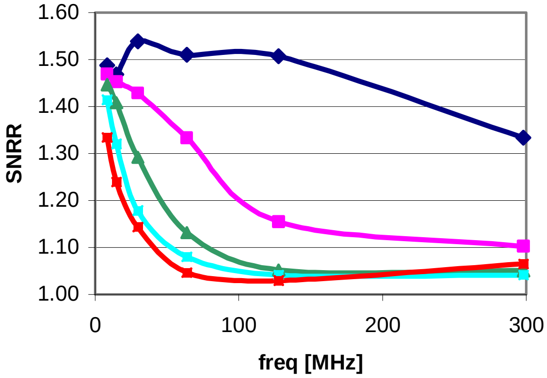


Fig 2: SNR improvement with LN_2 , load distance is 25 mm



DISCUSSION and CONCLUSION

It has been known for a long time that cooling the coil will reduce the coil losses. With parallel imaging becoming more popular, and high channel count the norm, cooling the coils may be inevitable if we want all small coil elements to stay patient noise dominant. The data above show that even at 300 MHz significant gains can be made if coils get smaller than 4 cm diameter, contrary to the believe that it only helps at low frequencies. In commercial RF coils the distance between coil and patient is sometimes significant to allow applicability to a large percentage of patient sizes, and that pushes the coil diameter for coil noise dominance upward.

In conclusion: this experiment shows coil Q data, and obtainable SNR improvements for a large variety of coil sizes, frequencies, load distances and temperatures, which is useful for the design of large channel count coil arrays for parallel imaging.

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