A Novel Radiolucent Phased Array Design Suitable for MR Guided Radiation Therapy

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Introduction:

MR guided Radiation Therapy (MRgRT) is a new hybrid technique that combines MR's soft tissue contrast for better accuracy in tumor delineation during the planning stage and reduction of healthy tissue damage during the treatment stage with Radiation therapy equipment such as LINACs. One more important aspect of such a hybrid system is the real time monitoring of the motion for the radiating tissue using MR. In such an occasion RF coils that are both radiolucent and MR compatible are placed as close as possible to the anatomy in the region of interest in order to achieve high signal-to-noise ratio (SNR). As a workflow benefit it is ideal to leave the coils in place during radiation therapy treatment. Recent attempts to design radiolucent coils have used aluminum as the conductor and have been successful [1]; however, aluminum coils have higher resistivity than copper which reflects in lower Q and subsequently lower SNR values for these coils. In addition aluminum is not an easy material to work with for RF coil fabrication.

In the present paper a novel RF coil design for spine and abdominal imaging is proposed [2]. The 8 channel phased array coil contains a combination of copper and dielectric layers such that there is no compromise on the imaging performance of the RF coil, while the imaging area of the coil appears transparent to X-ray radiation. The radiolucent coil structure can be placed into the patient couch without impeding X-ray imaging or radiation treatment. The proposed design does not include any lumped element components that could alter its X-ray signature. Preliminary results indicate that the proposed design has 20% higher Q and 10% better SNR than an equivalent aluminum coil structure. In addition, the proposed phased array structure in the imaging area has a uniform X-ray transparency of 1.1mm Aluminum equivalence (Aleq)[3], well below the 2.3 mm which is the required federal limit [3]. Volunteer imaging with the coil was performed indicating that the proposed design is ideal for covering the abdominal area.

Materials and Methods:

A prototype 8 channel phased array coil was constructed with a combination of thicknesses of copper and substrate such that it will be transparent during X-ray imaging and radiation treatment therapy (see Figure 1). The configuration comprises of 4 mutually decoupled loop arrays on each anterior and posterior parts with a targeted MR/X-Ray imaging volume of 40 cm in transverse and 20 cm along the S-I directions. In order for the coil to be transparent to X-ray imaging, all loops on the loaded condition were tuned to a desired frequency of 63.6MHz with no lumped components inside the X-ray volume. For the 8 channel phased array design, the copper thickness was chosen to be 1.0oz while the FR4 Substrate was measured to be 0.030" (0.762mm) in order to achieve uniform transparency for X-ray imaging. Unloaded Q of each of the loops was measured to be above 200, while the isolation between loops was measured to be better than –14 dB without pre-amp decoupling. . Including the active decoupling circuit and preamplifier effects, the unloaded Q of the elements is ~265, with an unloaded to loaded Q ratio of 4.8. For X-ray imaging of a component, FDA standards specify the maximum aluminum equivalence of objects between the patient and the image receptor to be 2.3 mm [3]. The maximum X-ray attenuation of each set of the array was measured utilizing a 100kV X-ray hard beam from a Siemens Artis biplane Angiography system and is measured to be 1.1mm.

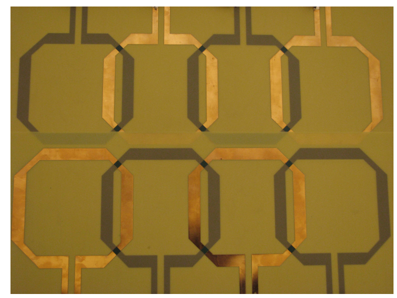

Figure 1. X-ray compatible coil

Figure 2. X-Ray image of the copper coil

Results:

In regards to MR imaging, performance comparisons between 2 loops of the 8 Channel copper array and a 2 loop aluminum array was made. For SNR comparison, a SE sequence using a Siemens 1.5 T Espree with TR/TE=300msec/10msec, slice thickness=3mm and FOV =25cm was performed. The SNR for the copper coil utilizing a 7.5 liter phantom solution of ($NiSO_4x6H_20/NaCl$) was measured to be SNR (Cu) = 72 while the SNR of the aluminum coil using the same phantom was measured to be SNR (Al) = 66.

X-ray imaging was also performed to determine the transparency of the 8 channel array. Using the Siemens Artis Biplane the X-ray imaging of the anterior part of the array was performed to evaluate the transparency of the coil structure. Figure 2 shows the X-ray signature of the coil structure. As the figure indicates there is no distinction between the Copper traces and the substrate which indicates a very uniform attenuation of the X-ray along the entire structure.

Volunteer imaging was also performed on a 1.5 T Siemens Espree system to evaluate the performance of the X-ray radiolucent 8 channel array. The prescribed protocol was targeting the abdominal area of a healthy volunteer (Figure 3) using a T2 HASTE sequence with IPAT=2 and TR/TE=1300/90ms, FOV=253mm*350mm.

Figure 3. T2-HASTE image

Conclusion:

A novel design of an 8 channel radiolucent phased array for MR guided Radiation Therapy was presented. The proposed design exhibits superior MR performance characteristics when compared with the equivalent aluminum design. In addition, the proposed design exhibits a uniform X-ray transparency image with no apparent distinction between the copper and its surrounding substrate, having a measured aluminum equivalence of 1.1mm. Volunteer imaging was also performed indicating that the proposed structure can be ideal for abdominal imaging.

References:

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[2] W. Schellekens, G. Scarth, RF Coil for MR Imaging which is not Visible in X-ray Image, U.S. Provisional patent application 826,191
[3] FDA, Code of Federal Regulations Title 21, section 1020.30