Actual Flip angle Imaging package

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Description The Actual Flip angle Imaging package can generate a Δf_0 map and a flip angle map.

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1 Introduction

Mapping of the RF transmit distribution is usually required to deal with spatial B_1^+ field inhomogeneity at high field ($\geq 3T$). Numerous B_1^+ mapping methods have been proposed with different underlying concepts, as discussed by Fautz (3).

The Actual Flip angle Imaging (AFI) sequence proposed by Yarnykh (6) is the gold standard method for mapping B_1^+ field with a fast 3D measurement. This method requires a proper spoiling scheme (Nehrke (4)) so that the steady state can be reached and the signal equation is correct for flip angle calculation.

Moreover, Boulant et al. (2) derived an analytical formula to correct for B_0 field variation in the evaluation of B_1^+ maps when non-selective square pulses are used. As shown by Amadon and Boulant (1) and Witschey Witschey et al. (5), gradient echoes can be added to the AFI sequence enabling a simultaneous mapping of B_0 and B_1^+ within the same sequence. Subsequently, the corrected B_1^+ can be computed at the same time within the sequence if needed. The B_1^+ field inhomogeneity is of special interest in spectroscopy application for which the reference voltage must be correctly set in a region of interest.

Here, we present an AFI based sequence developed under several IDEA software versions with inline reconstruction of Δf_0 field and flip angle (FA) maps. The sequence is not realistically suitable for pTx due to the very long acquisition time even with low 3D resolution settings.

2 Installation

2.1 Summary of files

The AFI package contains a ns_afi sequence (ns stands for NeuroSpin) and an associated ICE reconstruction program that computes the Δf_0 and FA maps. The following trees are showing the mandatory files and their location depending on the software version:

VB17 software

```
MedCom
├── MriCustomer
│   └── seq
│       ├── ns_afi.dll
│       └── ns_afi.x86
├── IceConfigurators
│   └── IceProgramAFI.ipr
├── bin
│   ├── IceAFI.dll
│   └── IceAFI.evp
└── MCIR
    ├── Med
    │   └── lib
    └── libIceAFI.so
```

VE11/VE12 softwares

```
MedCom
└── MriCustomer
    ├── seq
    │   ├── ns_afi.dll
    │   └── libns_afi.so
    └── ice
        ├── IceAFI.dll
        ├── IceAFI.evp
        ├── libIceAFI.so
        └── IceProgramAFI.ipr
```

2.2 Installation procedure

Execute the file **install_neurospin_seq_VXXX.bat** which copies the installation files to C:/MedCom according to the corresponding tree. For VE platform or higher, do not forget to switch to update mode by using the MrEmbeddedControlGui tool before executing the install script.

2.3 Optimized protocols

Depending on the system version, a set of protocols can be found in pdf format or edx/exar file can be imported into the system.

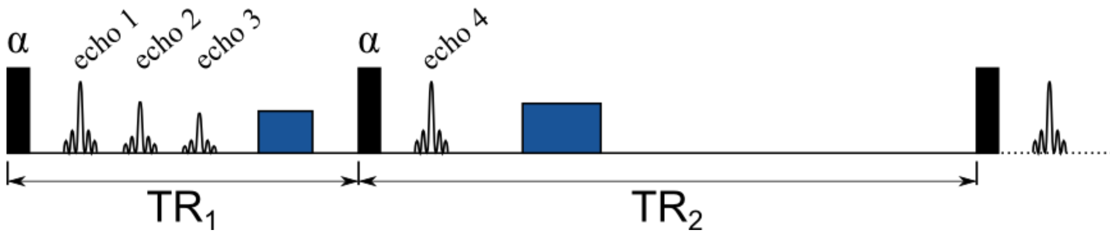

Figure 1: AFI sequence diagram

3 AFI sequence

3.1 Description

AFI sequence consists of two RF pulses followed by two different repetition times ($TR_1 < TR_2$). After each pulse, three gradient echoes are acquired during first the TR and one echo is acquired during second TR as shown in Figure 1.

FA **map expression:** Images acquired with echoes 1 and 4 ($TE_1 = TE_4$) during TR_1 and TR_2 respectively enable the FA map calculation using the following expression:

$$FA = arccos(\frac{rn-1}{n-r}) \; with : r = \frac{S_2}{S_1}, n = \frac{TR_2}{TR_1} \qquad [1]$$

S_1 defines signal of echo 1 occuring during TR_1 and S_2 defines signal of echo 4 occuring during TR_2.

Δf_0 **map expression:** The phase signal of the three echoes acquired during TR_1 enable the Δf_0 map calculation (echoes 1, 2 and 3 during TR_1) using a linear adjustment of the phases. Multi-echo acquisition is done during TR_1 because signal is stronger than the one during TR_2. The measured frequency range typically of $\pm 500Hz$ is given by the following equation:

$$\Delta f_0 = 1/(TE_2 - TE_1) \qquad [2]$$

B_1^+ **evaluation:** The B_1^+ can be evaluated by taking into account the effects of Δf_0. With a non selective square pulse, the expression is (2):

$$B_1^+ = \frac{FA}{b} + \frac{aFA^3}{b^4 - 3abFA^2} \qquad [3]$$

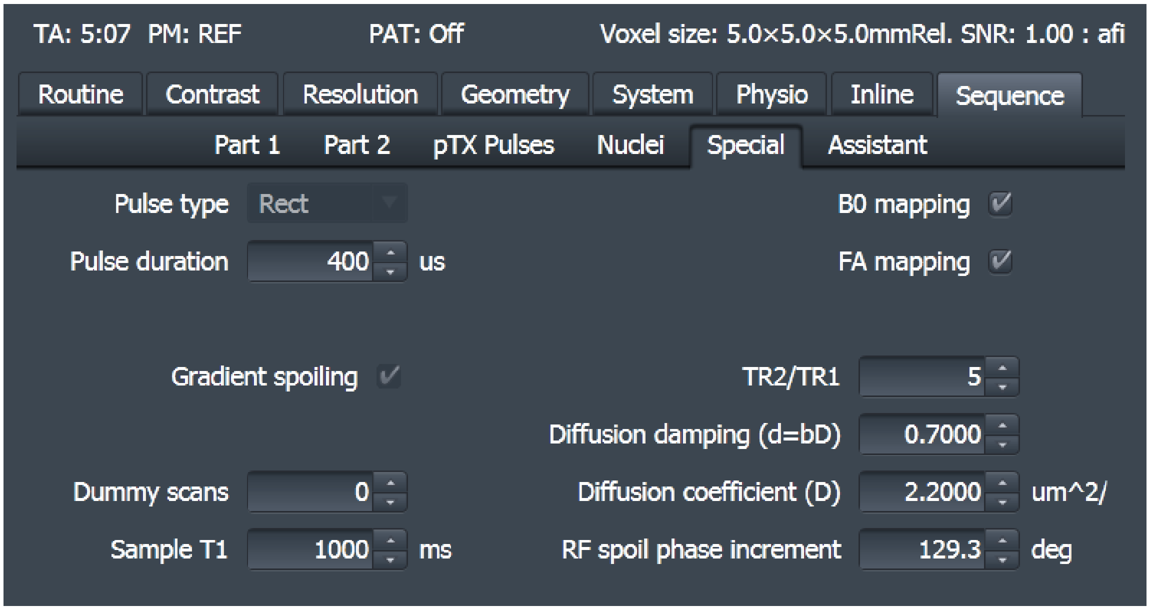

Figure 2: Special card : AFI mode

$d = 2\pi\tau$, $a = d^2/240$, $b = \sqrt{\frac{2-2cos(d)}{d}}$, and where τ is the RF pulse duration.

VR map: A voltage reference (VR) map can be computed from FA map. When the sequence is done at the beginning of a protocol, the VR map can be used to manually set the voltage reference on the adjustment window. One can ensure that the prescribed sequence flip angle is actually applied in a selected region of the anatomy. The VR map is calculated as follow:

$$VR = (\pi\tau RF_{voltage} FA)^{-1} \quad [4]$$

τ is the RF pulse duration and $RF_{voltage}$ is the prescribed RF voltage.

3.2 Special card options

The provided sequence can perform either an AFI or a FLASH acquisition. Switching between these two modes is achieved through the FA mapping checkbox on the special card. Special controls differ depending on the mode selected. This section details the different options available on the special card.

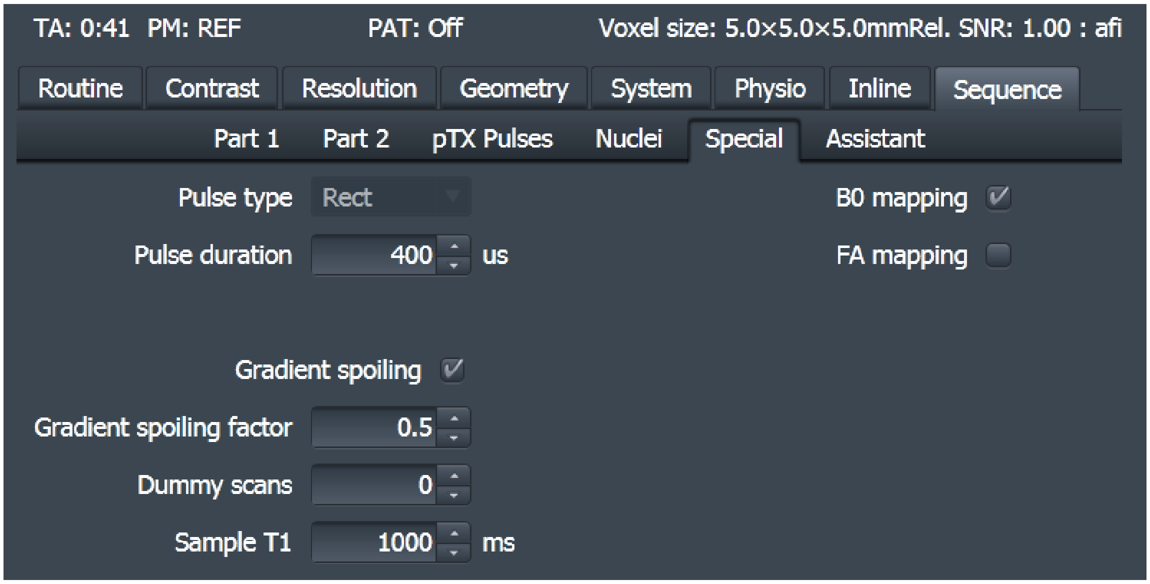

Figure 3: Special card: FLASH mode

RF pulse type: RF pulse type should be set to square (rect) to get FA mapping. You may also use your own RF pulse by selecting "Ext/pTx". This option will only appear if your pulse follows the specifications stated in Siemens IDEA documentation. Please note that B_0-corrected FA maps (i.e. B_1^+ maps) are available only when a square pulse is used.

Pulse duration: Pulse duration should be as short as possible to make the method insensitive to B_0 off resonances.

Gradient spoiling: (FLASH mode only !) Gradient spoiler moment, expressed in multiples of the readout gradient moment. By default (Siemens default value) it is set to 0.5 times the readout gradient moment. In AFI mode, gradient spoiling is configured in a different manner (see Diffusion damping and Diffusion coefficient below).

Sample T_1 / Dummy scans You may enter the T_1 of what you think is dominant in your sample, so as to get the Ernst angle and the number of repetitions needed before steady state if you ran a mere FLASH sequence at the Ernst angle. You may

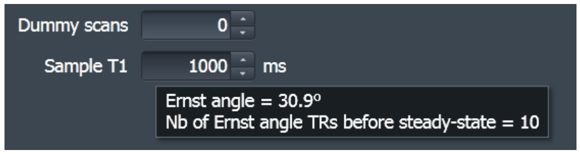

Figure 4: Special card: the sample T_1 parameter can be used to retrieve the corresponding Ernst angle in a tooltip.

read those numbers by sliding your mouse over the box. You also can set the number of dummy TRs accordingly in the box above (Dummy scans) if you wish.

B_0 **mapping** Activating this option will output an f_0 map. If "FA mapping" is also selected (see below), FA maps will be B_0-corrected. Please note that toggling B_0 mapping will automatically set the number of contrasts to 3 and force the reconstruction mode to "Magnitude+Phase". In some cases, you might need to increase the TR in order to check the box. This issue should be fixed in later versions. NB: You will not be able to activate B_0 mapping if any one of the "Save unfiltered images" options is checked in the "Resolution → Filter image" card.

FA **Mapping** Check this box in order to perform flip angle mapping. This will also activate a set of options – described below – on the special card. Please note that FA mapping mode will force gradient and RF spoiling on and increase the TR automatically. NB: You will not be able to activate FA mapping if any one of the "Save unfiltered images" options is checked in the "Resolution → Filter image" card. The following controls are available in AFI mode only:

- TR_2/TR_1 : $n = TR_2/TR_1$ should be typicaaly 5 or 6. It can be lengthened for measurement of small tip angles.
- Diffusion damping: Gradient spoiler integral may be set indirectly with the diffusion damping factor $d = bD$, where D is the diffusion coefficient of the sample, and $b = \gamma$ (Nehrke[3]). If $d < 0.1$, spoiling artefacts may result or the evaluated angles may be wrong depending on sample. Pick d as large as your gradient coils and amplifiers can withstand ($d = 1$ is safe for spoiling, but unsafe for duty cycle).
- Diffusion coefficent: The diffusion coefficient of the sample is used for diffusion damping parameter evaluation.

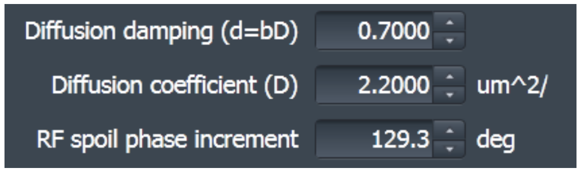

Figure 5: Special card: diffusion damping, diffusion coefficent and spoiling increment.

- RF spoiling phase increment: The RF initial phase is incremented by a multiple of that increment between consecutive pulses. But in TR_2, it is incremented n times more than in TR_1. This follows Nehrke's recommendation [3]. For $n = 5$, pick 129.3 as best choice. Please note that in FLASH mode, when RF spoiling is activated ("Sequence $\rightarrow$ Part 2" card), the RF spoiling increment is fixed to 50.0, as done in Siemens product sequences.

3.3 External pTx pulse

The AFI sequence can run an external pTx pulse defined within an ini file (ini content as described by Siemens). This file must be located in C:/MedCom/MriCustomer/seq/RFPulses and named "pTXRFPulseAFI.ini". The ini file is supposed to define a 3D non-selective RF pulse. It can eventually use gradient blips that will be played in the following frame of reference independently of the acquisition orientation :

- First column in file is played on gradient Y axis
- Second column in file is played on gradient X axis
- Third column in file is played on gradient Z axis

If "Ext/pTx" pulse type option (in Special card) does not appear, check that the ini file name matches the required name ("pTXRFPulseAFI.ini") and/or increase TE.

4 AFI reconstruction

The package is able to reconstruct additionnal series along with the standard magnitude and phase series : a Δf_0 map which unit is expressed in Hz and a FA map which units is expressed in 0.1 degree. An exemple of reconstructed images is shown in figure 6.

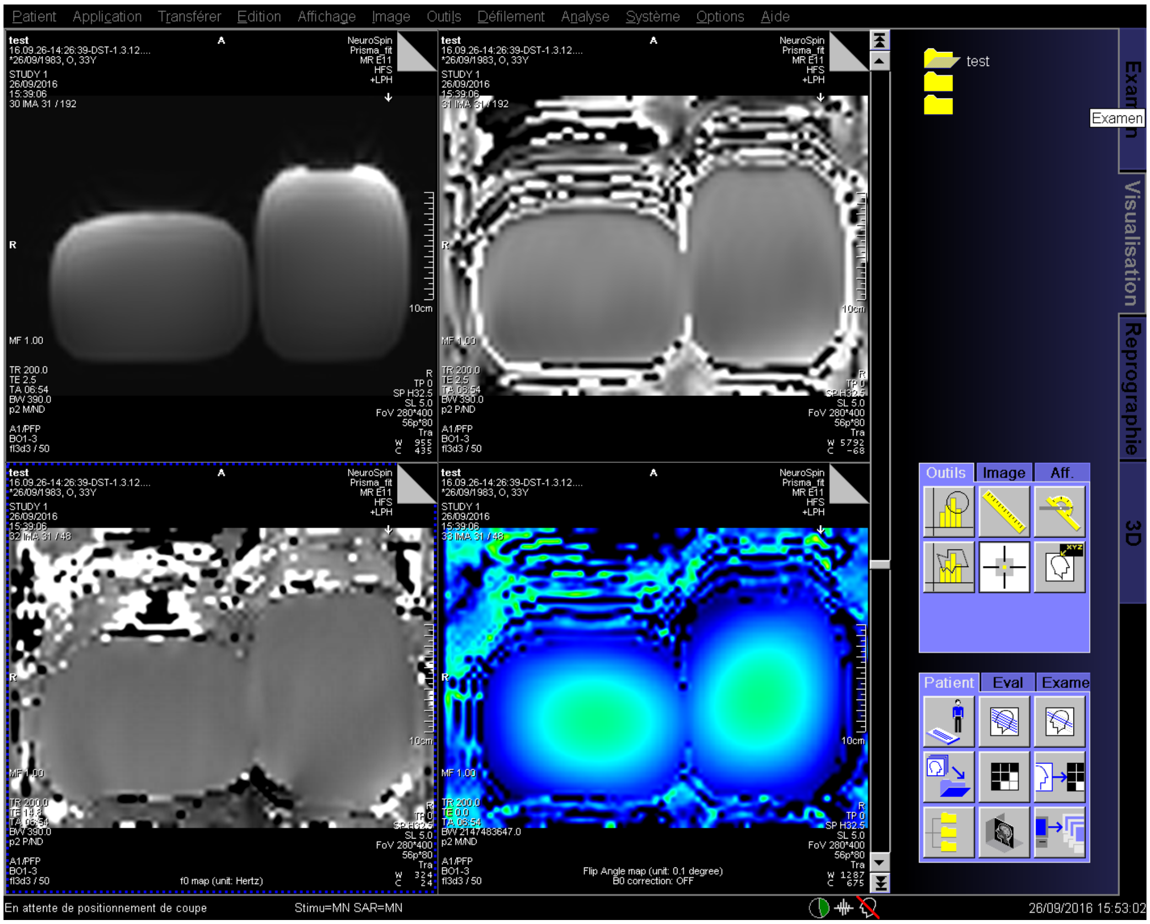

Figure 6: Reconstructed images from the AFI sequence, up-left: module images, up-right, phase images, bottom-left: offset frequency map, bottom-right: flip angle map.

References

1 Amadon, A. and Boulant, N. (2008), Simultaneous measurement of B0- and B1-maps with modified Actual Flip Angle Imaging sequence, *in* 'Proceedings of the International Society for Magnetic Resonance in Medicine', Toronto, Canada.

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3 Fautz, H. P. (2010), New Angles on B1 Mapping, Introduction, *in* 'Proceedings of the International Society for Magnetic Resonance in Medicine', Stockholm, Sweden.

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6 Yarnykh, V. L. (2007), '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* **57**(1), 192–200.
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