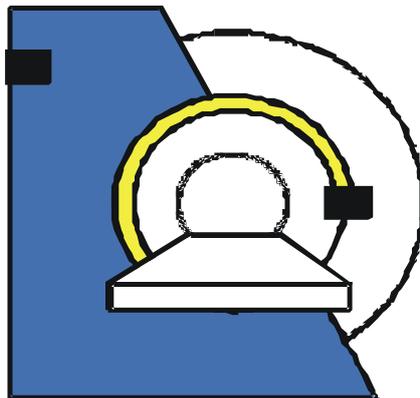# Multi-Echo EPI

Works-in-Progress package
Version 4.2

For the
SIEMENS Magnetom under VB15

Installation and User's Guide

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[1] The original version of this package was developed by Prof. Oliver Speck

# Table of Contents

# 1  Basic principles

## 1.1 Principle of Multi-Echo EPI

The basic timing scheme of Multi-Echo EPI is shown in Figure 1. It is based on the original EPI sequence proposed by Mansfield (1). After a single RF-excitation, n complete EPI images are acquired in a single shot. The phase gradient is rewound to the original starting position after each echo-image to ensure identical k-space trajectories for all echo-images (2).
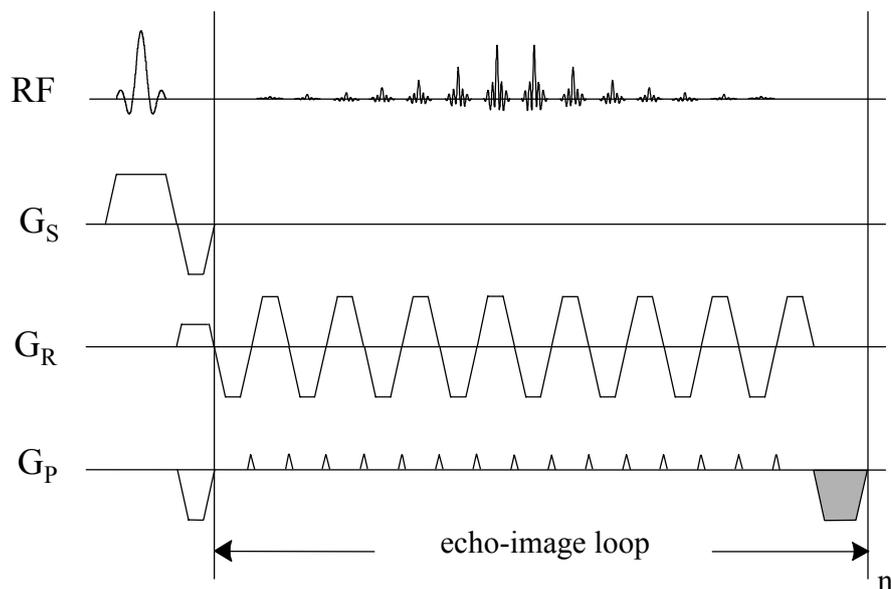


**Figure 1** – Basic timing of the Multi-Echo EPI sequence. The shaded gradient in phase encoding direction ensures identical k-space trajectories for all echo-images.

The resulting echo-images have different increasing echo times and thus T2*-weighting. The single echo-images correspond to standard gradient echo EPI images with the same echo time.

## 1.2 Image contrast of Multi-Echo EPI

The signal intensity of the single echo images of the Multi-Echo EPI sequence is simply given by:

$$S = S0 \, \exp(-TE / T2^*)$$

where $S0$ is the signal intensity at echo time 0, which corresponds to the proton density for long repetition times $TR$, and $TE$ is the echo time. Therefore, the echo times of the different echo-images should be on the order or less than the tissue T2*. Parametric images of the proton density and T2* can be obtained by fitting a model function to the signal intensities at the different echo times (3). Please see the processing options described below.
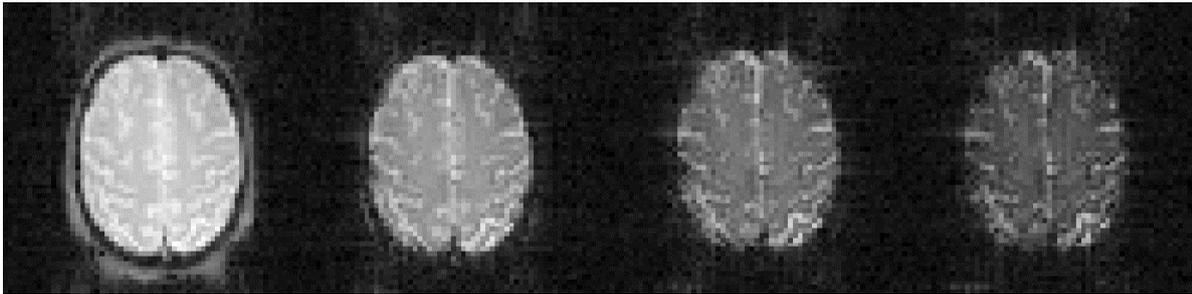


**Figure 2** – Head images acquired on Magnetom TRIO with the Multi-Echo EPI sequence with 4 different echo times in a single shot.


## 1.3 Processing options

Several processing options are given in the method. The different echo images are always saved separately as the original images and optionally parametric maps can be calculated in the reconstruction. Motion correction, EPI distortion correction and t-test can be performed. Please see sequence and protocols for details.


## 1.4 References

1. P. Mansfield, A.A. Maudsley. Planar Spin Imaging. J. Magn. Reson. 27, 101 (1977)
2. O. Speck, J. Hennig. Functional Imaging by $I_0$- and $T_2$*-Parameter Mapping using Multi-Image-EPI. Magn. Reson. Med. 40(2), 243-248 (1998)
3. O. Speck, T. Ernst, L. Chang. Bi-exponential modeling of multi gradient echo data of the brain. Magn. Reson. Med. 45(6), 1116-1121 (2001)
4. O. Speck, J. Hennig. Motion Correction of Parametric fMRI Data from Multi-Slice Single-Shot Multi-Echo Acquisitions, Magn. Reson. Med. 46(5): 1023-1027 (2001)

# 2  Software Installation Procedure

Please make sure that the Distortion Correction WIP package is installed on your system and working properly.

## 2.1  Automatic Installation

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

Start SDE shell or command shell (CMD).

Change into the 'bin'-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.

Create a new default protocol:
Open the Exam Explorer, select a Protocol location, select 'Insert … Sequence', select 'Folder: USER', select 'os_mepi2d', click 'Insert'.
Double click the new protocol and adjust the parameters as desired.

## 2.2  Manual Installation

The package consists of 10 files. The sequence file for the host, the sequence file for the MPCU, two ICE modules, each compiled for win32, xlinux64 and 'typelib', "IceProgram" text file, and the EVA protocol.

Copy the sequence .files to the customer sequence directory:
```
copy mz_mepi2d.dll %CustomerSeq%
copy mz_mepi2d.i86 %CustomerSeq%
```

Copy the win32 ICE modules and typelibs to the appropriate directory:
```
copy mz_MEPIFunctors.dll %MedHome%\bin
copy mz_MEPIFunctors.evp %MedHome%\bin
copy mz_PsfEvaFunctors.dll %MedHome%\bin
copy mz_PsfEvaFunctors.evp %MedHome%\bin
```

Copy the xlinux64 ICE modules and typelibs to the appropriate directory:
```
copy libmz_MEPIFunctors.so %MRIRHOME%\lib
copy libmz_PsfEvaFunctors.so %MRIRHOME%\lib
```

Copy the "ICE program" to the customer ICE directory:
```
copy mz_IceProgramMEPIOnline2D.evp %CustomerIceProgs%
```

**Multi-Echo EPI**

Copy the default EVA protocols to the customer default EVA protocol directory:
```
copy moco_dico_mepi.evp %CustomerEvaDefProt%\Bold
```

Create a new default protocol:
> Open the Exam Explorer, select a Protocol location, select 'Insert … Sequence', select 'Folder: USER', select 'os_mepi2d', click 'Insert'.
> Double click the new protocol and adjust the parameters as desired.

# Sequences and Protocols

## 2.3 General Remarks

Since the sequence is derived from the standard EPI sequence, most of the user interface and features are identical to this method. Due to the large number of images created in a short time, the images are saved to the database in the mosaic format. One mosaic-image contains all slices of one echo time for one repetition. Repetitions can be saved in multiple series if desired (Contrast card or BOLD card).

Prior to the first run of the sequence, the 3D standard shim procedure is performed to ensure best field homogeneity. As with standard EPI this option cannot be disabled.

Due to the high switching rates used in EPI imaging, the peripheral nerve stimulation monitor will sometimes not allow the measurement to be performed with the parameters selected. In general, a lower bandwidth will decrease the stimulation and a different selection of the readout gradient may also help (read direction along L/R-axis shows generally the lowest stimulation).

## 2.4 New Parameters
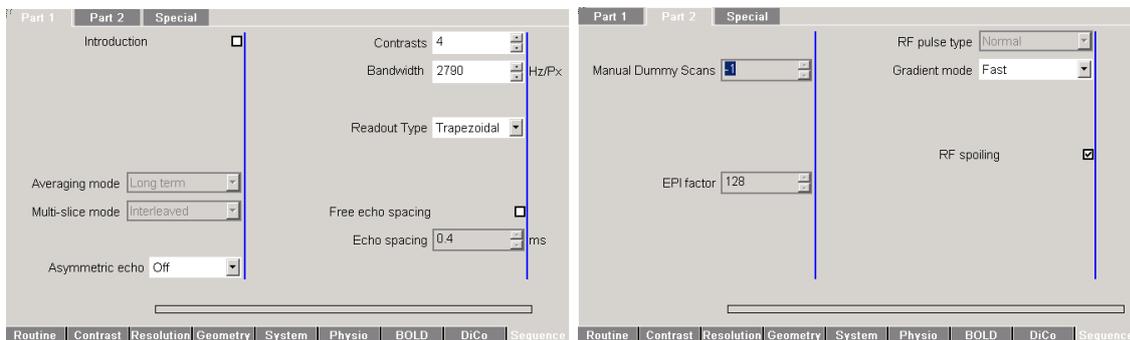


**Contrasts**: The number of echo-images per excitation can be set on the sequence card (part1) as the parameter contrasts. The number of echo-images can be selected between 1 and 16. The number of TE-times is changes accordingly. Please note that only the first echo time can be changed by the user. All other echo times are set to the minimum value according to the remaining selected parameters.

!!Attention!!: Even echo time 1 is adjusted to longer times without warning if required by another parameter! It is not set back to minimum if the parameter is changed back! Please check echo time 1 after changing other timing relevant parameters of the sequence.

**Separate Correction**: *(Not supported in VB13/15)* In the source code of the sequence card a new parameter 'Separate Correction' has been introduced. If this parameter is enabled (during compilation) each echo image is preceded by a new set of navigators used for the Nyquist ghost correction by the reconstruction. If the

feature is disabled the same correction is used for all echo-images. The echo times are somewhat shorter when this feature is disabled, however, in general the image quality is better with the separate correction enabled (especially for high imaging bandwidth). In some cases the signal in the later echoes is too low and the reconstruction introduces artifacts in the images (small noisy stripes in the image) if this feature is selected. Please contact the developer if changes are needed.

**T2\*-Fit (see skip T2-Fitting)**: *(Not supported in VB13/15)* This new feature allows online calculation of I0- and T2\*-maps from the echo images according to the model function shown in 1.2. I0 and T2\* are determined for each voxel who's intensity exceeds 8% of the maximum intensity in the first echo. I0 and T2\* of voxels with a signal intensity below this threshold are set to 0. The resulting T2\*-maps are scaled such that an image intensity of 1000 corresponds to a T2\* of 100ms. T2\* is forced to lie within physiological limits (0<T2\*<333ms). Values higher than 333ms are set to 334ms to avoid very large signal intensity differences in case of fitting errors and allow a T2\*-resolution of 0.1ms without overflows. Therefore, T2\* maps of phantoms with very long T2 and good homogeneity may be calculated falsely.

**Motion Correction (BOLD Tab)**: Similar to the motion correction in the a_ep2d_bold sequence a full 3D motion correction can be performed online. In the Multi-Echo EPI sequence this option enables the T2\*-Fit depending on the setting of 'skip T2-Fitting' (DiCo Tab). For most accurate results the motion correction is based on the I0-maps or the first echo image, which are used to determine the motion parameters. Subsequently these parameters are applied to reorient the T2\*-maps or remaining echos. Either the motion corrected T2\*-maps or the corrected single echo images are written to the database together with the original images (depending on the setting for 'skip T2-Fitting').

**Interpolation**: The interpolation should be set to 'k-Space'! (see 3D Filter)

**3D Filter**: The filter has the same function as in standard EPI (remember: smaller values cause stronger spatial filtering!).

**t-Test**: The online t-test and display work as in the original EPI sequence. However, the **t-test only works properly when motion correction is selected and T2\* fitting is performed**! Alternatively, T2\*-Maps can be processed within the BOLD-card.

**Trigger Output Control:** A periodical trigger signal can be generated from the sequence in order to synchronize the experiment e.g. with an external stimulus generator. On the Special Card of the Sequence Tab are 2 additional parameters to control the execution of the trigger output: **Trigger Volumes to Skip** is the number of measurements at the beginning of the scan (excluding the dummy scans performed by the system, which are not recorded). **Volumes Per Trigger** is the number of measurements from trigger to trigger. The trigger signal is put out at the beginning of the measurements specified before the excitation of the first slice. The output **Trigger Channel** and **Trigger Duration** can also be defined. Use OSC-signal 1 (in RF-

cabinet output osc 1) rather than the default, which is 0, in order to avoid trigger signals sent by the system, e.g. during adjustment.
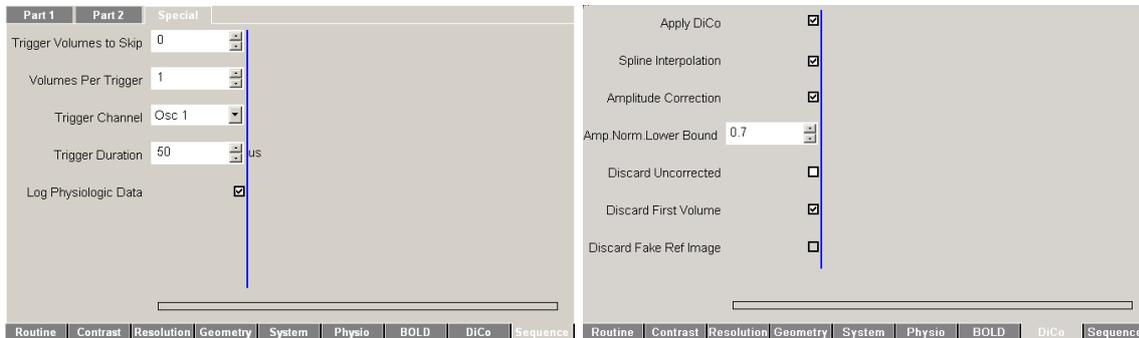


On the new **DiCo Tab** a number of parameters can be set to determine the reconstruction processing chain:
Remark on this DiCo Tab: Unfortunately, this tab can only be edited in the Exam Explorer and can not be viewed in the Exam task card during sequence prescription. However, this does not compromise functionality.

**Apply DiCo**: This check box enables EPI distortion correction. In order to correct for geometric distortions of the images, the reference scan has to be performed before the execution of the MEPI sequence. The reference scan (mz_ep2d_psf) is distributed with the EPI Distortion Correction package and has to be shipped and installed separately. (see documentation for the function of the next 5 check boxes).

# 2.5 Protocols

When the default protocol is created, motion correction is selected! Please adjust to your needs. Remember, t-test only works correctly when motion correction is enabled (due to inflexibility in the BOLD task card t-test could not be disabled for this condition).
As in the standard EPI sequence, the sequence automatically introduces 'dummy scans' at the beginning if more than one measurement is specified! The number of dummy scans depends on the TR.
The audible 340 microsecond delay between repetitions has been removed. Thus, the subject should not be able to hear the start of repeated measurements.