# 3D Spatial Excitation Using Variable-Density k-Space Trajectories

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## Introduction

Multi-dimensional spatially selective RF excitation pulses [1] are used in a variety of applications, e.g. to restrict the area of interest and to perform imaging or specific spectroscopic applications in a reduced field of view (FOV) [2,3]. For this purpose, signal is excited in a spatially confined 2D/3D region and an image is formed only within this area. Usually, "uniform" k-space trajectories are employed to define the multi-dimensional spatially selective RF excitation pulses. However, due to the finite k-space coverage, signal is also excited outside of the excitation field of view (FOX). One elegant solution to avoid interference/artifacts of this additional signal is the use of variable-density k-space trajectories [4,5], which cover the central region of k-space more densely than the outer region during application of the RF pulse. In this way, RF energy can be deposited at the low spatial frequencies with a finer resolution, thus influencing effectively a larger FOX. This methodology has been investigated for 2D RF pulses [4] and to a certain extent for 3D RF pulses [5], but the full variability of possible over-sampling schemes applicable in 3D has not been addressed so far. In this paper, the variable-density k-space trajectory concept for 3D spatially selective excitation is studied in more detail, based on the previous work.

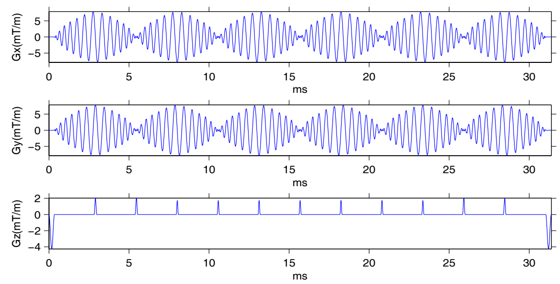


Fig.1. Gradients for a 3D variable-density RF pulse (radial + z)

## Methods

A 3D RF pulse based on a stack-of-spirals trajectory [6,7] was chosen in this work. This special trajectory offers the opportunity to study two different k-space sampling schemes – spiral and Cartesian – in variable-density applications simultaneously. Variable-density sampling of the 3D trajectory can be achieved for the 2D sub-spirals in the radial direction and for the remaining Cartesian dimension in the z direction according to: spiral: $k_{xy}(t) = k_{max}\, \Phi(t)\, F(\Phi(t))\, \exp(2\pi N \Phi(t))$ and Cartesian: $k_z(t) = k_{max}\, \Omega\,(t)\, H(\Omega(t))$ ($k_{max}$: max. k-space extension; N: number of spiral turns; $\Phi(t)$, $\Omega\,(t)$: temporal parameterization; $F(\Phi(t))$, $H(\Omega(t))$: radial/linear density variation). Various stack-of-spirals trajectories were studied by simulation to show how, by increasing the density in the center of the trajectory, the side lobe amplitude of the point spread function (PSF) is reduced. Phantom and in-vivo measurements were conducted to investigate the performance of 3D spatially selective variable-density RF excitation pulses, using different 3D excitation targets. The results were compared with those obtained by use of a conventional uniform-density trajectory ($F(\Phi) = H(\Omega) = 1$). Measurements were performed on a 1.5-T system (Philips Gyroscan, Best, the Netherlands) equipped with moderate gradients ($G_{max}$: 21 mT/m ramped in 0.2 ms). The body coil was used for signal transmission and reception. In the phantom measurements (Fig.2), a homogenous water-filled sphere (∅=27cm) was used, in which either a cube or a cylinder target were excited in a 3D FOX (16×16×16×cm³). The diameter of the cylinder, its height and the side length of the cube where chosen to cover at least 70% of the FOX. The different trajectories used are summarized in Table 1. The uniform trajectory was a stack of 10 spirals, each with five spiral turns. For all cases, the sampling theorem was satisfied in the outer k-space regions for the same FOX as for the uniform approach.

| 3D trajectory | OS / RO radial | OS / RO z | ΔN | $\Delta N_z$ | T |
|---|---|---|---|---|---|
| (1) uniform | 0 / - | 0 | 0 | 0 | 23 ms |
| (2) var. dens. (radial) | 1.5 / 0.55 | 0 | 1 | 0 | 26 ms |
| (3) var. dens. (z ) | 0 / - | 1.4 / 0.5 | 0 | 2 | 28 ms |
| (4) var. dens. (radial + z) | 1.5 / 0.55 | 1.4 / 0.55 | 1 | 0 | 31 ms |

Table1. 3D RF pulse parameters. OS: over-sampling factor, RO: region of over-sampling (fraction of $k_{max}$), ΔN extra spiral turns, $\Delta N_z$ extra spirals, T: pulse duration. The uniform trajectory used N=5 spiral turns and a stack 10 spirals.

## Results and Discussion

Figure 2 shows the excitation profiles of 3D spatially selective excitation pulses using a uniform (1) and a variable-density ((2) radial only, (3) z only, (4) radial+z) k-space trajectory measured in a homogenous water phantom. For excitation with a uniform density spiral, a significant amount of signal is generated outside the FOX. For the variable-density spiral, this is reduced considerably due to the different underlying PSFs, which is in agreement with simulations. Hence, the variable-density approach yields an effective way for outer FOX signal suppression that can be applied in the radial, the z, or both directions to gain more flexibility. Thus, the RF pulse can be tailored to the specific needs at the expense of increased pulse duration by about 35 % (radial+z). This duration can be shortened if the sampling density is reduced in the outer k-space area [5], but this could have a negative effect on the performance inside the FOX due to a slight Nyquist violation. Transmit SENSE [8,9], however, might offer a very promising way to shorten the pulses, thus making the variable-density concept more suitable for practical applications.

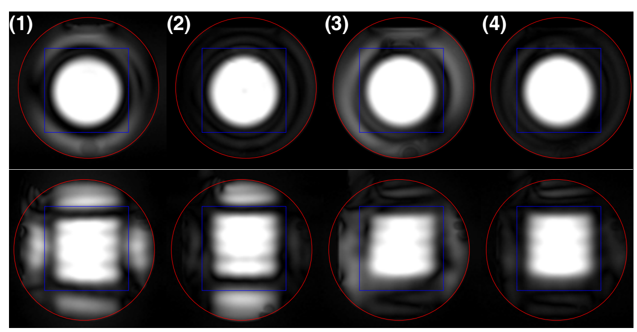


Fig. 2: 3D RF pulse outer-volume suppression performance measured in a water-filled sphere (27cm diameter, red circle) for the different sampling schemes (c.f. Table 1). The pulse target was a cylinder (13 cm diameter and height) in a cubic FOX (16 cm side length, blue square). Top row transverse views (xy-plane), bottom saggital views (xz-plane).

## Conclusion

The presented results illustrate the potential of the variable-density technique for spatially selective 3D RF pulses. The variable-density approach proves to be an effective scheme to reduce outer FOX signal excitation with only moderate increase of the pulse duration.

## References

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