

# PASTeUR package extension to slab-selective excitations and 3D-EPI for plug-and-play parallel transmit at 7 Tesla

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## Synopsis:

**Keywords:** Parallel Transmit & Multiband; High-Field MRI; RF Pulse Design & Fields; fMRI

PASTeUR is a package of sequences using non-selective parallel transmission Universal Pulses (UP) as a plug-and-play pTX solution alleviating  $B_1^+$  inhomogeneities. Here, we extend the UP solution to slab-selective excitations while preserving a plug-and-play philosophy. A slab of any thickness/orientation/rotation can be acquired without subject-specific calibrations. *In vivo* experiments performed with an fMRI protocol on a 3D-EPI show that the improved  $B_1^+$  homogeneity can result in higher SNR. Moreover, the slab-selective UP coupled with parallel imaging and segmented k-space acquisitions pushed further the quality of 3D-EPI.

**Summary of Main Findings:** The PASTeUR plug-and-play pTX package is extended to enable slab-selective Universal Pulses excitations. Their performance is demonstrated on 3D EPI and GRE sequences. Results showed improved flip-angle homogeneity resulting in a higher SNR, tSNR, as well as better anatomical images.

**Introduction:** Parallel transmission (pTX) is currently one of the best approaches to alleviate  $B_1^+$  field inhomogeneities, but usually comes with a cumbersome workflow. To address this challenge, the PASTeUR<sup>1</sup> package is a set of non-selective 3D sequences using the pTX Universal Pulses<sup>2</sup> (UP) solution including 3D GRE, MPRAGE, MP2RAGE and a SPACE with FLAIR and DIR modules. In this work, the slab-selective UP<sup>3</sup> (Slab-UP) were developed. Following the original plug-and-play philosophy of UP, a single slab-UP has been designed to outperform the CP mode slab for any slab thickness, orientation, and position. The performance of slab-selective UP was tested *in vivo* using state-of-the-art 3D-EPI<sup>4,5</sup> and 3D-GRE MR sequences, which will be included in the next PASTeUR release.

**Methods:** To avoid a cumbersome library of RF pulses for each slab thickness/position/orientation, a single universal  $k_T$ -point pulse<sup>6,7</sup> was designed to be employed on the whole brain (database of  $\Delta B_0$ /  $B_1^+$  field maps of 20 healthy subjects, 3  $k_T$ -points with sub-pulse duration: 920  $\mu$ s, total duration: 3.78 ms). The RF energy limits were chosen such that the square pulses could be replaced by high-time bandwidth product sinc pulses (up to 25) without exceeding hardware limitations (in particular the peak power). A dedicated sequence module dynamically generates a slab-selective gradient shape and carrier frequency according to the field of view (FOV) thickness, position and orientation chosen by the operator.

Acquisitions were performed on three healthy volunteers on a 7 Tesla Magnetom Terra system (Siemens Healthcare, Erlangen, Germany) equipped with an 8Tx/32Rx head coil (Nova Medical, Wilmington, MA, USA). The Slab-UP was first injected into an Actual Flip Angle (AFI) sequence to evaluate its imaging performance. A large slab covering the entire brain was acquired on two volunteers with flip angles of respectively 15° and 30°. The Slab-UP was then inserted into a 3D-EPI sequence and tSNR (temporal SNR) maps were acquired at 1.6 mm isotropic resolution ( $TR_{vol}/TE = 1.2s/26ms$ , FOV 206 mm, PF = 7/8, GRAPPA 2×4 with blipped-CAIPI<sup>8</sup> z-shift 2, 55 repetitions), in slab-selective CP mode and pTX slab-UP mode (48 slices), as well as non-selective CP and pTX (UP pulse from PASTeUR package) modes (100 slices). Different nominal flip angles were used, as specified in the following figures. Segmented, undersampled k-space acquisitions<sup>5</sup> at 0.8 mm<sup>3</sup> isotropic resolution were also performed with slab-selective CP and pTX Slab-UP modes ( $TR/TE = 47.2/19$  ms, FOV 210 mm, 90 slices, PF = 6/8, GRAPPA 3×1, segmentation factor 3). The acquisition time per slab was 12.7 s. Lastly, high-resolution susceptibility-weighted imaging (SWI<sup>9</sup>) was performed on a single volunteer with a slab-UP 3D GRE sequence (acq time: 5 min,  $TR/TE = 28/20$  ms, FA = 15°, spatial resolution: 0.3x0.3x3 mm<sup>3</sup>, GRAPPA 3).

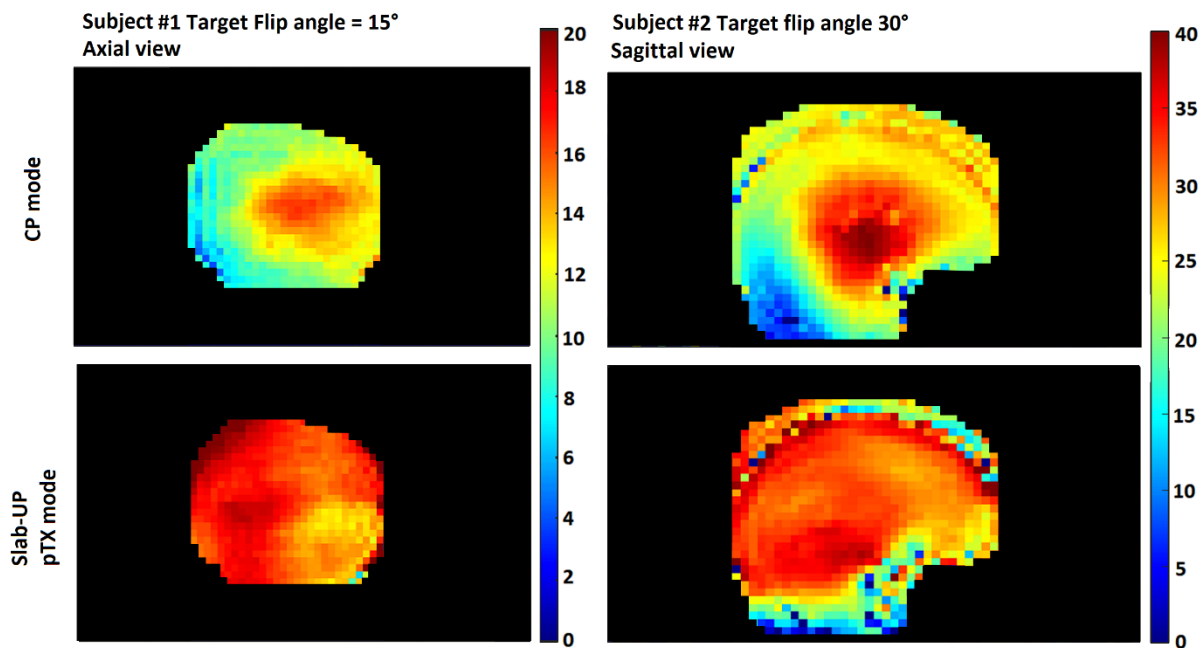
**Results:** Figure 1 shows AFI flip angle maps for the two volunteers in CP and pTX in slab-selective excitation modes. The Slab-UP mode yields a significantly more homogeneous flip angle distribution throughout the brain compared to the CP mode. The gap in performance is higher in the cortical areas of the brain and particularly in the cerebellum. Figure 2 displays tSNR maps acquired on the first volunteer in CP mode and pTX UP, in non-selective and slab-selective modes, with a nominal flip angle of 10°. The flip angle undershoot yielded by the CP mode in most parts of the brain resulted in a weaker tSNR than in pTX mode for both non-selective and slab-selective excitations. The difference in tSNR is the largest in the cerebellum, where the CP mode flip angle was very small. Figure 3 shows tSNR maps from acquired slabs (flip angle: 5°) on the second volunteer in CP and pTX modes. The slab is overlaid on a high-resolution anatomical image acquired with the 3D-EPI using the segmented k-space<sup>5</sup> acquisition and non-selective UP excitation. The slab fits perfectly the FOV with no aliasing suggesting that the slab-selective gradient and carrier frequency are correctly generated. Similarly to Figure 2, the tSNR is higher in pTX thanks to an improved  $B_1^+$  homogeneity. Figure 4 shows the slab with a high-resolution segmented k-space acquisition. The use of the slab-UP allowed to improve signal intensity in the cerebellum for both volunteers. Finally, Figure 5 illustrates high image quality obtained for SWI (minimum-intensity projection) at various slice positions. Note that image signal and contrasts are maintained even in the cerebellum.

**Discussion and conclusion:** This work reports the development of Universal Pulses extension to slab-selective excitations and their experimental validation in 3D-EPI and 3D-GRE sequences. This new feature allows benefitting from a reduced acquisition time thanks to the slab excitation as well as an improved  $B_1^+$  field homogeneity thanks to the UP at the same time. For 3D-EPI, the protocols used for the tSNR mapping were close to conventional fMRI protocols; the use of Universal Pulses was very beneficial SNR-wise. For SWI, the slightly increased duration and RF power of pTx Slab-UP did not require modifying sequence parameters. Following these positive results, the next PASTeUR package release will include slab-UP for all already available MR sequences, as well as a 3D-EPI sequence.

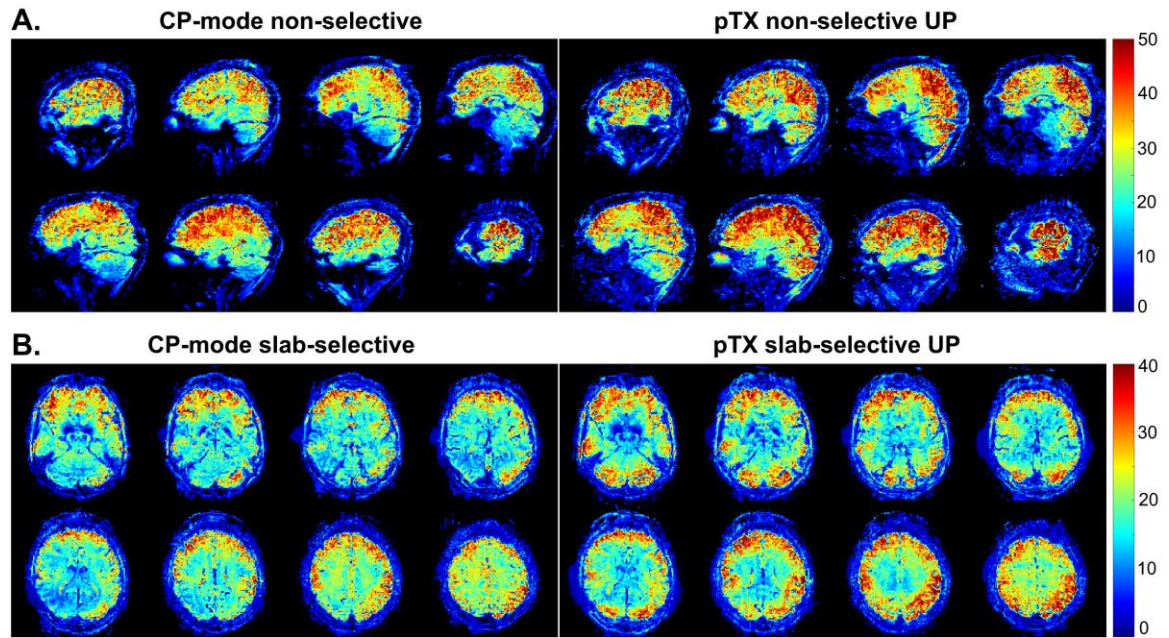
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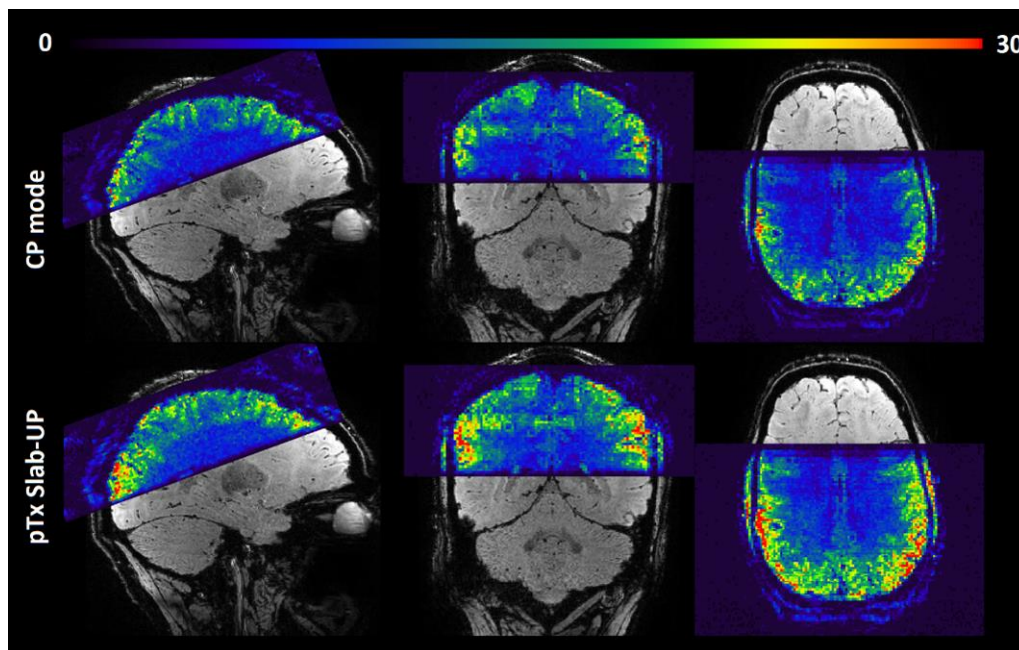
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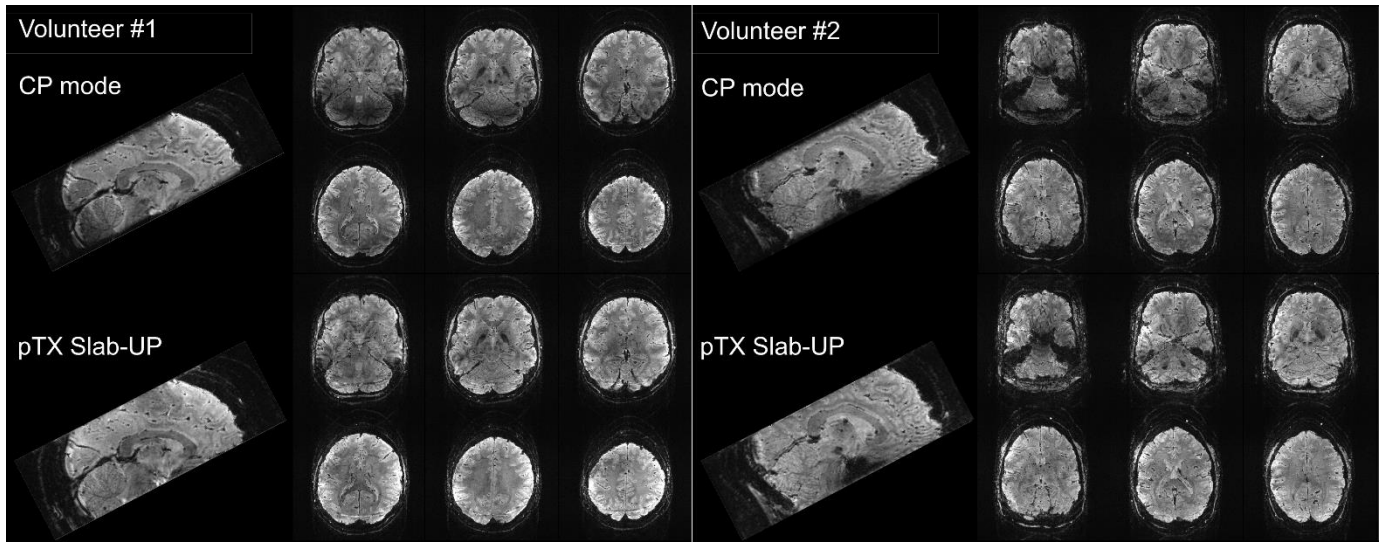
**Figure 1. AFI flip angle maps with 5 mm<sup>3</sup> isotropic spatial resolution in slab-selective in CP and pTX UP modes.** On the left are two axial images from subject #1 (target flip angle = 15°) acquired in CP mode on top and pTX using the Slab-UP pulse and sequence implementation. Similarly, on the right are two sagittal images from subject #2 (target flip angle = 30°). Flip angle maps acquired with slab-UP are more homogeneous.



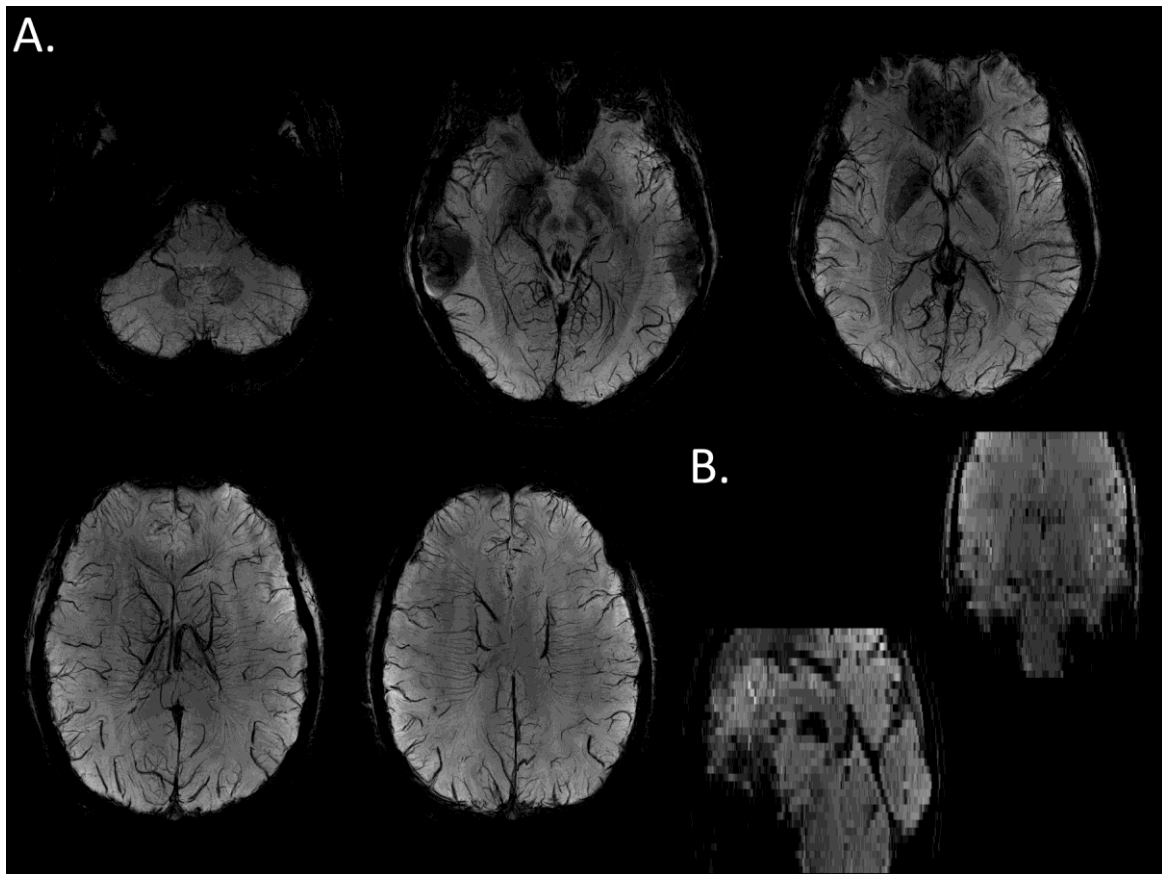
**Figure 2.** tSNR maps acquired in CP and pTX, and in non-selective (A) and slab-selective modes (B). For both non-selective and slab-selective modes, the pTX UP approach yields here a higher tSNR. The CP excitation does not reach the target flip angle in the cortex.



**Figure 3.** Orthogonal views of a tSNR map from an acquired slab (Flip angle 5°) overlaid on an anatomical image acquired with the same pTx non-selective 3D-EPI. From left to right, sagittal, coronal and axial view. Top, CP mode slab and in bottom pTx slab-UP images. The slab-UP yields a slab that exactly fits the CP mode FOV. Again, the improved  $B_1^+$  homogeneity yielded by the slab-UP excitation results in higher tSNR than in CP mode.



**Figure 4. 0.8 mm isotropic resolution slab acquired with the segmented 3D-EPI in CP and pTX slab-UP modes.** For each subject, sagittal and transverse views of the slab are illustrated, with top row displaying CP mode and bottom row displaying pTX slab-UP. Slab-UP excitation enables recovering signal in the cerebellum region, which suffered from the most severe B<sub>1</sub><sup>+</sup> inhomogeneities. The acquisition time for one volume is 12.7 s.



**Figure 5. SWI acquisition performed with a 3D-GRE sequence compatible with pTX slab-UP, with a 0.3x0.3x3 mm<sup>3</sup> spatial resolution in 5 minutes.** Several representative slices of the SWI minimum-intensity projection are illustrated (A). Reformats in coronal and sagittal orientation of the SWI volume are also provided (B). Note the high visibility of the venous system in all presented slices and orientations, including in the cerebellum where signal and image contrast are maintained using pTx Slab-UP.

**Presentation format:** Oral

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