

# **2D / 3D CINE PC-MRI Flow Sensitive 4D MRI Tissue Phase Mapping**

Customer to Customer C<sup>2</sup>P Package, Version 1.2

For the  
SIEMENS Magnetom Espree/Avanto/TRIO



## **Installation and User's Guide NUMARIS/4 VB15**

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# 1 General Remarks

## 1.1 Preface

This package being a substantial commitment from our side is provided free of charge for everybody to benefit. In order to encourage the continued development of the package feel free to reference the following paper(s) in you publications:

Markl M, Harloff A, Bley TA, Zaitsev M, Jung B, Weigang E, Langer M, Hennig J, Frydrychowicz A. Time-resolved 3D MR velocity mapping at 3T: Improved navigator-gated assessment of vascular anatomy and blood flow. *J Magn Reson Imaging* 2007;25:824–831.

## 1.2 Disclaimer

The software and the associated documentation (the “Software”) is provided “as is”, without warranty of any kind, express or implied, including but not limited to the warranties of merchantability, fitness for a particular purpose and noninfringement. In no event shall the authors or copyright holders be liable for any claim, damages or other liability, whether in an action of contract, tort or otherwise, arising from, out of or in connection with the Software or the use or other dealings in the Software.

## 1.3 Revision History

V 1.0	7.09.2007	Original release.
V 1.1	8.07.2008	Bug Fix Navigator Gating Added Maxwell correction Bug fix 'sum of squares' multi-coil reconstruction
V 1.2	6.05.2009	Added low SAR rf-pulse option

## 2 Method principles and implementation

ECG synchronized time-resolved 2D or 3D MR-velocity mapping (also termed phase contrast MRI) offers the opportunity to assess 3D blood flow characteristics with true 3D and temporal coverage of a cardiovascular region of interest. Alternatively, the technique can be used for the assessment of tissue motion, e.g. left ventricular myocardial motion.

The VB 13 implementation of this method provides the possibility to acquire time-resolved 2D or 3D phase contrast MRI data. Supported features include:

- 2D or 3D CINE PC MRI using prospective ECG gating
- Flexible adjustment of temporal resolution
- Parallel imaging using GRAPPA
- 1, 2, or 3-directional velocity encoding
- Independent adjustment of in-plane and through plane venc
- Adaptive respiratory navigator gating with real-time adjustment of the navigator acceptance window
- Black blood saturation for 2D CINE and Tissue Phase Mapping
- Optimized gradient wave forms for velocity encoding with minimal TE and TR

A more detailed description of the MR methodology and applications can be found in the following references:

### **MR Methods:**

Markl M, Harloff A, Bley TA, Zaitsev M, Jung B, Weigang E, Langer M, Hennig J, Frydrychowicz A. Time-resolved 3D MR velocity mapping at 3T: Improved navigator-gated assessment of vascular anatomy and blood flow. *J Magn Reson Imaging* 2007;25:824–831.

### **Assessment and analysis of 3D blood flow in the thoracic aorta:**

A. Frydrychowicz, A. Harloff, B. Jung, M. Zaitsev, E. Weigang, T. A. Bley, M. Langer, J. Hennig, M. Markl. Time-Resolved 3D MR Flow Analysis at 3T: Visualization of Normal and Pathological Aortic Vascular Hemodynamics. *J Comput Assist Tomo*, 2007;31:9-15

### **Assessment and analysis of 3D blood flow in intra-cranial arteries**

Wetzel S, Meckel S, Frydrychowicz A, Bonati L, Radue EW, Scheffler K, Hennig J, Markl M. In Vivo Assessment and Visualization of Intracranial Arterial Hemodynamics with Flow-Sensitized 4D MR Imaging at 3T. *AJNR Am J Neuroradiol* 2007;28(3):433-438.

### **Assessment and analysis of 3D blood flow in peripheral vessels**

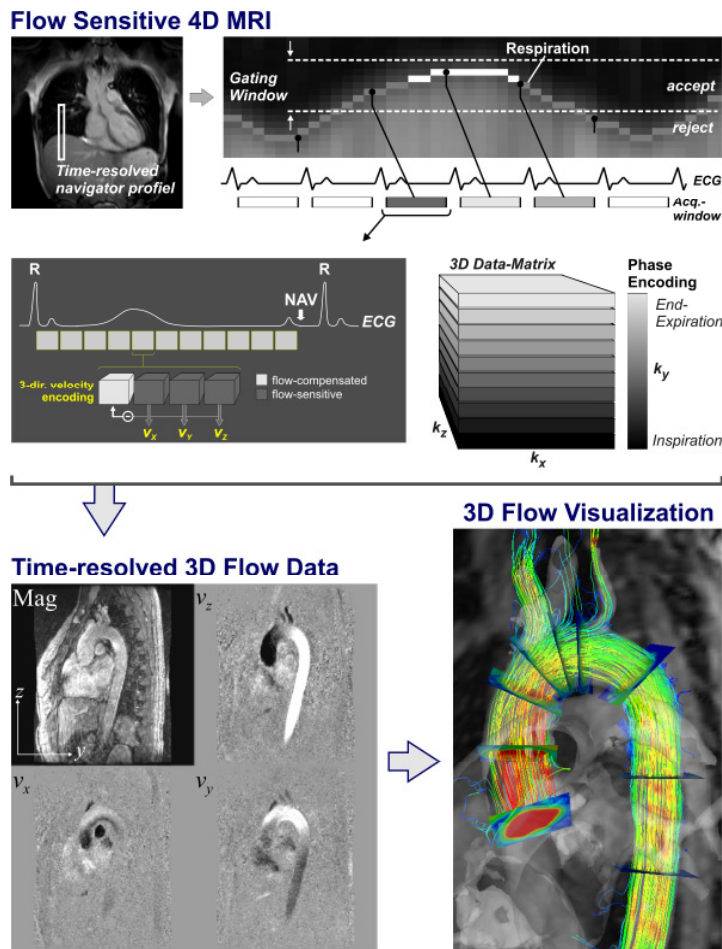
Frydrychowicz A, Winterer JT, Zaitsev M, Jung B, Hennig J, Langer M, Markl M. Visualization of iliac and proximal femoral artery hemodynamics using time-resolved 3D phase contrast MRI at 3T. *J Magn Reson Imaging* 2007;25(5):1085-1092.

**Assessment and analysis of 3D blood flow in the carotid arteries**

Harloff A, Albrecht F, Spreer J, Stalder AF, Bock J, Frydrychowicz A, Schöllhorn J, Hetzel A, Schumacher M, Hennig J, Markl M. 3D Blood Flow Characteristics in the Carotid Artery Bifurcation by Flow Sensitive 4D MRI at 3T. *Magn Reson Med* 2009, 61:65-74.

**Tissue Phase Mapping - assessment and analysis of myocardial motion**

Jung B, Foll D, Bottler P, Petersen S, Hennig J, Markl M. Detailed analysis of myocardial motion in volunteers and patients using high-temporal-resolution MR tissue phase mapping. *J Magn Reson Imaging* 2006;24(5):1033-1039.



**Figure 1.** Flow sensitive 4D MRI in the thoracic aorta: Schematic illustration of the respiration control by adaptive navigator gating and prospective ECG gating. For each time frame a flow compensated reference data set (Ref.) as well as three separate flow sensitive 3D volumes (flow sensitization in x, y and z) were successively collected. Three-directional blood flow velocities ( $v_x$ ,  $v_y$ , and  $v_z$ ) are calculated by subtracting the flow sensitized data from the reference volumes. The late diastolic navigator signal (NAV) of the lung-liver interface is used for prospective respiration estimation. Data within the acceptance range are sorted into k-space according to their respiratory position as schematically indicated for differently gray shaded sections of 3D k-space (lower right). The resulting magnitude and velocity data provides the opportunity to evaluate 3D blood flow within the entire aorta.

## 2D / 3D CINE PC-MRI

Note that extensive post-processing (data correction 3D visualization, flow quantification) is necessary to derive images as exemplary illustrated in figure 1 from the acquire data.

Post-processing and 3D visualization tools are **not** part of this package.

### 2.1 Implementation

The sequence is based on Siemens FLASH prototype sequence and on Siemens Navigator sources Version VA25.

The 2D / 3D CINE PC MRI package is implemented as a set of the following program modules:

- 2D / 3D CINE PC MRI sequence, based on rf-spoiled 3D CINE Phase Contrast gradient echo imaging
- ICE program for 2D / 3D CINE PC MRI reconstruction,

The flow-sensitive 4D MRI sequence is based on a basic product FLASH sequence and product navigator sequence building block which has been extensively modified.

The modified ICE program for flow-sensitive 4D MRI reconstruction performs phase difference calculations and magnitude averaging.

For each measurement, the ICE program produces 2 image series, which are stored in the image database on the host. One series contains all 3D CINE magnitude images while the second series contains all phase difference images.

## 3 Software Installation Procedure

The package consists of several 9 file types:

- 2D / 3D CINE PC MRI sequence file for the host
- 2D / 3D CINE PC MRI sequence file for the MPCU
- ICE program
- Installation script (install.bat)

An installation script, install.bat, is provided to automate the installation procedure. In case automatic installation fails, it is possible to proceed with manual installation, as described below.

### 3.1 Automatic Installation

*Automatic installation of on the scanner includes the following steps:*

Start SDE shell or command shell (CMD).

Change into the directory, where the package archive was unpacked.

Start the installation script by typing:

```
install.bat
```

Make sure that the script completed successfully without error or warning messages.

### 3.2 Manual Installation

*Manual installation of on the scanner includes the following steps:*

Start SDE shell or command shell (CMD).

Change into the directory, where the package archive was unpacked.

Copy the 2D / 3D CINE PC MRI sequence file for the host to the customer sequence directory:

```
copy mm_fs4DMRI.dll %CustomerSeq%
```

Copy the correct 2D / 3D CINE PC MRI sequence file for the MPCU to the corresponding sequence directory by execution the following command:

```
copy mm_fs4DMRI.ia86 %CustomerSeq%
```

Copy files for the 2D / 3D CINE PC MRI ICE program to the MedHome/bin directory:

```
copy mm_IceProgramNav.dll %MedHome%\bin
```

## 2D / 3D CINE PC-MRI

```
copy mm_IceProgramNav.evp %MedHome%\bin
```

Copy a file for the 2D / 3D CINE PC MRI ICE program to the MRIRHOME\lib directory:

```
copy libmm_IceProgramNav.so %MRIRHOME%\lib
```

Copy a file for the 2D / 3D CINE PC MRI ICE program to the CustomerIceProgs directory (don't forget to change into a different 'IceConf' directory and back).

```
cd IceConf
copy mm_IceProgramNav.evp %MRIRHOME%\lib
cd ..
```

Copy the external rf-file file to the customer sequence directory:

```
copy blackblood.dat %MEASDAT%
```

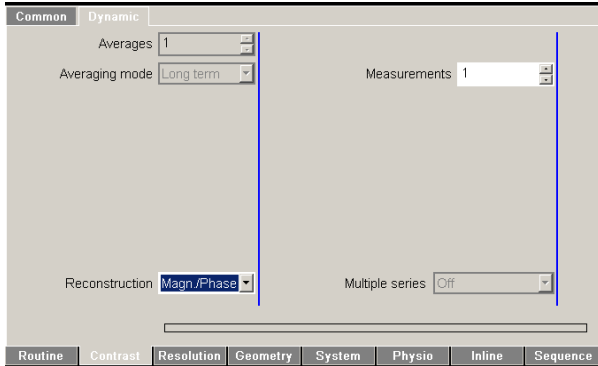
Create the new default protocols:

Open the Exam Explorer, select a protocol location, select 'Insert ... Sequence', select 'Folder: USER', select 'mm\_fs4DMRI', click 'Insert'. Double click the new protocol and adjust the parameters as desired.

# 4 Sequence and Protocols

Features regarding the protocol card:

## Contrast

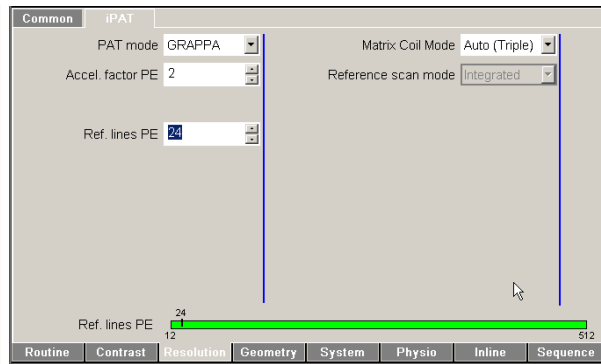
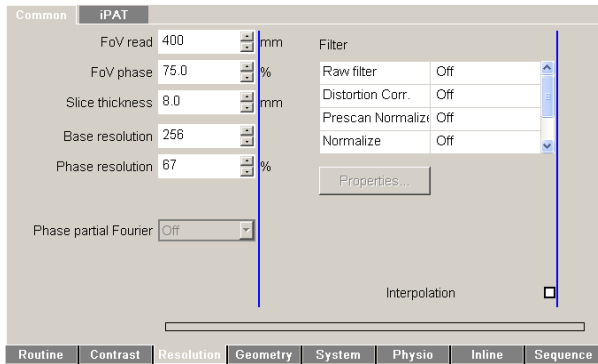


Reconstruction: Magn./ Phase is set automatically if velocity encoding is selected

Averages is not supported

Measurements: is not supported

## Resolution

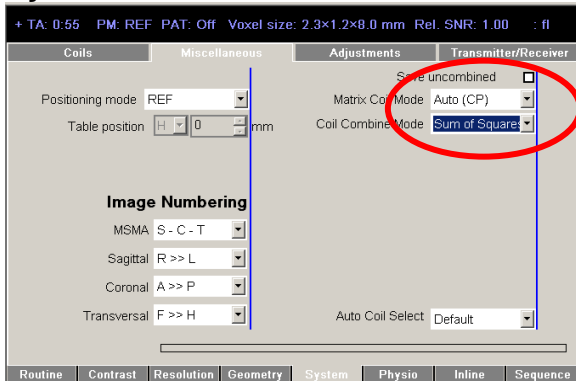


Phase resolution: flexible, but is adjusted to the number of heartbeats to acquire, (phase matrix divided by the segments has to be an integer)

IPAT mode GRAPPA: Parallel imaging using GRAPPA along the PE direction.

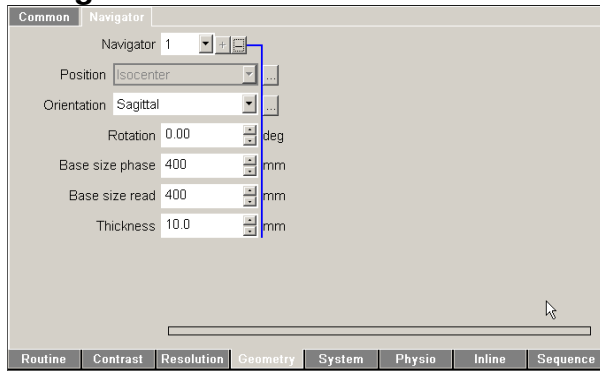
IPAT mode mSENSE: is not supported

## System / Misc



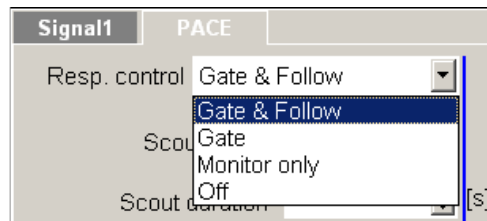
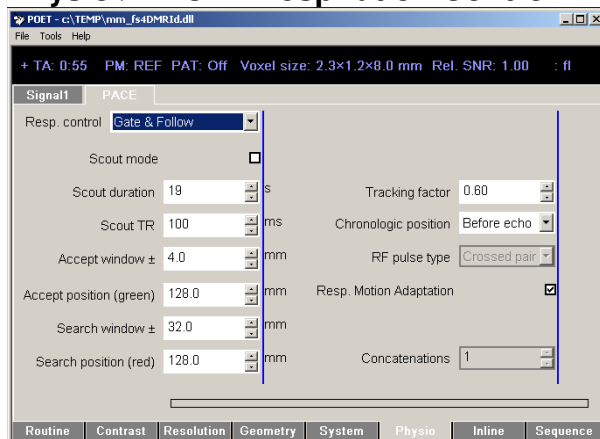
**Important:** Switch Coil Combine Mode to **Sum of Squares**

### Navigator



Standard Crossed pair navigators are used to track the position of the lung liver interface

### Physio / PACE - Respiration Control



#### Respiration Control:

Gate & Follow or Gate: Motion-adapted gating technique based on k-space weighting. The navigator is played out at the end of the cardiac cycle, and dependent on the current breathing position, corresponding k-space lines are acquired during the next cardiac cycle. The position of the gating window (for *Gate* and *Gate & Follow*) is shifted automatically according to the maximum (i.e. the expiration position) of the last 20 navigator echoes and is updated online during the measurement. This avoids a significant prolongation of measurements due to a change in the breathing pattern during a scan.

Resp. Motion Adaptation: should be switched on

Monitor only: not supported

Off: switch off navigator-tracking, for breath-held or non-thoracic applications

Scout mode: acquisition of breathing pattern for determination of navigator reference position.

Known bug: scout mode may not run due to SAR limitations.

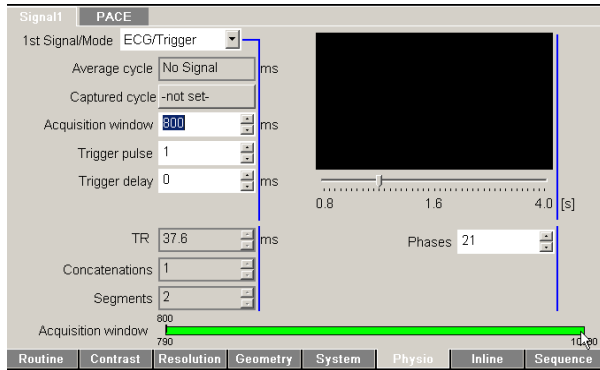
Solution: Increase 'Scout TR' to 150-200ms

or

use Navigator scout of any product sequence and copy parameters

Tracking factor / Chronologic position: not supported.

**Physio / Signal 1 - ECG gating**



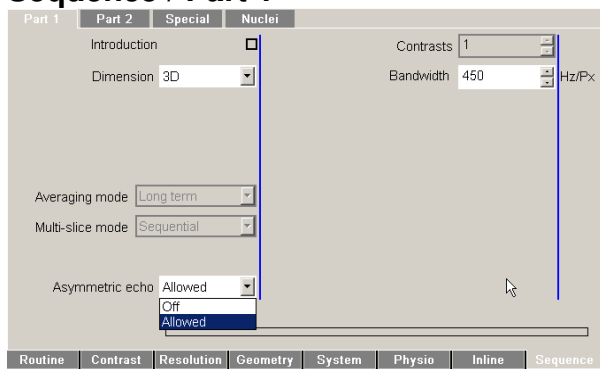
TR: temporal resolution (same as Sequence / Special / Temporal resolution)

Segments: number of k-space lines per cardiac phase and cardiac cycle.

For interleaved *n-D Velocity Encoding*:  
 $TR = Segments * (n+1) * Echo\ spacing$

Phases: should cover approximately 80-90% of the RR-interval. For TPM high temporal resolution measurements with 60 possible phases set only to 50 (i.e. ~100-150 ms less than the average cycle for TPM measurements and ~50 ms for flow measurements). The reason is that the additional time for the black blood pulses is needed (which are played out about every 100 ms) as well as for the navigators and their evaluation time is not considered for the calculation of the number of possible phases.

**Sequence / Part 1**

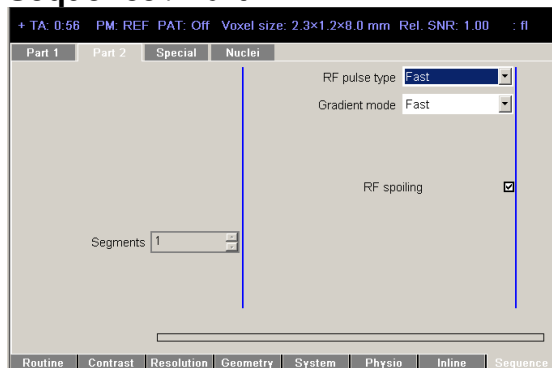


2D – 3D: 2D CINE PC and 3D CINE both implemented

Bandwidth: flexible

Asymmetric echo: can be switched on / off, it is recommended to use the asymmetric echo for optimized TE / TR and thus temporal resolution

**Sequence / Part 2**

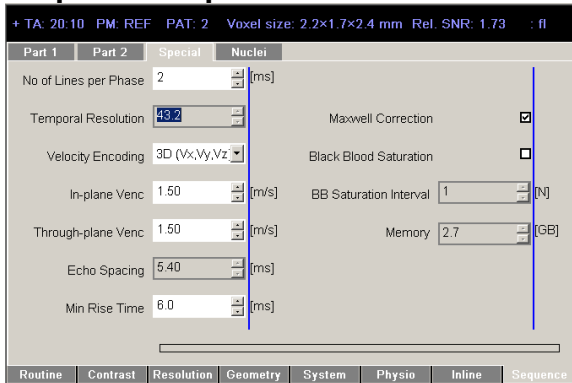


Gradient Mode: fast, normal and whisper selectable

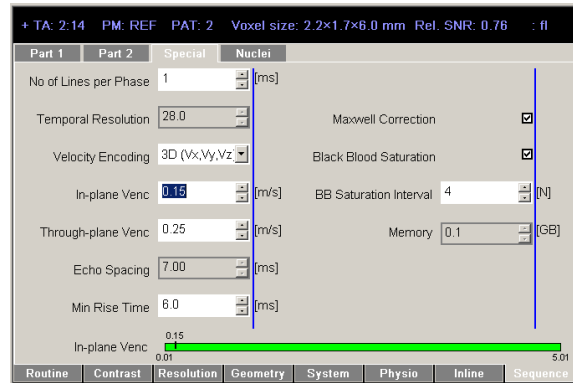
RF pulse type: fast & low SAR selectable

Rf-spoiling: should be switched on

## Sequence / Special



Example of the sequence special card for flow sensitive 4D MRI protocol



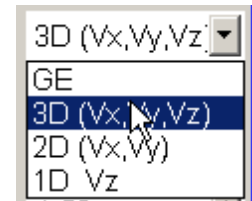
Example of the sequence special card for a 2D high temporal resolution TPM protocol

**Number of Lines per Phase:** Number of k-space lines that are acquired per phase, i.e. cardiac time-frame.

**Temporal resolution:** not editable, Corresponds to TR and is determined by the number of k-space lines per phase and the velocity encoding. Number of k-space lines that are acquired per phase, i.e. cardiac time-frame.

For *n*-D Velocity Encoding:  $TR = Segments * (n+1) * Echo\ spacing$

**Velocity Encoding:** The sequence can be operated in GE mode (no velocity encoding, simple 2D or 3D CINE MRI) or using through-plane (1D, Vz), in-Plane (2D, Vx, Vy) or full three-directional velocity encoding (3D Vx, Vy, Vz). Note that changing the settings in 'Velocity Encoding' will considerably affect the temporal resolution and total scan time.



**In-plane Venc and Through-plane Venc:** can be adjusted independently

**Echo spacing:** not editable, true underlying TR of the pulse sequence

**Min Rise Time:** Adjust the minimum gradient rise time used for the calculation of the gradient waveforms. Increasing the min rise time may help to overcome peripheral nerve stimulation problems.

**Black Blood Saturation:** only needed for TPM measurements.

**BB Saturation interval:** for TPM measurements, determines how often the black blood pulse is played out during one RR-interval. N determines the number of phases between 2 successive black blood pulses.  $BB\ interval = N * TR$ .

**Maxwell Correction:** Switch on / off Maxwell correction to reduce background errors.

**Memory:** Estimates the memory needed for the acquisition of the raw data for the selected set of scan parameters. Note that, depending on the MR system and memory available, parameter ranges may be limited, in particular for flow sensitive 4D MRI scans.