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GE Healthcare

Slice Timing Information for fMRI
Information for fMRI research users

Brice Fernandez
Rev 5

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Scope and Purpose

This document is intended to provide information about the implementation of EPI slice timing on scanners built by GE Healthcare to research users who are interested in performing slice timing correction for fMRI using popular 3rd party research tools like SPM/FSL/AFNI.
This information is only applicable to pulse sequences **EPIRT** (i.e. epi with fMRI option – with Brainwave RT) and **EPI** multiphase (i.e. epi with multiphase option).

Intended Use Limitation

The instructions given in this document are intended to be used for research purposes only.

Introduction

Slice timing correction is often one of the first steps of most fMRI preprocessing pipelines. However, slice timing correction requires the knowledge of the (relative) acquisition timing of each slice for a given volume. The acquisition timing depends on a number of parameters which are listed later.

Information given in this document is for the DV28.0_R01 software release except in section "Previous software releases (DV26, DV27/RX27)" where the differences with previous software releases are highlighted.

In this document, we will first describe how to use the Scanner UI to set the parameters which control slice acquisition timing, and where to find these parameters in the scanner UI and in DICOM image headers generated during the scan. Next, we will describe how the slice acquisition is performed as a function of the control parameters. Then, we will show how to extract the slice timing information and supply it to 3rd-party software. Finally, some MATLAB functions available on request will be presented together with some tips and tricks for EPIC programmers.

Control parameters

Parameters controlling the order of acquisition of the slices are:

- Repetition time (TR),
- The number of slices per volume (#Slices),

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- The HyperBand acceleration factor (HB factor – commonly named Multiband factor or MB factor),
- The slice order (i.e. Sequential or Interleaved),
- The slice direction (i.e. Ascending (Inferior-Superior direction) or Descending (Superior-Inferior direction)),
- Software release (i.e. DV28.0_R01, RX27.0_R02, DV26.0_R04 etc…).

On the Scanner GUI

On the scan prescription UI, the TR and #Slices are directly accessible. Note that for using EPI multiphase for fMRI research applications, "# of Acqs" has to be equal to 1 (i.e. all slices acquired in one TR) and the "Phase Acquisition Order" has to be "Interleaved" in the Multi-Phase tab.

The HyperBand acceleration factor is controlled by the "HyperBand Slice" entry in the acceleration tab (see Figure 1).

Figure 1: Screenshot of the scan prescription UI. The important parameters TR, #Slices and the "HyperBand Slice" acceleration factor are highlighted in red boxes for EPI with multiphase option and EPI with fMRI option (Brainwave). In yellow, some important parameters to verify when doing fMRI using the multiphase option.

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The slice order is always Interleaved for EPI multiphase, but with EPIRT (with fMRI option activated / brainwave) it is controlled by the “Slice Order” dropdown menu in the fMRI screen (accessible by clicking on the fMRI button in the “details” tab, see Figure 2).

The slice direction is usually called “Ascending” when the slices are acquired in the Inferior-Superior direction and “Descending” when the slices are acquired in the Superior-Inferior direction. The slice direction is directly controlled in the graphical prescription UI (GRx) when the slices are positioned (see Figure 3).

The Software release can be found on the Service Browser or by simply typing “getver” in a command window.

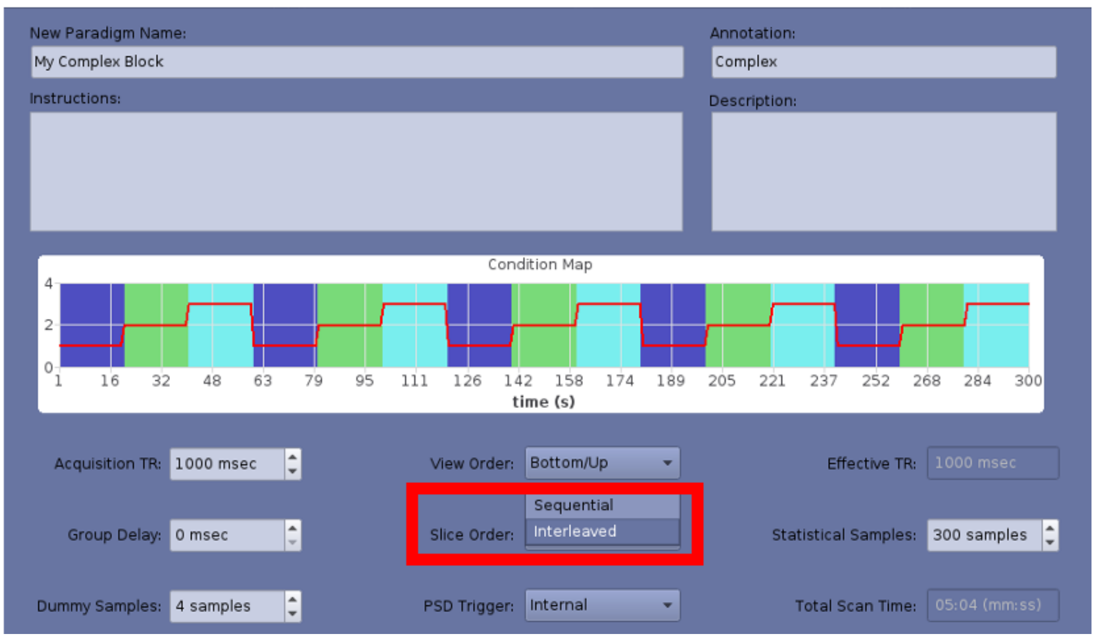

Figure 2: Screenshot of the fMRI screen. The Slice Order dropdown menu is highlighted in red and can be set to Sequential or Interleaved (default).

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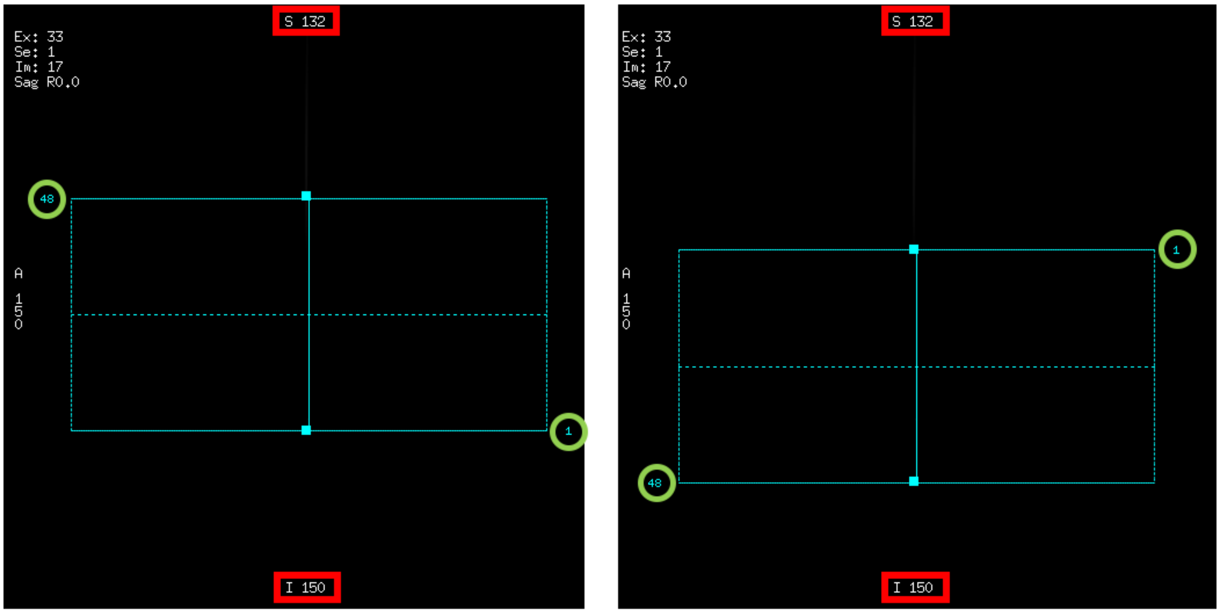

Figure 3: Screenshot of GRx showing slices prescribed in the Ascending direction (Inferior-Superior direction) on the left side and slices prescribed in the Descending direction (Superior-Inferior direction) on the right side. Note the orientation annotation of the localizer (highlighted in red) and the slice number (highlighted in green). On the left, slice 1 is the most inferior slice (Ascending) and on the right side, slice 1 is the most superior slice (Descending).

In the DICOM header

In this section, we look at where to find the parameters controlling the order of acquisition of the slices in the DICOM files. The DICOM attributes are written between double quotes and the corresponding tags are given in "Appendix 1: DICOM Fields".

The TR can be easily found in the standard DICOM attribute "Repetition Time".

The numbers of slice (#Slices) is generally not directly written. In general, the number of slices can be determined by finding the first image with "instance number" which has the same "slice location" as "instance number" 1 for "echo number" 1 (divided by the number of echoes in case of Multi-echo EPI scan). Seen otherwise, #Slices is the number of unique "slice locations" in a DICOM series. However, the private DICOM tag "Locations in acquisition" provides this information directly for both EPI and EPIRT. In the particular case of EPIRT (epi with fMRI option – with Brainwave RT), #Slices can be also found directly in the private DICOM attribute "Number of Slices per Volume".

The HyperBand acceleration factor (HB factor) is directly in the DICOM attribute "Multiband Parameters" (the first given value).

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The slice order (i.e. Sequential or Interleaved) is not directly accessible. The slice order is always Interleaved for EPI multiphase. For EPI with the fMRI option, the “paradigm name” and “paradigm UID” can be found in the DICOM files and used to retrieve the exact paradigm used. Using this information, the slice order can be found in the paradigm details using the protocol manager or the Brainwave Paradigm Manager (BWPM) accessible via the service browser or by typing “bwpm” in a command window (see the scanner user manual). The BWPM can also be used to extract paradigm-related information from a DICOM file in case the paradigm has been deleted (see usage of BWPM in the scanner user manual). However, for EPI with the fMRI option the slice order can be extracted from the DICOM tag “Protocol Data Block (compressed)” (see section MATLAB Functions) or deduced from the DICOM Tag “RTIA_timer” starting at the second volume. For EPI Multiphase, the slice order can be deduced from the DICOM Tag “TriggerTime”.

The slice direction (i.e. Ascending or Descending) is not directly accessible but can be easily deduced from the “slice location”. Assuming that the patient is scanned head-first in the supine position, if the difference between two consecutives entries “slice location” (in increasing “instance number” and for the same “Echo number”) is negative then the slice direction is Ascending (towards more superior slices) and Descending otherwise. For example, assuming a single echo scan, if “slice location” of “instance number” 1 is equal to -105.09 and “slice location” of “instance number” 2 is equal to -102.09, the difference is -3 (a negative value) so the slice direction is Ascending. On the contrary, if “slice location” of “instance number” 1 is equal to 75.6 and “slice location” of “instance number” 2 is equal to 72.2, the difference is 3.4 (a positive value) so the slice direction is Descending.

Finally, the software release can be found in the standard DICOM attribute “Software Versions”.

Slice order and timing implementation

In this section, the software release DV28.0_R01 will be considered. In addition, for EPIRT the “Group Delay” entry in the “fMRI Screen” is considered to be 0 msec.

Without HyperBand

Let’s start with the simplest case without HyperBand (HB factor = 1) and N_s slices and a given T_R. We define the time T_a for the acquisition for 1 slice as

$$T_a = \frac{N_s}{T_R}.$$

This will be useful knowing that the slices are evenly acquired over time. For now, we considered that the slice direction is Ascending. Then, if the slice order is Sequential, this simply means that the slices are acquired in straight order (i.e. $1, 2, 3, 4, 5, 6, \dots . N_s$). If the slice order is Interleaved, then the slices with odd number index $(1, 3, 5, 7, \dots)$ will be acquired first and the slices with even number index $(2, 4, 6, 8, \dots)$ will be acquired afterwards. This behavior does not change when the number of slices is even or odd. For a graphical representation, see Figure 4-a and Figure 4-c.

Let's write i the 1-based slice index number (i.e $i \in [1, N_s]$). In the Sequential Ascending case, the slice timing of slice i noted $T_s^{asc}(i)$ can be simply computed by

$$T_s^{asc}(i) = (i-1)T_a.$$

The slice timing could be offset by the echo-time and the RF excitation isocenter to be more precise, but this is not necessary as for slice timing correction the only important parameter is the slice timing difference. The Interleaved Ascending case is less straightforward to write. However, it is easy to compute and store in a new vector by taking first the odd slice indexes and then the even slice indexes. Finally, the slice timing for the Descending case (T_s^{desc}) is simply the reversed order of the Ascending case for both Sequential and Interleaved, so

$$T_s^{desc}(i) = T_s^{asc}(Ns + 1 - i).$$

The NIfTI file format used by most scientists stores images where the first three dimensions are spatial and ordered sequentially by dimension (ie x-direction, then y-direction, then the z-direction). The convention for axially acquired data is for the data to be saved to disk using RAS or LAS (e.g. rows store left-right data, columns store posterior-to-anterior, and slices store inferior-to-superior). The NIfTI spatial transforms (s-form and q-form) explicitly describe the conversion to-and-from rows, columns, and slices, to spatial dimensions. Note that coronally and sagittally-acquired data will store slices in the anterior-posterior and left-right dimensions, respectively. It is important to note the difference between the slice directions "Ascending" and "Descending" because the slice direction always increases toward the superior direction in the NIfTI header for axial acquisitions whereas the EPI acquisition does not necessarily follow this convention. We advise you to check your data (acquisition, dicom and NIFTI) to ensure you have the correct slice direction.

In Figure 4, a graphical representation is given for an example using 36 slices and HB factor 1 for slice order Sequential/Interleaved and slice direction Ascending/Descending.

In Table 1, a numerical example is given for 9 slices, HB factor 1 and a T_R of 0.9 seconds for different combination of slice orders and slice directions.

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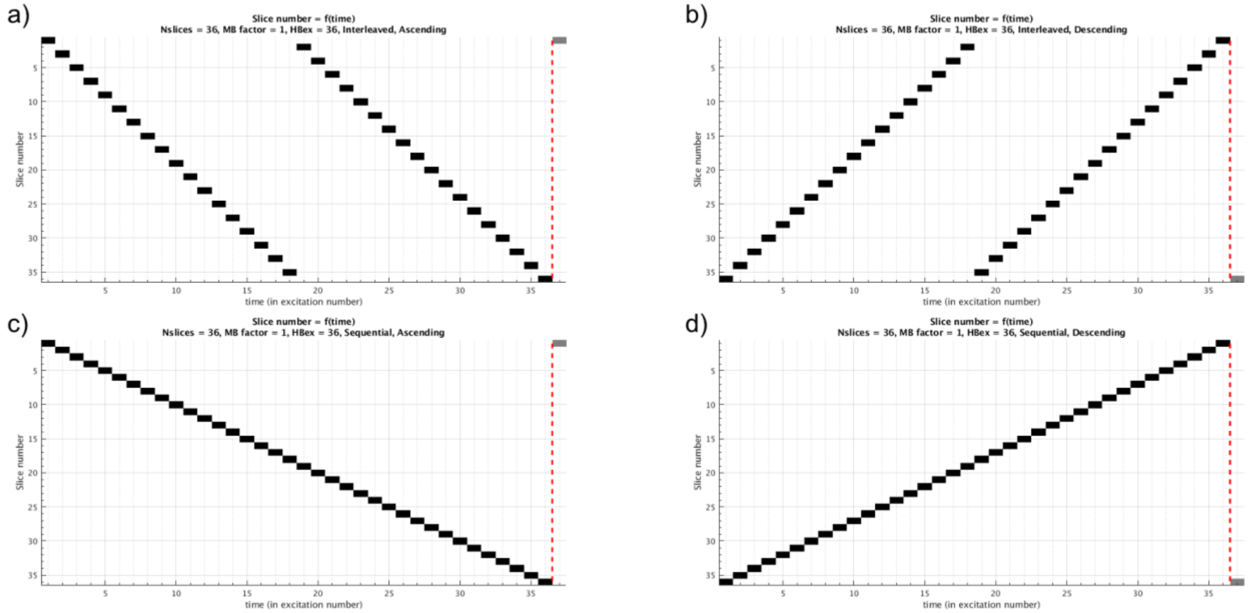

Figure 4: Simple plots of the slice number as a function of time (in consecutive excitation numbers). In this figure, the number of slices is 36 and the HB factor is 1 (no HyperBand/Multiband). (a) case Interleaved, Ascending, (b) case Interleaved, Descending, (c) case Sequential, Ascending, and (d) case Sequential, Descending. The red dashed line signifies the end of the acquisition of volume N and the beginning of the volume N+1. In grey, the first excited slice of the next volume is also plotted.

Time index	Slice index				Slice Timing (second)			
	Ascending		Descending		Ascending		Descending	
	Sequential	Interleaved	Sequential	Interleaved	Sequential	Interleaved	Sequential	Interleaved
1	1	1	9	9	0	0	0.8	0.8
2	2	6	8	4	0.1	0.5	0.7	0.3
3	3	2	7	8	0.2	0.1	0.6	0.7
4	4	7	6	3	0.3	0.6	0.5	0.2
5	5	3	5	7	0.4	0.2	0.4	0.6
6	6	8	4	2	0.5	0.7	0.3	0.1
7	7	4	3	6	0.6	0.3	0.2	0.5
8	8	9	2	1	0.7	0.8	0.1	0
9	9	5	1	5	0.8	0.4	0	0.4

Table 1: Numerical example for 9 slices and a T_R of 0.9 s for all possible slice orders and directions.

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With HyperBand

When HyperBand is used, the same principle applies but all the simultaneously excited slices need to be considered as a single slice.

In the case of HyperBand, the number of slices N_s is different from the number of HyperBand excitations HB_{ex}. The latter is defined as:

$$HB_{ex} = \frac{N_s}{HB_{factor}}$$

with HB_{factor} the HyperBand factor: the number of simultaneously excited slices. Regarding the slice timing, each HyperBand excitation excites HB_{factor} slices spaced by $HB_{ex} - 1$ slices, so the HB_{factor} simultaneously excited slices will have the same slice timing.

Let's start with the simplest case, where N_s is divisible by HB_{factor} (so HB_{ex} is an integer). Moreover, we first consider that HB_{ex} is an odd integer just like in the Human Connectome Project (HCP) fMRI protocol where $N_s = 72$, $HB_{factor} = 8$, so $HB_{ex} = 9$ and that the slice direction is Ascending. In the case of a Sequential slice order, the consecutive HyperBand excitations simply excite the next contiguous slices. Regarding the slice timing, we need to modify the definition of T_a to be the time needed for the acquisition of HB_{factor} simultaneous slices as:

$$T_a = \frac{T_R}{HB_{ex}} = \frac{TR}{N_s}\, HB_{factor}$$

which generalizes the previous definition of T_a. Then, still in the Sequential case, the slice timing for each simultaneous excitation is simply

$$T_s^{HBasc}(j) = (j-1)\, T_a$$

with j the integer 1-based time index in the interval $[1, HB_{ex}]$, and this timing $T_s^{HBasc}(j)$ needs to be set for the HB_{factor} excited slices $i = j + k\, HB_{ex}$ for all k in the integer interval $\left[0, HB_{factor} - 1\right]$. To illustrate this principle in the Sequential Ascending case for the HCP protocol, the slice number as a function of time is plotted in Figure 5-c. As you can see in Figure 5-c, for each time index j (x-axis) HB_{factor} slices i (y-axis) are excited and hence they get the same slice timing, as time index j increases contiguous slices are excited.

The Interleaved Ascending case is, once again, less straightforward to write, but it is easy to compute and store in a new vector by taking first the odd time indexes j and then the even time indexes. The Interleaved Ascending case for the HCP protocol is illustrated in Figure 5-a. As you can observe, this is a simple time index odd/even re-ordering of the Sequential Ascending case (Figure 5-c).

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Finally, the slice timing for the Descending case (T_S^{HBdesc}) is simply the reversed order of the Ascending case for both Sequential and Interleaved, so

$$T_S^{HBdesc}(i) = T_S^{HBasc}(N_s + 1 - i).$$

The Descending case is illustrated in Figure 5-b and Figure 5-d.
Note the principle presented for HyperBand generalizes the single-band case, which is simply the HyperBand case with $HB_{factor} = 1$.

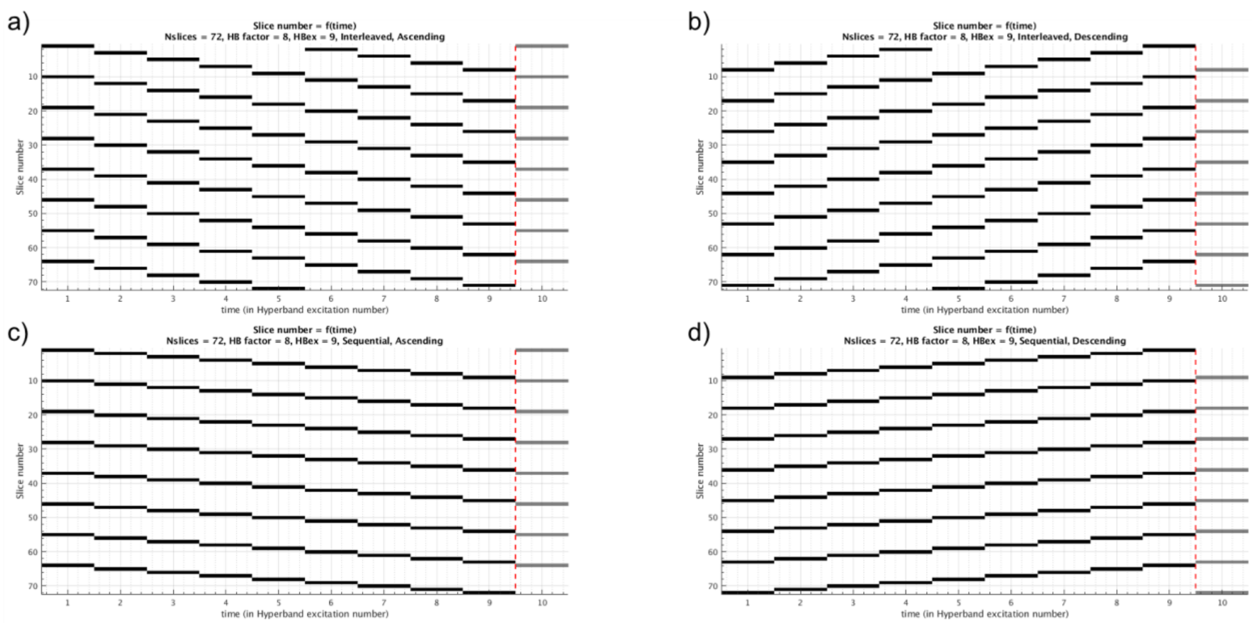

Figure 5: Simple plots of the slice number as a function of time (in consecutive HyperBand excitation numbers). In this figure, this is the Human Connectome Project fMRI protocol. The number of slices is 72 and the HB factor is 8. (a) case Interleaved, Ascending, (b) case Interleaved, Descending, (c) case Sequential, Ascending, and (d) case Sequential, Descending. The red dashed line signifies the end of the acquisition of volume N and the beginning of the volume N+1. In grey, the first simultaneously excited slices of the next volume are also plotted.

So far, we have been considering that HB_{ex} is an odd integer, now let's consider the case that HB_{ex} is an even integer. For the Sequential slice ordering, this does not change anything. In the Interleaved case, the problem is that the slices of the last HyperBand excitation of a given volume might be contiguous with the slices of the first HyperBand excitation of the next volume. This is precisely what we want to avoid in the Interleaved case as this might lead to some interference (see Figure 6-a). However, in GE systems on early version of HyperBand (from DV26 to RX27.0_R02) an extra HyperBand excitation was added such as HB_{ex} become an odd integer to avoid any interferences, then at reconstruction the extra slices were omitted (see next section). Nowadays,

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in recent software releases (RX27.0_R03 and subsequent releases), to avoid this situation when HB_{ex} is an even integer, the order of the two lasts excitations is simply inverted (see Figure 6-b). The Descending case remains the reversed order of the Ascending case.

The last case that requires attention is when the number of slices N_s is not divisible by HB_{factor}. While unlikely, this situation might happen in practice. In this case, the number of HyperBand excitations HB_{ex} is rounded to the next integer value (using the "ceil" function). This leads to some extra excited slices and these extra slices are simply removed after reconstruction (before DICOM generation) as they do not fall into the prescribed volume. An example is given in Figure 7 for the Sequential and Interleaved cases when HB_{ex} is an even integer. Once again, the Descending case remains the reversed order of the Ascending case.

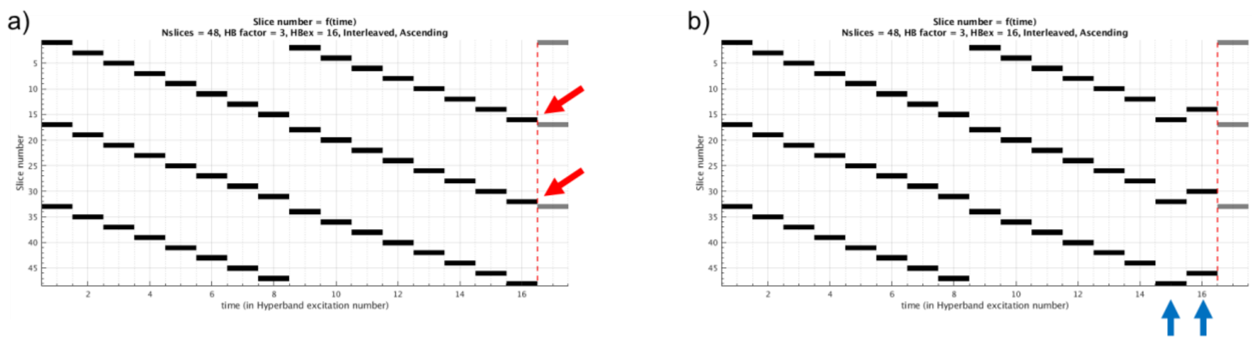

Figure 6: Plots of the slice number as a function of time (in consecutive HyperBand excitation numbers) in the case of Interleaved slice order with HB_{ex} an even integer. In this example, there is 48 slices with a HB factor of 3 (Interleaved, Ascending). (a) illustration of the potential slice interference in the case HB_{ex} is an even integer (red arrows). However, note that it was never done this way on GE systems (see next section). (b) the solution we currently use to avoid the interference by inverting the order of the two last HyperBand excitations (blue arrows). As in previous figures, the red dashed line signifies the end of the acquisition of volume N and the beginning of the volume N+1. In grey, the first simultaneously excited slices of the next volume.

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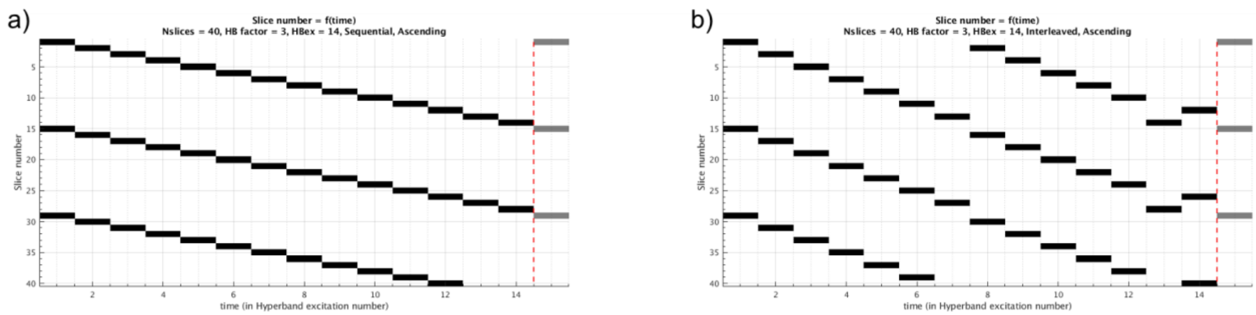

Figure 7: Plots of the slice number as a function of time (in consecutive HyperBand excitation numbers) when the number of slices is not divisible by the HyperBand factor. In this example, there is 40 slices with a HB factor of 3 (Ascending case). This leads to $HB_{ex} = 14$, hence the total number of slices is 42 ($HB_{factor} \times HB_{ex}$) so 2 slices need to be removed. (a) In the Sequential case, the extra slices are the last of the excitation number 13 and 14. (b) In the Interleaved case, the extra slices are the last of the excitation number 7 and 13.

Previous software releases (DV26, DV27/RX27)

Prior to the software release RX27.0_R03 (starting at DV26.0), the order of the last two excitations was not inverted when HB_{ex} was an even integer, but they were an extra HyperBand excitation such as HB_{ex} become an odd integer and the extra slices (not prescribed) were simply omitted during reconstruction. For example, in the case of 48 slices with a HB factor of 3 (Interleaved, Ascending), this will lead to the situation presented in Figure 8-a for the software releases prior to RX27.0_R03, and to the situation presented in Figure 8-b for the software release RX27.0_R03 and later.

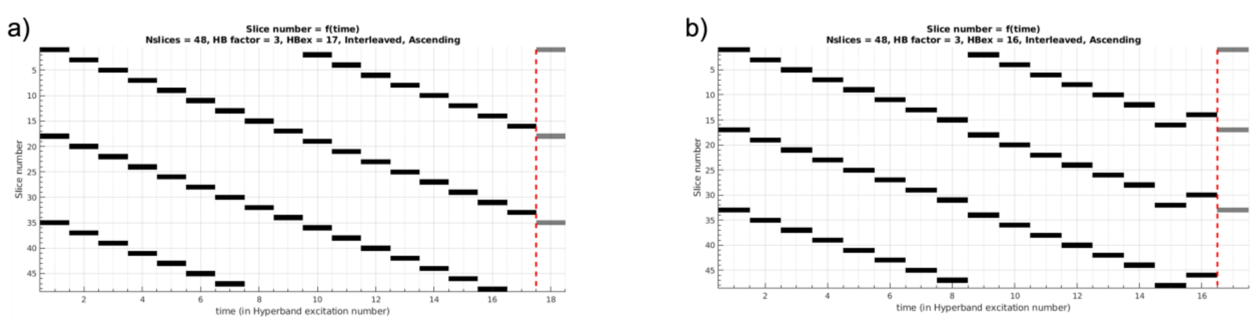

Figure 8: Plots of the slice number as a function of time (in consecutive HyperBand excitation numbers) in the case of 48 slices with a HB factor of 3 (Interleaved, Ascending) for (a) the software releases prior to RX27.0_R03 and (b) for the software release RX27.0_R03 and later. Note that in (a) HB_{ex} is 17 (and not 16) and that one slice has been removed for excitation number 8, 9 and 17.

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In (b) HB_{ex} is 16 as expected and the two last excitations are inverted. In both cases, there are no interferences between consecutives excitations.

About Group Delay

Even though rarely used, both EPI Multiphase and EPIRT allow the user to introduce a delay after the acquisition of a volume. For EPIRT, this is controlled by the field “Group Delay” in the “fMRI screen” (see Figure 2). Applying a “Group Delay” influences the “Effective TR” which is the “Acquisition TR” plus the “Group Delay” (these two different fields are visible in the “fMRI screen” - see Figure 2).

For EPI Multiphase, a fixed delay can be introduced by setting the “Delay After Acq” in the Multiphase tab (see Figure 1). In this case, it is also possible to introduce variable delays after each volume acquisition by simply checking the box “Variables Delays” and by filling the desired delays after each volume in the table below (see Figure 1). These delays have an effect on the “Effective TR”.

In every case, the main TR entry (in the main UI) corresponds to the “Acquisition TR” which is reported in the “Repetition Time” DICOM field. Note that this delay does not change the slice timing within a given volume.

Finding the slice timing information

The following information is only applicable to RX28.0_R01 and later software releases.

In the particular case of EPI multiphase, the slice timing information can be found directly in the DICOM header. For this matter, the DICOM tag “TriggerTime” (see Appendix 1: DICOM Fields) needs to be extracted from the DICOM images of the first volume and for echo 1. Be careful, in case of Descending slice directions, the resulting time vector needs to be reversed manually or sorted in increasing “Slice Location” order as detailed in the section “Slice order and timing implementation”.

In the case of EPIRT, the slice timing information is written to a text file at the time of slice prescription. This means that when you prescribe a fMRI series, a text file /usr/g/bin/fMRI_slicestamping.txt is written. This file is available immediately after a click on the “Save Rx” button but **will be overwritten by the next** fMRI task (in the scan manager or in the protocol manager). Consequently, ensure you are grabbing the right file at the right time. Once again, in case of Descending slice directions, the time vector found in the text file needs to be reversed manually or sorted in increasing “Slice Location” as detailed in section “Slice order and timing implementation”. The values given in the text file are in 10^{th} of millisecond.

Another possibility for EPIRT to get slice timing information can be found in the DICOM tag “RTIA_timer” (see Appendix 1: DICOM Fields) when extracted from images corresponding to the second volume. Once the “RTIA_timer” values are extracted for the second volume, the resulting “RTIA_timer” vector should be sorted in increasing “Slice Location” order (important for the Descending case). The TR (or the minimum value of the resulting “RTIA_timer” vector) should then be subtracted from the time for each slice.

MATLAB Functions

Several MATLAB functions are provided to help extracting the slice timing control parameters and the slice timing information needed to apply slice timing correction using 3^{rd} party software for research purposes. These functions were tested on MATLAB R2019a and R2020b.

The function “SliceTiming” computes the slice timing in millisecond based on the control parameters (see section Control parameters). Optionally, this function can plot a graphical representation of the slice timing as, for example, in Figure 7.

The function “ReadSliceTimingFile” reads the file /usr/g/bin/fMRI_slicestamping.txt and returns the slice timing in milliseconds, the output vector is also reversed in case of a Descending slice direction. This function can also plot the resulting slice timing if desired.

The “PlotSliceTiming” function is the core function used to make most of the plot presented in this document and it is used by “SliceTiming” and “ReadSliceTimingFile” for generating the plots.

The function “decodeGEProtocolDataDicom” allows the user to decode the compressed Protocol Data Block (0025,101B) in a human readable format.

The last function is “getSliceTimeInfoFromDicoms”. The function takes a DICOM folder as input and tried to extract the control parameters. If all control parameters are extracted appropriately the function “SliceTiming” is called and the results is added as output. Additionally, various information (“TriggerTime”, “RTIA_timer”, “Group Delay”, etc…) from the DICOM are extracted and reversed/reformatted as needed.

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The script “example_slice_timing_usage.m” provides usage example of the presented functions. The documentation of each function is available directly by using the standard help function of MATLAB.

DICOM To NIFTI Converter

There are many DICOM to NIfTI converter available. We recommend using the latest release of the converter “dcm2niix” from Chris Rorden (https://github.com/rordenlab/dcm2niix) as it extracts the slice timing information (and many other information) accurately for a wide range of software releases.

There is also a MATLAB alternative by Xiangrui Li (https://github.com/xiangruili/dicm2nii).

Contact

Please contact Brice Fernandez if you have questions regarding this document or post directly in the MR Collaboration Community Forum or GE Connectome Forum (www.gecares.com). Feedback and comments are welcome.

Revision history

Revision	Date	Document Author	Reason for change
1	24SEPT2020	Brice Fernandez	Initial version - Language editing by Mark Symms
2	15OCT2020	Brice Fernandez	NIfTI storage convention and slice direction clarifications
3	28OCT2020	Brice Fernandez	Few corrections and additional information
4	22APR2021	Brice Fernandez	Corrected Collaboration portal address
5	29SEPT2021	Brice Fernandez	Corrected the pre-RX27.0_R03 case

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Appendix 1: DICOM Fields

The DICOM conformance statements can be found here:

- https://www.gehealthcare.com/products/interoperability/dicom.

Attribute	Tag	Comments
Scan Options	(0018,0022)	Parameters of scanning pulse sequence. The presence of the text string "MP_GEMS" indicate the multiphase mode (so not with fMRI option / Brainwave), and "HYPERBAND_GEMS" indicate that HyperBand was used. In every case, "EPI_GEMS" must be present.
Instance Number	(0020,0013)	A running number that identifies a given image.
Echo Number	(0018,0086)	The echo number for a given image.
Repetition Time	(0018,0080)	Repetition Time (TR)
Trigger Time	(0018,1060)	For EPI multiphase only, this entry provides information about slice timing.
Software Versions	(0018,1020)	Software version of the equipment.
Number of echoes	(0019,107E)	Number of echoes
Slice Location	(0020,1041)	Relative position of the image plane in mm.
Locations in acquisition	(0021,104F)	Locations in acquisition (i.e. Number of slices #Slices)
RTIA_timer	(0021,105E)	For epiRT (EPI with fMRI option) only, it provides information about slice timing starting at volume 2 and following.
Protocol Data Block (compressed)	(0025,101B)	Protocol Data Block (compressed) corresponding to inputs in the UI.

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Delay After Slice Group	(0043,107C)	For epiRT (EPI with fMRI option) only, this is the "Group Delay" entry in the fMRI screen.
Multiband Parameters	(0043,10B6)	Value 1 = Multiband factor, Value 2 = Slice FOV Shift Factor, Value 3 = Calibration method
Number of Slices	(2001,1051)	For epiRT (EPI with fMRI option) only, this is the number of slices per volume (in private group brainwave)
Paradigm UID	(2001,1071)	Paradigm Unique ID (in private group brainwave). For EPIRT (EPI with fMRI option) only.
Paradigm Name	(2001,1072)	Paradigm Name (in private group brainwave). For EPIRT (EPI with fMRI option) only.