

SEA imaging using a dual planar array and fourth gradient coil for phase compensation

John C. Bosshard¹, Mary P. McDougall^{1,2}, and Steven M. Wright^{1,2}

¹Electrical & Computer Engineering, Texas A&M University, College Station, TX, United States, ²Biomedical Engineering, Texas A&M University, College Station, TX, United States

Introduction:

Single Echo Acquisition (SEA) imaging [1, 2] allows acquisition of an MR image in a single echo by employing an array of RF receive coils with confined field patterns. Because the voxel size is comparable to the coil dimension, the B1 phase gradient due to the RF coil elements results in intravoxel signal cancellation, a complication found early in using this technique and discussed in detail elsewhere [3]. As this phase gradient is approximately linear, a gradient pulse imparting an opposite phase gradient in the sample has been used to compensate for the coil phase. However, the coil phase gradient reverses on opposite sides of the array, restricting the SEA technique to uniplanar arrays or requiring a more complicated transmit / receive configuration [4] when using coils of cylindrical or other geometries. This paper shows that a fourth gradient coil which produces a field linearly varying in two directions [5] enables SEA imaging with arrays of dual-planar or “sandwich” configuration, allowing simultaneous rapid imaging of dynamic processes occurring at the boundaries of a sample. This platform also allows high resolution imaging over slabs, useful for MR microscopy and histology [6], however the fourth gradient is not necessary at high resolution as the voxel size is small relative to the coil.

Methods:

A biplanar fourth x-gradient coil designed using the target field method [7] was constructed of 4 oz double sided copper clad board using an in-house milling machine. The boards were attached by epoxy to several layers of FR-4 and mounted to an acrylic former. An RF volume excitation coil and a removable array and sample platform were also integrated into the former, shown in Figure 1. The entire probe is inserted and locked into the 26 cm ID system gradient coil. By designing an x-gradient coil with symmetric current in the top and bottom planes at $y = \pm 4$ cm, the field reverses at the $y = 0$ cm plane, resulting in a gradient G in the magnetic field B described by $G = \partial^2 B / \partial x \partial y$, with 5% linearity over a $6.4 \times 6.4 \times 1$ cm sample.

The sandwich receive coil array is positioned with its top and bottom planes symmetrically spaced about the gradient reversal plane such that the phase compensation gradient reverses midway between the array planes, with a small offset in positioning correctable by pulsing the system x-gradient. This results in the region of the sample near the top and bottom arrays experiencing opposite phase compensation gradient pulses, allowing simultaneous SEA imaging of the top and bottom of the sample. As evident from the above equation describing the gradient field, because the coil produces a y varying x-gradient, it must also produce an x varying y -gradient. This unwanted gradient results in through-slice dephasing and reduced signal at the edges of the FOV, but is not a significant problem with slice thicknesses less than 0.2 mm when the fourth gradient is set to produce a phase gradient of ± 25 rad/cm over a 1cm slab.

A non-selective RF pulse was applied to an integrated volume RF coil and a set of SEA images was acquired using two 32 channel arrays of planar pair coil elements positioned above and below a 1.3 cm thick sample. The phase encode table served as a method of sweeping phase compensation gradient values with the acquisition repeated for different amplitudes of the fourth gradient, which was controlled by LabVIEW. The echoes were stacked in a 4D matrix (channel, RO, PE, fourth gradient) and SEA images were extracted using the compensation values producing the best images from each array.

Results and Discussion:

Using the fourth gradient coil to provide slice dependent coil phase compensation, SEA images were obtained simultaneously from two 32 element planar pair arrays positioned above and below a sample, as shown in Figure 2. The number of coils contributing to each image is half of previous SEA images because a 64 channel receiver is used to receive from two arrays simultaneously. Without the fourth gradient, the system gradient can be selected to provide appropriate phase compensation, indicated by k-line number, to yield a SEA image from either the top or bottom array but not both simultaneously. There is some distortion at the left and right edges of these images due to the simultaneous effect of the x dependent y -gradient and the B1 gradient of the RF coil. If two thin slices were simultaneously excited rather than the entire slab, the distortion could be replaced by loss of signal intensity. Extending the SEA technique to both sides of a sample will facilitate applications in which dynamic conditions at the top and bottom boundaries are of interest, such as in non-periodic flow or MR elastography.

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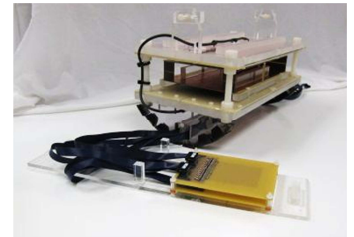


Figure 1. Fourth gradient coil with integrated RF volume excitation coil shown with an insertable 64 element planar pair receive array in a “sandwich” configuration.

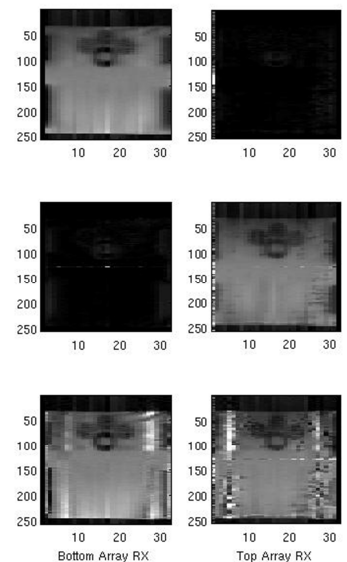


Figure 2. SEA images acquired by the bottom array (left) and top array (right) resulting from compensation gradients of k-line 134 (top row), k-line 124 (middle row), and k-line 129 with the fourth gradient set to produce a variation of ± 4 rad/cm over a 1cm slab (bottom row). Employing the fourth gradient yields images from both arrays simultaneously.