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Rotating Linac-MR: B_0 Orientation Invariant Quadrature Detection

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INTRODUCTION

The 0.5 T rotating B_0 Linac-MR consists of a dual solenoid magnet MRI that is mounted on the same gantry as the linear accelerator used for radiotherapy[1]. Sharing a gantry means the main magnetic field (B_0) remains parallel to the treatment beam at all gantry angles. This parallel oriented system leads to minimal dose distribution perturbation due to the magnetic field and avoids tissue interface dose effects due to electron return effect[2].

Mounting the magnet on a rotating gantry creates a unique MRI system where the orientation of the B_0 changes with gantry angle and so may change between acquisitions. The rotation occurs around the axis parallel to the length or AP direction of the patient table. Precession of the nuclear magnetization then can always be detected along this axis during imaging. However to have quadrature-like sensitivity, the second component of the radio frequency (RF) magnetic field must also be detected, and unlike conventional systems, the orientation of the second component of RF signal changes with gantry angle and is always perpendicular to the beam axis and B_0.

AIM

The aim is to develop a planar, out of beam, three channel RF-coil array that will have quadrature sensitivity in a rotating B_0 Linac-MR. Its performance should be uniform across gantry angles and must better than a single coil doing linear detection.

METHODS

The design combines three co-axial coils (Figure 1): a single turn coil and two orthogonally oriented butterfly coils[3]. The advantage of this design is that the coils are electromagnetically isolated while sharing the same disk and taking up minimal physical space. The array is sensitive to RF signal in any plane, and due to the symmetry of the butterfly coils, if positioned standing on the table top should achieve gantry angle independent performance.

Each coil is was designed in KiCad and printed on a double-sided PCB (70 µm copper, 6 mm wide traces) with the two butterflies sharing a PCB. Each buttefly is a split 24 cm ⌀ loop. The single turn (24 cm ⌀) coil was on a separate PCB for isolation adjustment. Tuning and matching was adjusted to ensure best performance of each channel. Isolation was measured and adjusted to better than -12dB though the addition of copper tape to strategically alter the coupling between the coils.

Imaging tests were carried out on the 0.5 T Alberta Rotating B_0 Linac-MR (Figure 2).

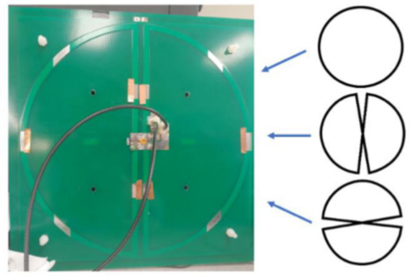

Figure 1 – Planar design of the three channel array consisting of a single turn coil and two orthogonally oriented butterfly coils (respectively horizontal and vertical).

Figure 2 – Imaging set-up on the Alberta Rotating B_0 Linac-MR (magnet at 0°). The coil can be seen standing next to a cylindrical phantom.

RESULTS

Bench measurements show that each of the coil channels has high Q and the decoupling between the channels was sufficient (Table 1). The single turn coil channel can be considered for comparison with the array's performance.

Imaging performance varied only slightly across gantry angle. Qualitatively the extent of the phantom (19 cm ⌀, 15 cm high, 55 mM NaCl & 5 mM NiCl2; ASG Superconductors, Genova, Italy) is well captured at all gantry angles. The sensitivity pattern of coil array is also very similar at all three gantry angles (Figure 3).

Quantitatively, the SNR was determined from the ratio of the signal magnitude at the center of the image and the standard deviation of noise images acquired by nulling the excitation pulse[4]. For the axial slices, the SNR varied across gantry angle slightly (Figure 5). The maximum combined SNR (weighted root sum of squares [wRSS] combination[5]) occurred at 0° and the minimum at 45°. More interestingly, the two butterfly channels individually showed the expected behaviour of having significant (factor of 3) changes in SNR from optimal gantry angle to poorest gantry angle. Due to the orthogonal orientation of the butterflies their maxima and minima occur 90° out of phase so their root mean square was approximately constant across gantry angle. For the axial slice, the three channel array achieved SNR approximately double that of the single turn coil channel.

Isolation between channels was also evaluated using noise correlation between the three channels (Figure 4).

Table 1 – Coil Quality and Coil Element Decoupling

Coil Element	Q-value	Coupling to Next Coil Element (dB)
Single Loop	100 +/- 10	-16
Horizontal Butterfly	80 +/- 10	-12
Vertical Butterfly	95 +/- 10	-25

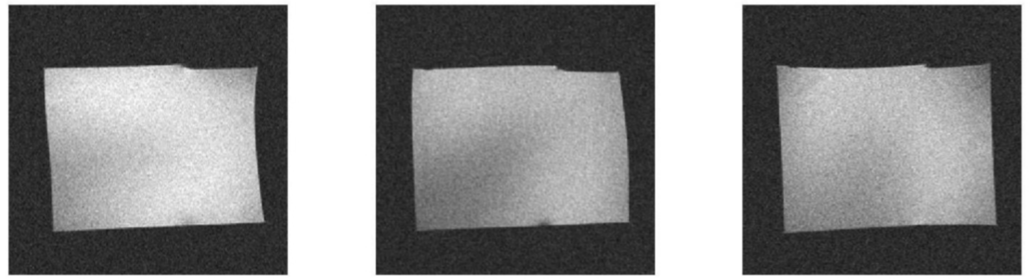

Figure 3 – Example weighted root-mean-squares (wRSS) reconstructed combined images from the three channel array at three gantry angles, 0°, 45° and 90° (left to right). These images are axial slices through the center of the phantom; 9.5 cm from the array.

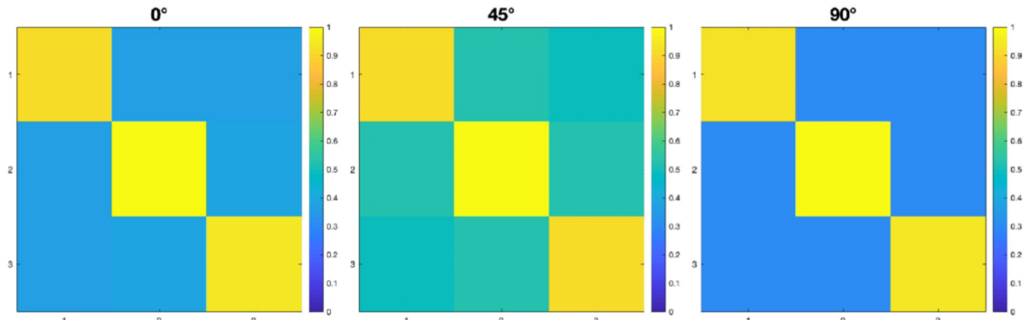

Figure 4 – Noise correlation between the three channels at gantry angles 0°, 45° and 90° (left to right).

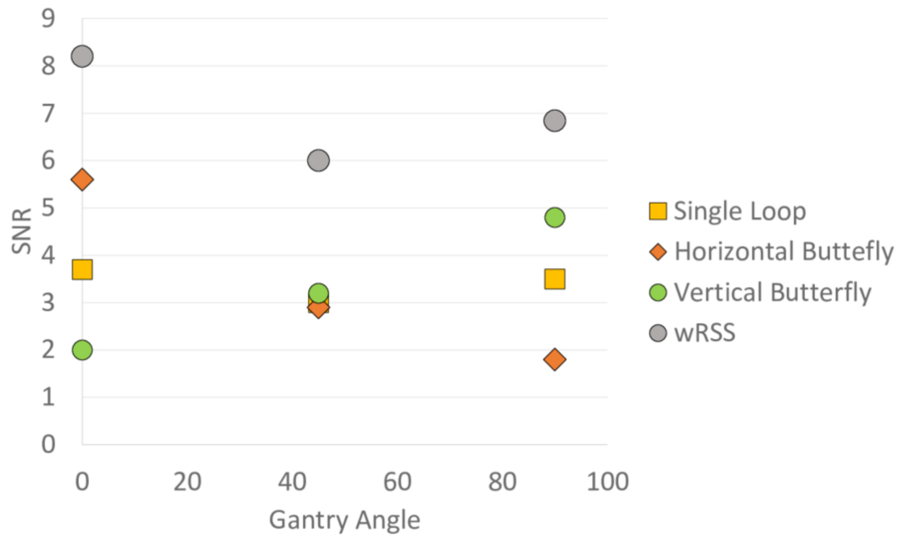

Figure 5 – Gantry angle dependence of SNR achieved with each coil channel and the combined wRSS image. The two butterfly coils, horizontal (orange diamonds) and vertical (green circles) are rotated 90° relative to one another. When the gantry angle is 0° the main magnetic field is vertical. Thus in this position, the vertical butterfly is parallel and detects little of the precession which is occurring in the perpendicular plane. The SNR of the combined image is dominated by that of the single turn and horizontal butterfly. This situation is same but with the vertical butterfly at a gantry angle of 90°. At 45°, the two butterflies each contribute, but their root sum of square is such that the total coil array SNR remains approximately the same as at the extremes.

CONCLUSIONS

A three-channel array achieves uniform sensitivity at all gantry angles was realized by combining a single turn loop with two butterfly coils. Despite the rotation of the main magnetic field the performance of the array remains approximately constant thanks to the compensatory behaviour of the identical butterfly channels that are rotated 90°.

The planar arrangement of the channels means the coil can easily be positioned on any external surface of a patient and can easily be placed outside the beam. While the chosen planar design has limitations in decoupling of the adjacent channels, tolerable noise correlation can still be achieved.

In comparison to a single turn, linear reception coil, the array achieves double the SNR at every gantry angle, due to the use of multiple coils to receive signal.

This work highlights that novel combinations of existing technology can be an effective way to maximize the SNR of the Rotating B_0 Linac-MR

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