

Application Guide & Release Notes

Multi-Band EPI C2P

Release 010c
28 March 2014



Center for Magnetic
Resonance Research

UNIVERSITY OF MINNESOTA

Driven to DiscoverSM

Conditions of Use

This package is provided to support collaborative research projects between the University of Minnesota and users of Siemens MRI equipment, in accordance with a current C2P agreement.

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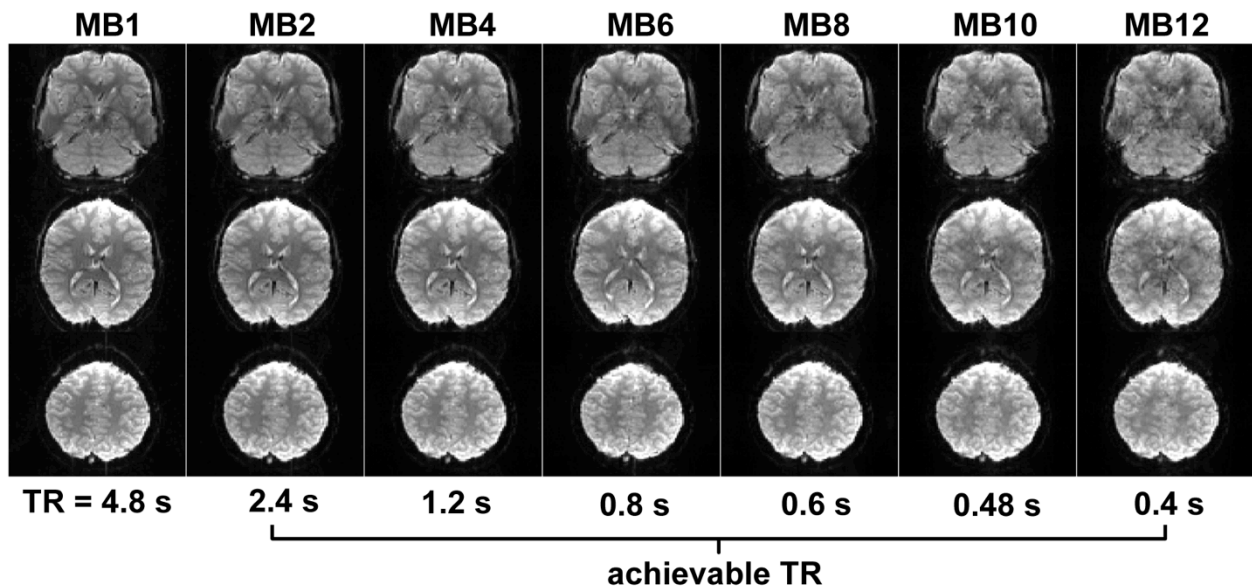
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Overview

Multi-banded RF pulses can be used to accelerate volume coverage along the slice direction by simultaneously exciting and acquiring multiple slices and subsequently unaliasing them using parallel imaging principles and the spatial information available in multi-channel RF array coils.

This allows for a direct reduction in the volume T_R by the number of simultaneously excited slices (i.e., the multiband (MB) factor or the slice acceleration factor). For example, the figure below shows the minimum achievable T_R for a 64-slice, 2 mm isotropic resolution GRE-EPI acquisition using various MB factors:



Such a significant reduction in minimum T_R is very useful in studies of the brain. In particular, the ability to sample more rapidly while preserving whole-brain coverage is of great benefit to resting-state fMRI. It is also useful to reduce the otherwise long total scan times required for diffusion-weighted imaging techniques such as HARDI and DSI.

Sequence Description

The pulse sequences in this package are based on the product ep2d_bold, ep2d_se, and ep2d_diff sequences from Siemens.

Multi-banded RF pulses are calculated by the sequence using linear combinations of the same RF pulses used in the product sequences. To improve the MB unaliasing performance, partial FoV shifts are applied using gradient blips along the slice direction during the EPI readout. The optimum shift factor is selected automatically by the sequence.

More detailed information about the pulse sequence and image reconstruction implementation can be found in the following references:

Moeller S, Yacoub E, Olman CA, Auerbach EJ, Strupp J, Harel N, Uğurbil K. Multiband multislice GE-EPI at 7 tesla, with 16-fold acceleration using partial parallel imaging with application to high spatial and temporal whole-brain fMRI. *Magn Reson Med*. 2010;63(5):1144–1153. [\[PubMed\]](#)

Setsompop K, Gagoski BA, Polimeni JR, Witzel T, Wedeen VJ, Wald LL. Blipped-controlled aliasing in parallel imaging for simultaneous multislice echo planar imaging with reduced g-factor penalty. *Magn Reson Med* 2012;67(5):1210–1224. [\[PubMed\]](#)

Xu J, Moeller S, Auerbach EJ, Strupp J, Smith SM, Feinberg DA, Yacoub E, Uğurbil K. Evaluation of slice accelerations using multiband echo planar imaging at 3T. *Neuroimage*. 2013 Dec;83:991-1001. [\[PubMed\]](#)

Auerbach EJ, Xu J, Yacoub E, Moeller S, Uğurbil K. Multiband accelerated spin-echo echo planar imaging with reduced peak RF power using time-shifted RF pulses. *Magn Reson Med*. 2013 May;69(5):1261-7. [\[PubMed\]](#)

Sotiropoulos SN, Moeller S, Jbabdi S, Xu J, Andersson JL, Auerbach EJ, Yacoub E, Feinberg D, Setsompop K, Wald LL, Behrens TEJ, Uğurbil K, Lenglet C. Effects of image reconstruction on fiber orientation mapping from multichannel diffusion MRI: Reducing the noise floor using SENSE. *Magn Reson Med* 2013;70(6):1682-1689. [\[PubMed\]](#)

Hardware and Software Requirements

Versions of the multi-band accelerated sequences are currently provided for three Siemens software versions, supporting several system types. It may be possible to use the sequences with other systems not list (e.g. 1.5T systems), but compatibility has not been tested.

VB17A: MAGNETOM Trio, a Tim System 3T, MAGNETOM Verio 3T, and MAGNETOM 7T. The 32-channel head coil is highly recommended for 3T. The 12-channel Head Matrix is not recommended, but it can be used for acceptable image quality at low acceleration factors. For 7T, the Nova 32-channel coil is recommended.

VD11D: MAGNETOM Skyra 3T and MAGNETOM Skyra ConnectomS 3T. The 32-channel head coil is recommended. The Head/Neck 20 coil can also be used, but image quality will be diminished at higher acceleration factors.

VD13A-SP2: MAGNETOM Skyra 3T. The 32-channel head coil is recommended. The Head/Neck 20 coil can also be used, but image quality will be diminished at higher acceleration factors.

VD13A-SP4: MAGNETOM Skyra 3T. The 32-channel head coil is recommended. The Head/Neck 20 coil can also be used, but image quality will be diminished at higher acceleration factors.

VD13C: MAGNETOM Skyra 3T. The Head/Neck 20 coil can also be used, but image quality will be diminished at higher acceleration factors.

VD13D: MAGNETOM Prisma 3T. The 32-channel head or Head/Neck 64 coils are recommended.

Installation Procedure

1. Restart the system (reboot host and MRIR, or restart *image calculation* and the syngo *Exam* task card). This is necessary to unload possibly locked shared objects.
2. Login as “Advanced User”.
3. Extract the .zip file to a temporary directory
4. Run the installer .bat file
5. If the installer reports any error, please restart the system and try again.
6. If a sample protocol is available for your system, it will appear at the end of the USER tree in the Exam Explorer. If a sample protocol is not available, create a default protocol in Exam Explorer by selecting Insert Sequence, USER, then cmrr_mbep2d_* for the desired sequence variant.

Usage

These sequences are based on the Siemens product ep2d_* family of sequences; most of the protocol parameters are the same.

The most important changes appear on the following measurement cards:

Routine Card

The screenshot displays the MRI Routine Card interface. On the left side, parameters include: Slice group (1), Slices (72), Dist. factor (0%), Position (Isocenter), Orientation (Transversal), Phase enc. dir. (A >> P), AutoAlign (---), and Phase oversampling (0%). On the right side, parameters include: FoV read (192 mm), FoV phase (100.0%), Slice thickness (2.00 mm), TR (818 ms), TE (31 ms), Multi-band accel. factor (8), Filter (None), and Coil elements (HEA;HEP). At the bottom, a slider for the Multi-band accel. factor is shown, ranging from 2 to 12, with a green bar indicating the current value of 8. The bottom navigation bar includes tabs for Routine, Contrast, Resolution, Geometry, System, Physio, BOLD, and Sequence.

Multi-band accel. factor: This parameter is only editable if the number of slices is greater than 1. The number of slices must be an integer multiple of the multi-band acceleration factor. The maximum acceleration factor is 16 in the current release if iPAT is not used, otherwise the product of the MB accel. factor and the iPAT factor may not exceed 12.

Slices: The number of slices must be an integer multiple of the multi-band acceleration factor. It may be necessary to reset the multi-band accel. factor to 1 in order to select an arbitrary number of slices; a new multi-band accel. factor can then be reselected.

Averages: Online averaging has been disabled due to incompatibility with the online reconstruction.

Dist. factor: There must be a minimum gap of 100% of the slice thickness between adjacent bands in the RF pulse. Therefore in a case where the number of bands is equal to the number of slices, a minimum distance factor of 100% will be required. In the usual case where slices \gg bands, however, a distance factor of 0% can be used.

Contrast/Common Card

The image shows a software interface for MRI parameter configuration. It has two tabs: 'Common' and 'Dynamic', with 'Dynamic' currently selected. The interface is divided into several sections. The top section contains TR (3650 ms) and TE (95 ms) input fields with up/down arrows. To the right, there are two dropdown menus: 'Fat suppression' set to 'Fat sat.' and 'Grad. rev. fat suppression' set to 'Disabled'. Below these, there is an 'MTC' checkbox (unchecked) and a 'Magn. preparation' dropdown menu set to 'None'. The bottom section features a 'Flip angle' input field set to '78 deg' with left/right arrows. Below the flip angle is a 'TR' slider bar, with '3650' at the left end and '30000' at the right end. At the bottom of the interface is a row of tabs: 'Routine', 'Contrast', 'Resolution', 'Geometry', 'System', 'Physio', 'Diff', and 'Sequence'.

Grad rev. fat suppr. (SE/diffusion only): If enabled, the polarity of the slice select gradients will be reversed between excitation and refocusing. This can provide effective fat suppression at no cost in time or SAR. It can also result in signal losses in areas of B₀ inhomogeneity. Typically it is most useful at 3T.

Sequence/Special Card

The screenshot displays the 'Special' tab of the 'Sequence/Special Card' interface. The 'Excite pulse duration' is set to 2560 us. Other parameters include 'Single-band images' (unchecked), 'Online multi-band recon.' (set to 'Online'), 'FFT scale factor' (1.00), 'Triggering scheme' (Standard), and 'Starting ignore meas' (0). A progress bar at the bottom indicates the 'Excite pulse duration' is 2560, with a range from 880 to 16380. The interface includes tabs for 'Part 1', 'Part 2', and 'Special' at the top, and 'Routine', 'Contrast', 'Resolution', 'Geometry', 'System', 'Physio', 'BOLD', and 'Sequence' at the bottom.

Excite pulse duration: The required RF pulse voltage increases linearly with the multi-band acceleration factor. Here the pulse length of the excitation RF pulse can be manipulated manually at the cost of T_E and bandwidth.

Verify on the System|Transmitter/Receiver card that the voltage of all pulses, especially those with names similar to “MBExc” and “MBRef” (SE/diffusion only) are below the system maximum value. Otherwise, the pulse(s) will be clipped and the flip angle(s) will be less than expected. A warning message will pop up on the host if this occurs.

Refocus pulse duration (SE/diffusion only): This parameter will appear arrayed beneath the Excite pulse duration parameter in SE or diffusion sequences. It allows for manually controlling the duration of the refocusing pulse(s) only.

Single-band images: Select this checkbox to send the single-band reference images to the database in a separate series (e.g. for quality

control). NOTE: this option is not compatible with FMRI post-processing and motion correction (the single-band images will be quietly discarded in this case).

MB RF phase scramble: Select this checkbox to optimize inter-band phase offsets in the RF pulse shape to reduce the required peak RF power (ref. *Proc. ISMRM* 2012, #2209). Overall SAR is unchanged. This option is currently only defined for MB acceleration factors 3-8.

Time-shifted MB RF (SE/diffusion only): Select this checkbox to temporally offset the bands in the RF pulse shape to reduce the required peak RF power (ref. *MRM* 2013;69:1261-7). Overall SAR is unchanged. For SE and monopolar diffusion, the “aligned- T_E ” scheme described in the reference is used. Refer to the tooltip for specific shift offset information.

SENSE1 coil combine: Select this checkbox to use a SENSE R=1 algorithm for SNR-optimized coil combination (ref. *MRM* 2013;70(6):1682-9). Coil combine mode “sum of squares” must also be selected on the System/Miscellaneous card.

Log physiology to file: Select this checkbox to save physiological signals (cardiac, respiration, ECG, external) to a file. The files will be stored in C:\MedCom\Log\Physio\ on the host computer (MRC).

Invert RO/PE polarity: Select this checkbox to automatically apply a 180-degree in-plane rotation to the acquisition parameters (e.g. to use for eddy current correction in post-processing).

Online multi-band recon.: *Online* will reconstruct the multi-band accelerated images in ICE and send them to the database. *Aliased* will send the aliased images directly to the database without reconstruction (for debugging). *None* is equivalent to EmptyIc (e.g. for later reconstruction offline).

If the optional remote reconstruction service is configured, the option to enable it will be found here.

FFT scale factor: This parameter may be used to adjust the image brightness, i.e. to optimize dynamic range. Note that on VD11D and newer platforms 16-bit DICOM format is used.

Triggering scheme (*BOLD/SE only*): This parameter, and the arrayed parameters below it, can be used to control the sending of the external trigger signal (EXT_TRIG) per slice, per volume, and/or controlled by a custom paradigm. Refer to the tooltip for details. The paradigm definition is similar to that of the BOLD card. If scheme “standard” is selected, the external trigger will be sent once at the start of each repetition (same behavior as the product sequences).

Important Issues (not bugs)

This release will expire on 1 June 2014!

- Only diffusion modes “MDDW” and “Free” are compatible with multi-band. The other modes have been disabled. The MDDW license is therefore required to insert the MB diffusion sequence.
- It is not possible to use FMRI post-processing and/or motion correction and also save the single-band reference images. If both are selected, the ICE program will silently discard the single-band reference images. It is generally not recommended to use these post-processing steps since they slow down the online reconstruction and can very easily be performed offline (often with better results).
- Demanding diffusion acquisitions with high b values may fail with gradient duty cycle errors if the highest gradient amplitudes are requested on the same axis over several consecutive T_R s. This can be avoided by using e.g. a randomized vector table (in “Free” mode) to distribute the gradient demand more evenly over time. (This also applies to the product diffusion sequence.)
- Monopolar+ and bipolar+ diffusion schemes are not available. Unfortunately Siemens does not make the code to enable these modes available for customer sequences.
- Reconstruction is sometimes slow, especially with iPAT enabled. This is unavoidable due to the complexity of the unaliasing calculations, but it is something that we continually aim to improve. It is recommended to have the fastest available MRIR/MARS from Siemens. Using the [remote reconstruction service](#) can offer dramatic performance improvements, approaching real time.

Known Bugs

Please refer to <https://github.com/eauerbach/CMRR-MB/issues> to read and submit bug reports.

Version Changes

Release 010c, 28 March 2014

(eja: vd13a/59bad81, vd13c/1b2c8d6, vd13d/4b0f402)

- VD13C: Fixed issue preventing SE sequence from being inserted.
- VD13A: Fixed issue where diffusion mode Free could not be selected in new protocols, related diffusion UI slowness.
- VD13D: New protocols now default to gradient mode Performance if it is available (e.g. for Prisma).
- Removed non-functional diffusion modes (only MDDW and Free are supported).

Release 010b, 13 December 2013

(eja: seqs only all versions; vb17a/41a9b7e, vd11d/R010/dae2076, vd13a/sp2/3451f7c, vd13a/R010/fd129fc, vd13d/R010/7d45ede; added 29 Jan 2014: vb19a/6a5af2e, vd13c/2bfb96d)

- VB17A: Fixed scanner crash and reboot if a non-MB sequence was used following a MB sequence in the same session.
- VD13D: Fixed incorrect orientation labeling of slices with the “invert RO/PE” option selected.
- VD11D/VD13x: Fixed inconsistent synchronization of frequency feedback acquisition. This could result in timing errors of ~20ms per T_R and degraded image quality for certain protocols.
- If the “log physiology to file” checkbox is selected, the directory C:\MedCom\log\Physio will now be created if it does not already exist.
- iPAT reference scan for R=2 is now segmented as it was in previous versions (protocols with larger numbers of reference lines should no longer break on import).
- Descending slice order should now work properly (really).

Release 010a, 22 November 2013

(eja: vb17a/857e1d9 all seqs, vd11d/R010/2638d72 diff seq only)

- VB17A: Fixed display of current measurement in the status bar.
- VB17A/VD11D: Fixed inability to select diffusion mode Free.
- VB17A: RF pulse durations can now be set freely for single-band SE/diffusion protocols on UHF systems.

Release 010, 20 November 2013

(eja: vb17a/r206, vd11d/R010/6fea7e1, vd13a/sp2/49ca23b, vd13a/R010/5b5bc96, vd13d/R010/eacfbce)

- The number of preparation scans acquired at the start of the measurement has been reduced, notably for diffusion protocols and protocols using iPAT.
- VD13A: Transmitter feedback is now specifically disabled for Skyra systems by default. This new feature is currently causing crashes with multiband pulses; Siemens may fix it in a future hardware update.
- Gradient reversal fat suppression is now an independently selectable option. In previous versions it was automatically enabled if fat suppression modes “none” or “strong” were selected (following Siemens default behavior since VD11).
- New options have been added for sending optical trigger signals per slice or repetition.
- New options have been added to use phase scrambling and/or time-shifting approaches to reduce peak RF power.
- Clipped RF pulse warning window should no longer pop under the exam window.
- Descending slice order should now work properly.
- VB17: iPAT>2 should work now on pTX systems.
- VD13: Images should no longer jump in the phase direction.
- Copying sequence parameters from other protocols should be more reliable.
- UI responsiveness and stability should be improved.

Release 009a, 21 May 2013

(eja: seq/ICE VB17A r158/r157, VD11D r236/r234, VD13A-SP2 r22/r20)

- VB17: Fixed inability to load existing diffusion protocols.
- Minimum T_E/T_R should now match previous versions.

Release 009, 15 May 2013

(eja: VB17A r157, VD11D r234, VD13A-SP2 r20)

- First “development” release.
- Added VD13A-SP2 version.
- Dramatic image quality improvements. All images should appear significantly sharper, and MB+iPAT performance is especially improved.

- The maximum allowed MB factor has been increased from 8 to 16.
- Allowed MB*iPAT factors have been increased to 12.
- Many user interface improvements. The user interface should be more responsive and more stable in general.
- All diffusion modes aside from MDDW and Free have been disabled. Previously the other modes were selectable but would crash image reconstruction.
- Saving single-band images in combination with FMRI postprocessing and/or motion correction will no longer crash image reconstruction (the single-band images will be discarded).
- Minimum T_E/T_R /thickness increments have been reduced.

Release 008, 13 February 2013

(eja: seq/ICE VB17A r121/r122; VD11D r206/r205)

- First “stable” release.
- Added options for reconstructing phase images
- MB+iPAT reconstruction improvements

Release 007, 21 November 2012

(eja: VB17A r113; VD11D r195)

- Reconstruction speed improvements
- Fixed occasional occurrence of intensity variations between bands in some (mostly diffusion) protocols
- VD11: Siemens product frequency feedback/update enabled
- VD11: Checkbox added to invert readout and phase encoding gradient polarity (useful for post-processing eddy current corrections)
- SENSE1: image comment now indicates whether SENSE1 has been applied
- SENSE1: susceptibility-induced signal loss reduced

Release 006b, 21 June 2012

(eja: VB17A r92)

- VB17: fixed cases in monopolar diffusion where spoiler gradients failed to be played out for single-band $b=0$ reference scan

Release 006a, 23 May 2012

(eja: VB17A r91; VD11D r154)

- Fixed memory leak which caused recon to eventually crash for long series
- VB17: fixed FFT scaling factor for SENSE1
- Minor improvements to exported physiological log data

Release 006, 18 May 2012

(eja: VB17A r88; VD11D r151)

- Expiration date extended to 1 December 2012
- Added spin-echo EPI sequence variant
- Fixed clipped RF pulse dialog false alarms (for real this time...)
- VD11: fixed crash when physiological logging is enabled
- VB17: improved EPI ghost correction for BOLD variant
- VB17: fixed DTI recon preparation failure for certain syngo patch levels
- Limited max. MB factor to 3 for diffusion
- Removed non-working “free echo spacing” checkbox
- Misc. UI improvements

Release 005, 6 April 2012

(eja: VB17A r75; VD11D r125)

- Image quality improvements for MB7 and MB8
- Added SENSE1 coil combination option
- Restored option to save single-band reference images to a separate series
- Fixed clipped RF pulse dialog for VB17 diffusion refocusing pulses
- Further reconstruction speed improvements

Release 004a, 20 March 2012

(eja: VB17A r72; VD11D r111)

- Fixed incompatibility with protocols created with earlier revisions
- Reconstruction speed improvements

Release 004, 20 March 2012

(eja: VB17A r71; VD11D r110)

- Fixed DTI recon crash when postprocessing was explicitly not selected
- Added warning dialog on host if (MB) RF pulses will be clipped

- Fixed crash when creating new DTI protocols
- Fixed gradient errors on systems with lower slew rates (e.g., Verio)
- UI responsiveness, stability improvements
- Removed “single-band images” option due to unresolved ICE crashes; will restore in a later release

Release 003, 27 January 2012

(eja: VB17A r64; VD11D r78)

- Reconstruction speed improvements
- MB+iPAT image quality improvements
- Added option to save single-band reference images to a separate series
- Reduced number of prep scans at start of BOLD measurement
- Adaptive coil combine now compatible with MB (VD11D only)

Release 002a, 4 January 2012

(eja: VB17A r60; VD11D r61)

- VB17A ICE program expiration date fixed

Release 002, 18 November 2011

(eja: VB17A r58; VD11D r61)

- Diffusion variant (ep2d_diff) released
- iPAT (GRAPPA only) enabled
- Option to log physiological data to file added
- Additional FFT scale factor UI parameter added (VB17 only)
- Bug fixes

Release 001, 26 September 2011

(eja: VB17A r50; VD11D r36)

- Initial public release