



**HAL**  
open science

## Z-segmentation of a transmit array head coil improves RF ramp pulse design at 7T

Gaël Saïb, Raphael Tomi-Tricot, Vincent Gras, Franck Mauconduit, Nicolas Boulant, Alexandre Vignaud, Michel Luong, Eric Giacomini, Edouard Chazel, Denis Le Bihan, et al.

### ► To cite this version:

Gaël Saïb, Raphael Tomi-Tricot, Vincent Gras, Franck Mauconduit, Nicolas Boulant, et al.. Z-segmentation of a transmit array head coil improves RF ramp pulse design at 7T. Joint Annual Meeting ISMRM-ESMRMB 2018, Jun 2018, Paris, France. hal-01633707

**HAL Id: hal-01633707**

**<https://hal.science/hal-01633707>**

Submitted on 17 Nov 2017

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

# Z-segmentation of a transmit array head coil improves RF ramp pulse design at 7T

Gaël Saïb<sup>1</sup>, Raphael Tomi-Tricot<sup>1</sup>, Vincent Gras<sup>1</sup>, Franck Mauconduit<sup>2</sup>, Nicolas Boulant<sup>1</sup>, Alexandre Vignaud<sup>1</sup>, Michel Luong<sup>3</sup>, Eric Giacomini<sup>1</sup>, Edouard Chazel<sup>1</sup>, Denis Le Bihan<sup>1</sup>, Laurent Le Brusquet<sup>4</sup> and Alexis Amadon<sup>1</sup>

<sup>1</sup>CEA/ISFJ/Neurospin/UNIRS, Gif-sur-Yvette, France, <sup>2</sup>Siemens Healthineers France, Saint-Denis, France, <sup>3</sup>CEA/DRF/IRFU/SACM, Gif-sur-Yvette, France, <sup>4</sup>Laboratoire des Signaux et Systèmes, Université Paris-Saclay/CentraleSupélec/CNRS, Gif-sur-Yvette, France

## SYNOPSIS

In Time-Of-Flight sequences, ramp pulses such as TONE's are frequently used to compensate for thru-slab blood flow saturation in cerebral MRA. At Ultra High Field, fast-kz spokes in parallel transmission allow to mitigate  $B_1^+$  heterogeneities in the slab selection process. Here we extend their use for TONE pulses and show improvement of the flip angle ramp fidelity with a homemade z-segmented head array in comparison to a purely azimuthally-distributed commercial coil.

## INTRODUCTION

Time-Of-Flight (TOF) sequences suffer from blood flow saturation (BFS) effects avoiding the full visualization of the arterial vasculature in the human brain [1]. Several studies demonstrated that crescent flip angle (FA) profile excitations compensate this effect in the slab direction [2, 3]. Despite the 7T MRI benefits in terms of SNR and contrast for TOF sequences [4], at this field strength,  $B_1^+$  heterogeneities hamper reaching the targeted ramp profiles everywhere in the brain. So far fast-kz spokes have proven useful to homogenize slice or slab profiles, especially in conjunction with parallel transmission (pTx) [5]. In this context, spokes are here associated with TONE pulses to provide a linear FA ramp profile. The impact of a pTx coil array segmentation along the slab direction (z) is sought by comparing the performances of the implied RF weight optimizations with two pTx head arrays: a purely azimuthally-distributed commercial coil and a homemade z-segmented coil.

## MATERIALS & METHODS

3D  $B_0$ - and  $B_1$ -mapping of a human head was performed with 5-mm resolution on a 7T scanner (MAGNETOM, Siemens AG, Healthineers, Erlangen, Germany) with an 8-Tx/Rx RAPID head array (RAPID Biomedical GmbH, Rimpar, Germany) and our homemade 12Tx/22Rx "ASTRE" coil [6]. The ASTRE coil includes 1 Tx/Rx circularly polarized patch close to the top of the head and 11 Tx/Rx azimuthally-distributed dipoles segmented in two rows along the z-direction to provide degrees of freedom for controlling the FA profile in this direction. Either coil was connected to an 8-channel amplifying Tx-array system, eight of the dipoles in the ASTRE configuration being pairwise coupled. Different spoke excitations were optimized to select a variable flip angle pattern from 10° to 40° in a 50-mm slab located in the upper part of the brain, which is highly impacted by BFS effects. The spoke excitations were composed of three identical but weighted sub-pulse waveforms played at optimized  $(k_x, k_y)$ -locations. The k-space encoding matrix in the Small Tip Angle approximation was built using the 3-D  $B_0$  and  $B_1$  maps measured on the same volunteer in both coils. Joint optimization of  $(k_x, k_y)$ -locations and complex RF weights for each channel and spoke was performed under SAR and power constraints [7,8]. The maximum peak amplitude per channel was set to 160V for both coils. Although the ASTRE coil withstands a higher average power per channel than RAPID, power constraints were fully relaxed by increasing the TR to 1000 ms and the sub-pulse duration to 3 ms to proceed to a fair comparison. In this context, two optimization criteria were formulated in a Magnitude Least Squares problem. The first one ( $c_1$ ) consisted in minimizing the root-mean-squared error from the desired FA ramp pattern, simply based on virtual square pulses played at the spokes  $(k_x, k_y)$ -locations.

$$c_1 = \frac{\| |FA_{computed}| - |FA_{desired}| \|_2}{\sqrt{N_{vox}} \cdot |FA_{center}|}$$

where the RMS is computed over all voxels in the slab. Then a conventional sub-pulse SINC waveform with  $TBW=10$  was applied to each weighted spoke to insure slab selection.

The second criterion ( $c_2$ ) aimed at minimizing the RMS error from a constant FA, the target at the center of the slab (25°), while a predesigned ramp waveform applied to the weighted spokes took care of the desired linear slice profile.

$$c_2 = \frac{\| |FA_{computed}| - |FA_{center}| \|_2}{\sqrt{N_{vox}} \cdot |FA_{center}|}$$

In that case, the TONE waveform was obtained by multiplying the frequency response of the above SINC pulse by the wanted ramp, and by inverse Fourier transforming the resulting product.

All FA profiles and ramp RMS errors (normalized to  $25^\circ$ ) were computed with a full Bloch simulation under Matlab. Prior to this study, FA measurements were performed with an AFI sequence [9] on a phantom to validate the FA patterns returned by the Bloch simulation (Figure 1).

## RESULTS & DISCUSSION

Figure 2 compares the sum of  $B_1$  magnitudes available for transmission for both RF coils. Thanks to its 3 transmit segments along  $z$ , ASTRE offers a better potential for controlling the FA profile in that direction. Indeed, considering  $c_1$ , ASTRE almost succeeded in generating the desired profile without using a ramp excitation waveform. This was impossible to perform using RAPID. However as expected, addressing  $c_2$  while using an adapted sub-pulse shape eased the fidelity to the ramp profile. Then the NRMSE and slab profile were slightly better for ASTRE and significantly improved for RAPID (Figure 3, Table 1).

## CONCLUSION

Z-segmented transmit coils facilitate the TONE desired ramp profile useful to compensate the BFS effects in off-centered locations for TOF at 7T. Yet non segmented coils can still perform ramp profiles provided adequate RF waveforms. Then  $kz$ -spokes were proved useful to improve in-plane homogeneity with such ramp pulses.

## REFERENCES

1. Schmitter S, Wu X, Auerbach EJ, Adriany G, Pfeuffer J, Hamm M, et al. Seven-Tesla Time-of-Flight Angiography Using a 16-Channel Parallel Transmit System With Power-Constrained 3-dimensional Spoke Radiofrequency Pulse Design: Investigative Radiology. 2014 May;49(5):314–25.
2. Atkinson D, Brant-Zawadzki M, Gillan G, Purdy D, Laub G. Improved MR angiography: magnetization transfer suppression with variable flip angle excitation and increased resolution. Radiology. 1994;190(3):890–4.
3. Priatna A, Paschal CB. Variable angle uniform signal excitation (VUSE) for three dimensional time-of-flight MR angiography. Journal of Magnetic Resonance Imaging. 1995;5(4):421–7.
4. Von Morze C, Xu D, Purcell DD, Hess CP, Mukherjee P, Saloner D, et al. Intracranial time-of-flight MR angiography at 7T with comparison to 3T. Journal of Magnetic Resonance Imaging. 2007 Oct;26(4):900–4.
5. Setsompop K, Wald LL, Alagappan V, Gagoski B, Hebrank F, Fontius U, et al. Parallel RF transmission with eight channels at 3 Tesla. Magnetic Resonance in Medicine. 2006 Nov;56(5):1163–71.
6. Amadon A, et al. Comparison between commercial RF head coils and a new hybrid transmit-array coil based on 12 transmit elements and 22 receive elements for an 8-channel transmission system at 7T. poster#? Proceedings ISMRM 2016, Singapore
7. Dupas L et al Two-spoke placement optimization under explicit specific absorption rate and power constraints in parallel transmission at ultra-high field. Journal of Magnetic Resonance. 2015 59-67
8. Hoyos-Idrobo A et al. On variant Strategies to solve the MLS Optimization Problem in Parallel Transmission Pulse Design and Under Strict SAR and Power constraints. IEEE Transactions on medical imaging, VOL. 33, NO. 3, MARCH 2014
9. Yarnykh VL. Actual flip-angle imaging in the pulsed steady state: A method for rapid three-dimensional mapping of the transmitted radiofrequency field. Magnetic Resonance in Medicine. 2007 Jan;57(1):192–200.
10. A. Amadon, M. A. Cloos, N. Boulant, M.-F. Hang, C. J. Wiggins, and H.-P. Fautz, Validation of a very fast  $B_1$ -mapping sequence for parallel transmission on a human brain at 7T, p. 3358, ISMRM 2012, Melbourne.
11. S.M. Smith. Fast robust automated brain extraction. Human Brain Mapping, 17(3):143-155, November 2002.

## FIGURES

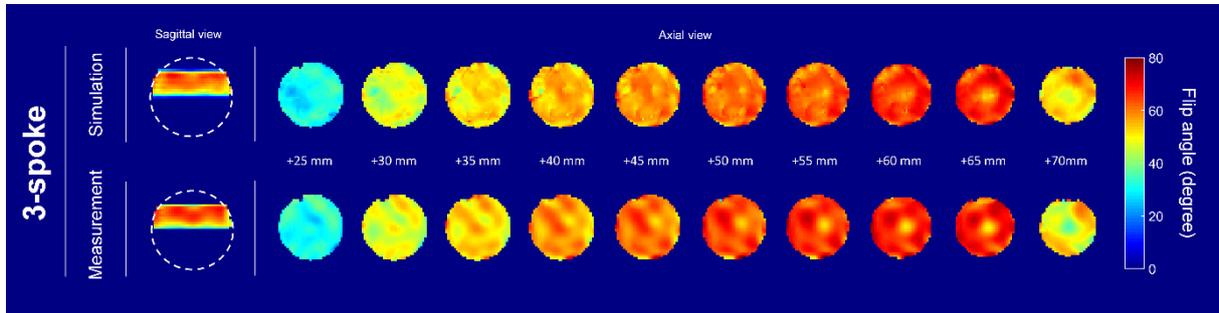


Figure 1: Agreement between FA simulation and measurements with 3-spoke excitations targeting FA=45° to 75° in a 50-mm slab of a spherical water phantom using the ASTRE coil: this validates the simulations performed in this study.

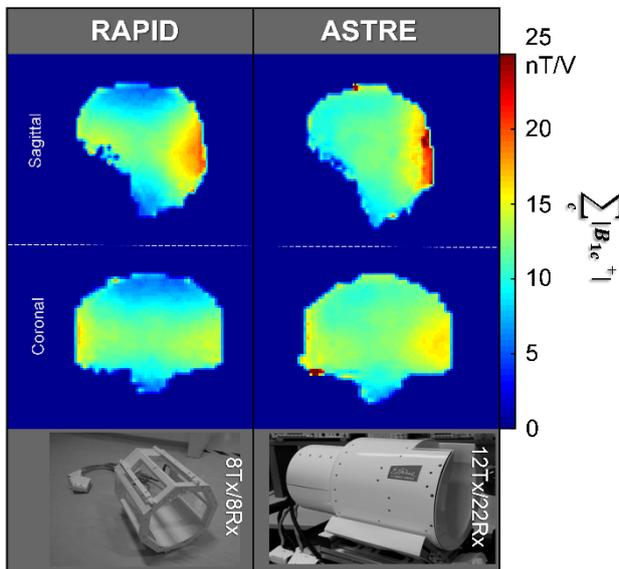


Figure 2: Sum of Tx-channel B1+ magnitudes for the RAPID and ASTRE coils. The individual B1 maps were acquired with the XFL sequence [10] on the same volunteer for each coil. The maps were masked using the Brain Extraction Tool [11] to focus the pulse design on the brain only.

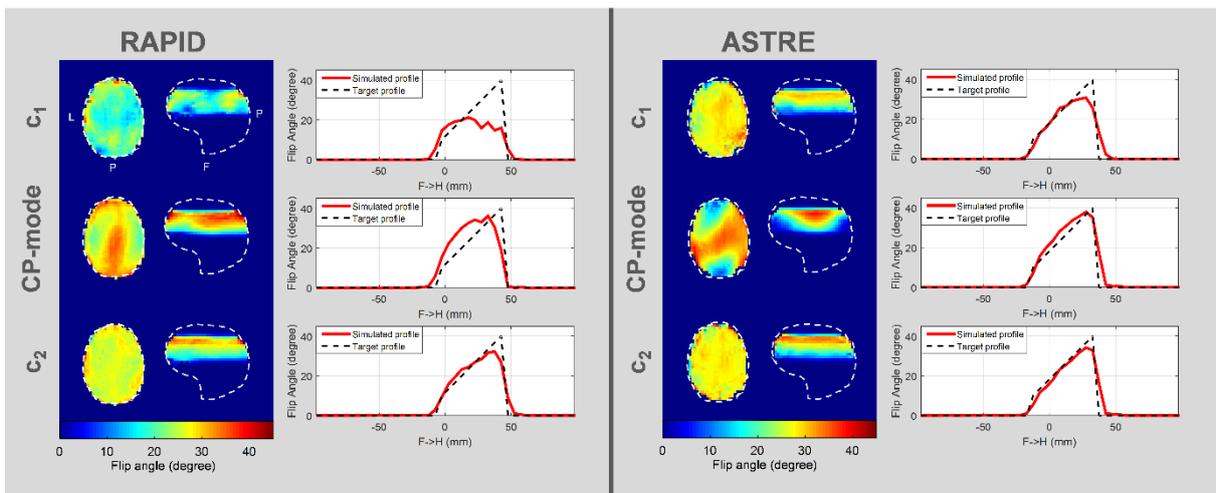


Figure 3: Flip angle Bloch simulations for 3-spoke excitations following c1 and c2 designs, and for the standard circularly polarized (CP) mode (TBW=10). As for c2, the CP-mode was performed using a ramp excitation waveform. Axial and sagittal flip angle maps and associated slab profiles are shown at the center of the slab of interest.

<b>NRMSE (%)</b>	<b>RAPID</b>	<b>ASTRE</b>
3-spoke ( $c_1$ design)	38.5	20.6
CP-mode	27.7	26.8
3-spoke ( $c_2$ design)	18.1	15.0

Table 1: Final FA-NRMSE according to  $c_1$ , obtained from FA-map Bloch simulations after each pulse design presented in Methods and Fig. 3.