The efficiency of 3T body transmit array coils

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INTRODUCTION

Body imaging at 127 MHz (3T protons) has shown significant inhomogeneities in the RF transmit field due to wavelength effects and permittivity of tissue. Proposed techniques to counter these effects like B_1 shimming and Transmit Sense all require a whole Body transmit array coil [1]. The only exception is if one is limited to 2 transmit channels. In that case a regular birdcage coil with 2 orthogonal input ports can be applied. Utilizing all modes in a degenerate birdcage as an array is also possible [2]. Since each element in a whole body transmit array excites only a small portion of the volume, and is usually much closer to the RF shield than to the patient, coil losses are dominant, and significant RF power is needed per element to create B field in the center of the coil volume. Due to the dominant coil losses, the volume transmit array heats up, causing possible failure or detuning. It is the purpose of this investigation to compare the power efficiency of different transmit array designs.

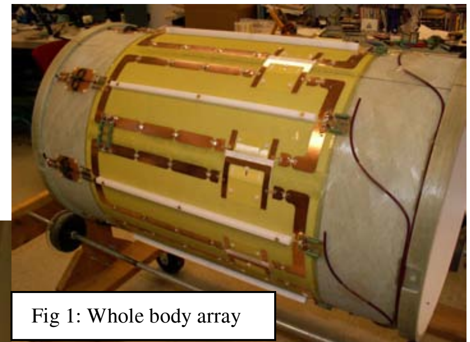

Fig 1: Whole body array

METHODS

A 3T whole Body 8 channel RF transmit array coil (Fig 1) was constructed with a patient bore of 600 mm. The elements of the coil were at a diameter of 614 mm, the RF shield consisting of a fine copper mesh (325 lines/inch), was at a diameter of 650 mm. This whole body coil had 8 rectangular elements of dimension 190 by 560 mm center to center. Copper strips are 1 inch wide. Each loop has 12 capacitive junctions of 36 pF each. Rectangular loops are separated by 64 mm center to center. Body coil elements had an isolation of at least –15 dB with any neighboring element due to special overlap boards created to minimize coupling. Cable trap baluns were applied to minimize energy transfer into common mode cable currents. Images were made in a 3T MR scanner with 8 transmit channels to determine its efficiency and flip angle distribution. Temperature rise measurements were performed with 2 ms square pulses 5% duty cycle at a net forward power of 2 KW into each channel. Apart from this full size coil, 3 scale models were developed: A 41% scale model of the same 8 loop coil design was constructed on an acrylic former (Fig 2). The coil elements were at a diameter of 10 inches, and the RF shield was at a diameter of 10.5 inches. Loops were 68 by 230 mm with a 28 mm separation from neighbors. It was decided to keep the scale models on 127 MHz so the coil could be used in the 3T system. Each loop element had 4 junctions of 33 pF.

In addition to the loop array scale model 2 TEM transmit arrays, an 8 channel and a 16 channel (Fig 3) version of the same diameter as the 8 loop scale model, were constructed. The strips were ½ inch wide, and 190 mm long so that the Z field of view (-3 dB points) would be the same as in the 8 loop model. Each strip was connected to the shield via a 45 pF capacitor. One end of the strip was matched to 50 ohms. All scale models had better than –15 dB isolation with any neighbor due to the application of well known decoupling transformers or capacitive networks. All scale models had 50 ohm micro-stripline baluns. Models were connected to either an 8 way or a 16 way splitter, and phase shifters chosen such that a homogeneous birdcage mode was emulated via a cosine distribution of current phase. Full S parameter matrices were measured for all of the models. A calibrated flux probe was then placed in the center of all coils to measure the B^{+}_1 field generated by a standard amount of net forward power, corrected for reflected power, coupling to neighbors, and losses in the splitter, phase shifters and cables. The flux probe was constructed from semi rigid coax to prevent it from picking up E fields. The cable connecting the fluxprobe to the analyzer was routed via the axis of the coil and had multiple baluns to prevent cable modes.

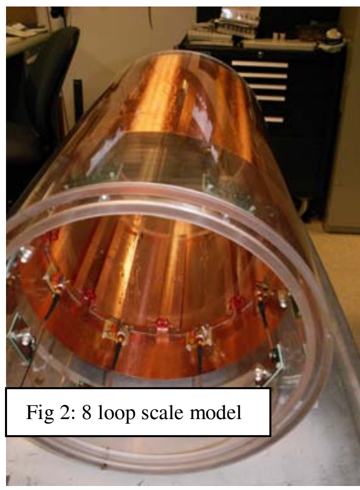

Fig 2: 8 loop scale model

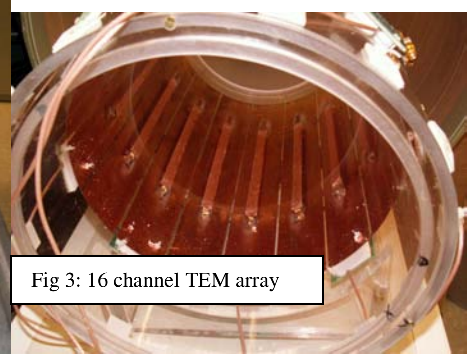

Fig 3: 16 channel TEM array

RESULTS and DISCUSSION

The whole Body array had elements with a Q of 360, which decreased when loaded with a person from 120 for those elements touching the shoulders to 340 anterior to the patient. Each element produced 3μT of peak B_1 in the empty coil center at a net forward power of 2KW. Temperature rise was plotted over time for 2 KW 2 ms square pulses with a duty cycle of 5% into a single element in the empty coil. Thermal equilibrium was reached after 20 minutes with a bore temperature rise of 40 degrees C.

The scale model 8 loop design and the TEM arrays had empty Q's of 164 and 160 respectively. In both cases there was negligible Q change when inserting a rectangular phantom 15 by 15 by 38 cm with 3.368 g/l $NiCl_2 \cdot 6H_2O$ and 2.4 g/l NaCl. Calibrated measurements on the scale models show that the 8 channel TEM and 16 channel TEM arrays are respectively 1.1 and 3.5 dB more efficient than the 8 loop design when emulating a cosine current distribution as in the homogeneous mode of a birdcage.

CONCLUSIONS

The small distance between the coil elements and the RF shield make these arrays very inefficient. Add to this the fact that none of the elements sets up a B field that is homogeneous throughout the volume as would be the case in a birdcage, as well as the fact that in the 8 loop design adjacent conductors from neighboring elements carry currents that are 135 degrees out of phase in this emulated mode, and one gets an array where most of the power is converted to coil heat, rather than B field. The TEM design wins from the loop design because there is no similar cancellation of B field from neighboring conductors. The 16 element TEM wins from the 8 element TEM because most losses are coil losses (theoretically one would expect a 3 dB efficiency difference, compared to the 2.4 dB measured). In general transmit arrays with this shield distance are inefficient, coil losses dominate resulting in a rise in coil temperature. Better arrays can be built by increasing the coil to shield distance, and by going to a TEM style array with as many elements as possible. If the number of transmit channels is smaller than the number of array elements, several elements can be combined via a splitter and phase shifter and still result in an efficiency increase over the smaller array element count.

REFERENCES

[1] P. Vernickel et al. proceedings of the ISMRM annual meeting, Seattle, 2006, abstract 123

[2] J. Nistler et al. proceedings of the ISMRM annual meeting, Seattle, 2006, abstract 2566