Reduced FOV excitation using a SPSP pulse and a static second-order shim gradient

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Purpose

In imaging, sometimes only a particular region of the object is of interest. However, reducing the FOV results in aliasing, while encoding the full FOV requires greater scan time. Various methods exist to excite a reduced FOV. Multidimensional RF pulses provide spatial selectivity in more than one direction by encoding the RF in multidimensional k-space [1]. Spatial selectivity in three dimensions, however, requires pulses that are prohibitively long. One solution is to use parallel excitation and exploit the different spatial sensitivities of the coils to shorten the RF pulse [2], but parallel transmit hardware is not available at most MRI sites. Another solution uses saturation bands on regions outside the target FOV [3], but is usually not perfect in practice due to heterogeneous saturation. A new method to excite a reduced FOV was developed by [4], and uses a spatial-spectral (SPSP) pulse in the presence of a static $Z2$ gradient to excite a disc-shaped region. The $Z2$ gradient is used on many MR scanners for shimming, thus, the method may be easily implemented widely. The method was used to excite thin slices at isocenter. Here, we extend the method to excite thicker regions at arbitrary locations.

Methods

The $Z2$ gradient produces a field $B_0(x,y,z) = G_{Z2}(z^2 - (x^2+y^2)/2)$ (see Figure 1), where G_{Z2} is the gradient amplitude. The field is circularly symmetric in the x-y plane, so a SPSP with a given bandwidth will excite a disc-shaped region if the disc is thin, i.e. $\Delta z \ll r$, where r is the target radius and Δz is the slice thickness. Note that it is also possible to design a SPSP pulse to excite thicker slices by matching the center frequency of the passband to the frequency at the center of the FOV along z (see Figure 2). The FT of such a response may be difficult to calculate analytically, and thus may necessitate sampling the transform along the k-space trajectory to design the pulse. We require a bandwidth $BW = \bar{\gamma}|G_{Z2}|r^2$ (assuming the center of the field is on-resonance) and maximum k-space extent $k_{\max} = TB/2\Delta z$, where TB is the time-bandwidth of the subpulses (see Figure 2). To avoid excitation from the opposed null, we require $\Delta T < (2\bar{\gamma}G_{Z2}R^2 + BW)^{-1}$, where R is the radius of the object in the slice of interest. Shifting the FOV can be done by first shifting the field with the addition of linear gradients and a frequency offset:

$$\begin{aligned} B_0(x-x_0, y-y_0, z-z_0) = {} & G_{Z2}(z^2 - (x^2+y^2)/2) \\ & -2G_{Z2}z_0z + G_{Z2}x_0x + G_{Z2}y_0y \\ & +G_{Z2}(z_0^2 - (x_0^2+y_0^2)/2) \end{aligned}$$

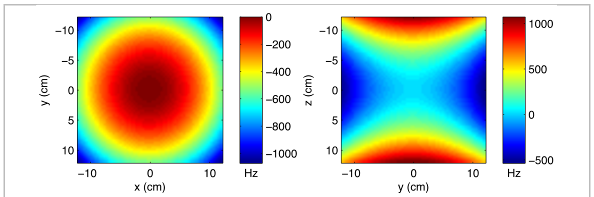


Figure 1: B_0 map produced by $Z2$ gradient.

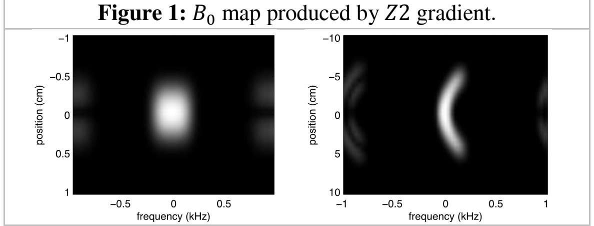
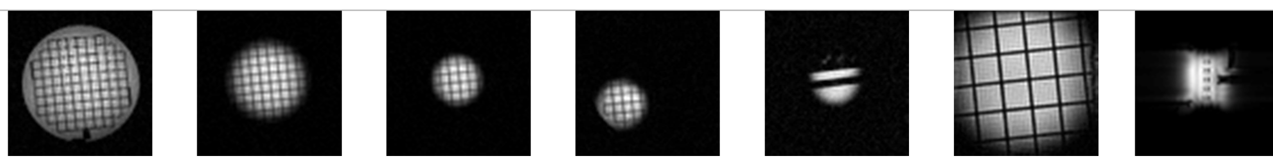


Figure 2: Spatial-spectral responses for a) r = 4 cm, Δz = 0.5 cm, b) r = 4 cm, Δz = 10 cm

The same SPSP can be used for shifts in x or y if the opposed null still falls outside the object. For a shift in z, however, frequency (or phase) modulation must be applied, with $\Delta f = \bar{\gamma}G_z z_0$, where G_z is the amplitude of the RF encoding gradient. To calculate the G_{Z2} amplitude, a B_0 map was collected using a 3DFT dual-echo B_0 mapping sequence, with matrix size = 64 x 64, FOV = 24 cm, and ΔTE = 0.5 ms, and a second-order polynomial was fit across the B_0 map along z at $r = 0$. Using the relationships described above, SPSP pulses were designed to excite target regions of different sizes and at different locations (see Figure 3). Images were acquired with a 2DFT sequence with matrix size = 64 x 64, FOV = 24 cm, and Δz = 0.5 cm, unless otherwise noted.

Results



a) b) c) d) e) f) g)

Figure 3: Full and reduced FOV acquisitions using a grid phantom. a) FOV = 24 cm, b) r = 6 cm, c) r = 4 cm at isocenter, d) at $x_0 = y_0 = -4$ cm, and e) at z_0 = 4 cm, f) r = 4 cm and FOV = 8 cm, g) r = 4 cm, Δz = 10 cm (side view projection)

Discussion

A SPSP and $Z2$ gradient were used to excite a thin disc-shaped region. By applying linear gradients, a frequency offset, and RF frequency modulation, the target region was shifted in x, y, and z. A SPSP whose passband varies with z was used to excite a thicker cylindrical region. Reduced FOV excitation using this approach can be combined with 2D or 3D imaging, and used to increase spatial resolution, increase SNR, or reduce scan time. The method, however, has various limitations. The $Z2$ gradient can no longer be used for shimming, and because it is static, it must be treated as a source of off-resonance and require correction for long echo times or readouts. Because the spectral component of the SPSP now controls spatial selectivity, it cannot be used to target a specific chemical species, i.e. water. The $Z2$ shim gradient is weak, producing a bandwidth of a few hundred hertz across a standard FOV, in comparison to over a hundred kilohertz from the linear gradients. This results in long RF pulses, even with the high encoding efficiency of the $Z2$ gradient, as well as greater sensitivity to off-resonance. In regions near air-water interfaces, off-resonance can render this method impractical. Future work will focus on developing a stronger pulsed $Z2$ gradient to address these limitations, and using a single-shot readout for rapid high-resolution imaging.

References

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