Investigation of slice excitation using transmit arrays and non-selective RF pulses

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INTRODUCTION

Curved slice generation was introduced and discussed by Börnert, targeting imaging of the spine in the neck and pelvic region as well as imaging of the cortical surface of the brain [1], and was later examined by others as well [2]. The method essentially consists of tailored 2D or 3D RF pulses, with time consumption and complexity being known challenges. The escalation of work at high fields has renewed the interest in selective RF excitation, and thus reducing the time consumption (and managing the RF power deposition) of these types of complex RF pulses has been the catalyst behind much of the parallel transmission work examined recently [3-5]. This paper examines an alternate method for curved slice generation using simple non-selective RF pulses and the rapidly varying field pattern (i.e. tipping bands) of long and narrow array elements, such as those used in the array geometry for Single Echo Acquisition (SEA) imaging [6]. In this way, a slice is generated in a plane that follows the array surface, with the depth controlled by varying the duration or power of the hard RF pulses. Proof of principle in a plane and along a curved surface was conducted with 8 elements using a "forced current excitation" technique in which transmission line lengths guaranteed load independence and thus equal element currents [7-9]. A 64 channel transmitter [10-11] was then used to excite a 64 element planar array to obtain initial results in planar slice generation over a larger surface using variable power levels and phase control.

METHODS

The "forced current excitation" technique was borrowed from the antenna literature [7-8] and utilizes transmission line behavior to enforce equal currents at each element, independent of the load impedances (and mutual impedances). The concept is diagramed in **Fig. 1** for use in discussion: From transmission line theory, the voltage along a transmission line can be expressed as $V(z) = \frac{I_L}{2}\left[(Z_L + Z_0)e^{\gamma z'} + (Z_L - Z_0)e^{-\gamma z'}\right]$, where I_L is the desired load current, Z_L is the load impedance (a function also of mutual impedances between coils), Z_0 is the characteristic impedance of the line, and γ is the propagation constant. Setting the line length (z') equal to a quarter wavelength results in an expression that shows a load current dependent only on the characteristic impedance and the voltage at the common point: $I_L = \frac{V\left(\lambda/4\right)}{jZ_0}$. Using this feed structure to eliminate the effects of coil to coil coupling gave us an effective technique to study the proposed slice generation methodology. For initial testing, an 8-element array of planar pair coils similar to the geometry used for the SEA array [6] was constructed on FR-4 PC board, fed at a single point, with quarter wavelength lines splitting from that point to each element. Images were acquired to assess the effects of coil-to-coil field pattern interactions/cancellations that were expected due to modeling. All images were acquired using a 4.7T/33cm scanner and Varian Unity/Inova console, gradient echo sequence (TR/TE 500/7msec), non-selective RF pulse transmission through the array coil, and reception with a volume coil. Field cancellation was observed (discussed further in 'results'), and half-wavelengths of transmission line were added to alternating elements, reversing the phase between adjacent elements (see **Fig. 1** for clarification) to create uniform excitation over the surface of the array. The FCE technique was then employed to feed 8 elements (out of 32) of a flexible array wrapped around a 4.1cm diameter cylindrical phantom and the imaging procedure was repeated, this time increasing the non-selective RF pulse power through the array to observe control over the depth of the curved slice that was generated.

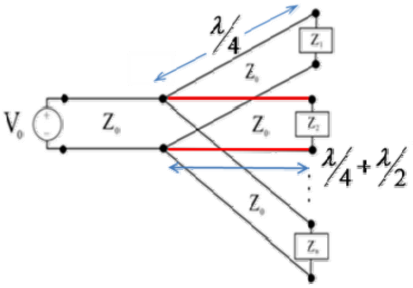

Fig. 1 Diagram of the "Forced Current Excitation" technique for feeding a multi-element array at a single point and using line lengths to enforce equal currents independent of loading.

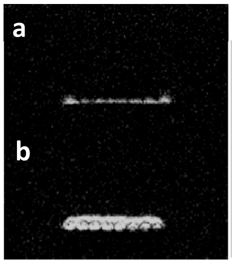

Fig. 2 Axial images through an 8-element array fed using the FCE method (a) with in-phase elements, showing field cancellation between elements and (b) with alternating elements 180° out of phase, showing uniform excitation over the array coil.

Following the promise indicated by the FCE experiments, a 64 channel transmitter constructed in-house [9,10] was used to excite a 64-element array of planar pair coils with exactly the same footprint and planar geometry as the original SEA array coil, but tuned with variable capacitors rather than varactors so that the array could be used for transmission. A single RF source (from the Varian scanner) with -15dBm power level was used and the power levels and relative phases on the 64 channels were adjusted through the GUI interface for the transmitter. The same gradient echo imaging procedure was used: transmission with non-selective RF pulses of increasing power through the array, and reception with a volume coil. The 180° phase shift between alternating elements was applied using the control interface for the 64-channel transmitter.

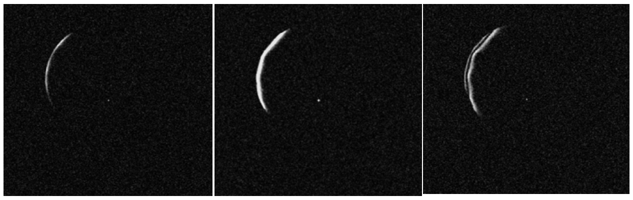

Fig. 3 Curved slice generation using non-selective RF pulses transmitted through an 8-element flexible array wrapped around a 4.1cm diameter phantom. Power was increased from left to right, increasing the depth of excitation. Uniform excitation of a second tipping band is observed at the highest power level.

RESULTS & DISCUSSION

Figure 2 contains the images obtained from the 8 element planar array fed using the FCE method with and without 180° phase alternation between elements. We had previously modeled the array and anticipated the field cancellations when the elements were in-phase, and the uniform excitation parallel to the plane of the array when the elements had alternating phases. **Figure 3** shows the successful generation of curved slices using non-selective RF pulses of increasing power transmitted through a conformed array using the FCE method. **Figure 4** contains the initial efforts to recreate the experiment using our 64-channel transmitter and a 64 element planar array. The coil-to-coil coupling, even in small amounts, is shown to heavily influence the ability to uniformly excite a slice, particularly visible at the higher power level. While this was obviously the most advantageous aspect of employing the FCE method of excitation for initial testing, the FCE method is limited in (at least) two respects: 1) it is difficult to use the array coil in T/R mode, and, 2) while this case works with 180° out-of-phase currents, that may not be optimal in all cases. Therefore the immediate future work for this project involves optimization of the slice excitation using the transmitter control capabilities. The general method of slice generation over the conformed surface of an array, however, has been shown to be feasible, and, due to the speed of the slice generation using non-selective pulses, is an ideal technique to use in conjunction with SEA imaging or other applications where imaging of curved surfaces would be required.

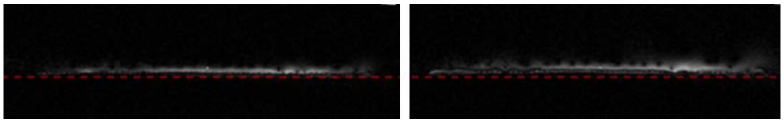

Fig. 4 Axial images through a 64 element planar array coil using non-selective RF pulses at increasing power levels (left to right) delivered by a 64 channel transmitter constructed in-house. The dashed red line indicates the bottom of the phantom. Element-to- element coupling affects the ability to generate controlled uniform slice excitation at depth; however the transmitter control system is capable of optimization in the future.

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