CMRR Multiband Sequence Slice Order

revision 1.1
12/13/13

Center for Magnetic Resonance Research
University of Minnesota

1. Slice numbering

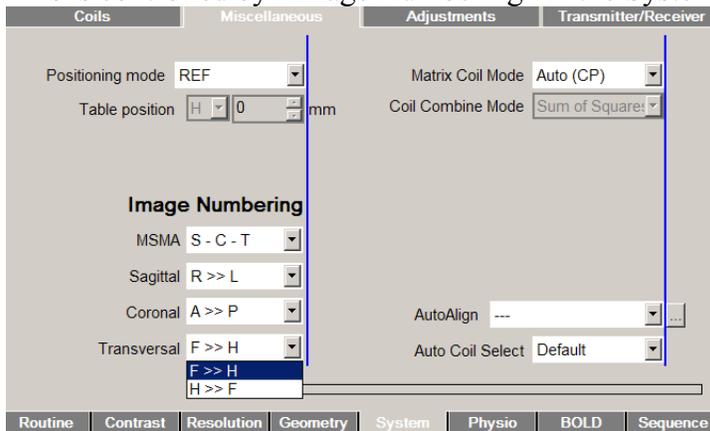This is controlled by "Image Numbering" in the System->Miscellaneous card.

Figure 1. Siemens UI for slice numbering.

In the example above, the sSliceArray.asSlice[0] from the Siemens shadow field in the DICOM header corresponds to the lowest transverse slice towards the feet for a transverse acquisition protocol. Zero-based index slice array is used in this document.
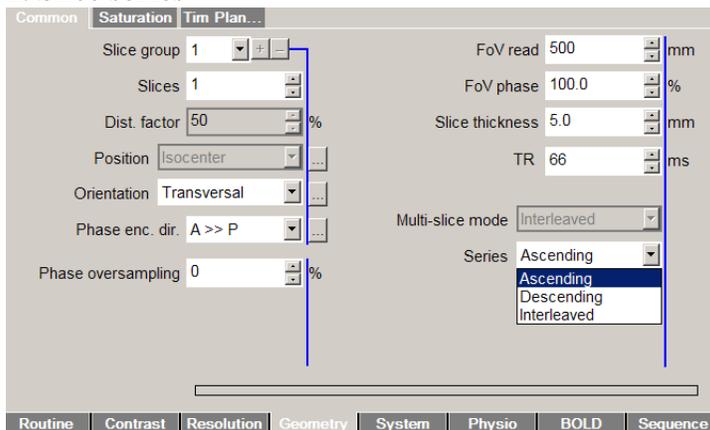
2. Slice series

Figure 2. Siemens UI for slice series.

Both interleaved and non-interleaved slice series are supported.

2.1 Non-interleaved slice series

For ascending and descending slice series, slice timing correction is straightforward. Slice cross-talk effects are similar to conventional single band acquisitions.

2.2 Interleaved slice series

Slice cross-talk effects are minimized with interleaved slice series, hence this is the selected option in the default protocol.

2.2.1 Single band acquisition (Siemens product behavior)

Siemens varies the starting slice based on the number of slices (even or odd). If there are an odd number of slices, $slice_0$ is acquired first. If there are an even number of slices, $slice_1$ is acquired first.

Example:

9 slices: 0,2,4,6,8,1,3,5,7
8 slices: 1,3,5,7,0,2,4,6   <- this is what Siemens product sequence does
8 slices: 0,2,4,6,1,3,5,7   <- **not** what Siemens product sequence does!

2.2.2 Multiband acquisition

We define number of shots as the total number of slices divided by the multiband factor. For 2, 3, and 4 shots, obviously, there is no way to avoid adjacent slice in adjacent excitation. Default interleave pattern is used by skipping every other slice (also Siemens product behavior). Note that slice excitation **always** starts with $slice_0$ in CMRR multiband C2P sequences. For simplicity, we use a multiband factor of 2 for examples below, which can be generalized to any multiband factor.

Example:

Slices=8, Multiband=2, NumberOfShots=4, IncrementSlice=2 (Siemens default)

Slice excitation order: 0,4 - 2,6 - 1,5 - 3,7, which reads as multiband $slice_0$ and $slice_4$ are excited together first, followed by multiband $slice_2$ and $slice_6$ excited together, etc …

In the example above, $slice_5$ and $slice_6$ are excited in adjacent order.

For number of shots >= 5, interleaved slice series have been implemented to guarantee that no adjacent slices are exited in adjacent order. Two scenarios (odd or even shots) exist. In either scenario, slice excitation starts from $slice_0$, which is different from the Siemens product behavior (section 2.2.1).

2.2.2.1 Odd number of shots

Default interleave pattern is used by skipping every other slice (also Siemens product behavior). Adjacent slice in adjacent excitation does not occur.

Example:

Slices=10, Multiband=2, NumberOfShots=5, IncrementSlice=2 (Siemens default)

Slice excitation order: 0,5 - 2,7 - 4,9 - 1,6 - 3,8

or

Slices=14, Multiband=2, NumberOfShots=7, IncrementSlice=2 (Siemens default)

Slice excitation order: 0,7 - 2,9 - 4,11 - 6,13 - 1,8 - 3,10 - 5,12

2.2.2.2 Even number of shots

Default interleave pattern by skipping every other slice inevitably leads to cases of adjacent slices in adjacent excitation. This can be shown in the example below.

Example:

Slices=16, Multiband=2, NumberOfShots=8, IncrementSlice=2 (Siemens default)

Slice excitation order: 0,8 - 2,10 - 4,12 - 6,14 - 1,9 - 3,11 - 5,13 - 7,15

or

Slice excitation order: 1,9 - 3,11 - 5,13 - 7,15 - 0,8 - 2,10 - 4,12 - 6,14

In either case above, $slice_7$ and $slice_8$ are excited in adjacent order.

To avoid this issue for any protocol with more than 6 even number of shots, we use an increment-n-slice interleave pattern, where $n_{increment}$ (i.e. IncrementSlice) depends on n_{shots} (i.e. NumberOfShots). The algorithm is illustrated in the pseudo-code below:

```
if n_shots is even
        n_increment = (n_shots / 2) - 1;
        if n_increment is even
                n_increment = n_increment - 1;
        end
end
```

Example:

Slices=16, Multiband=2, n_{shots}=8, $n_{increment}$=3

Slice excitation order: 0,8 - 3,11 - 6,14 - 1,9 - 4,12 - 7,15 - 2,10 - 5,13

Slices=20, Multiband=2, n_{shots}=10, $n_{increment}$=3

Slice excitation order: 0,10 - 3,13 - 6,16 - 9,19 - 1,11 - 4,14 - 7,17 - 2,12 - 5,15 - 8,18

special case: n_{shots}=6, which uses the following special order (e.g., Slices = 12, Multiband=2)

Slice excitation order: 0,6 - 2,8 - 4,10 - 1,7 - 5,11 - 3,9

3. Slice timing

The most convenient and practical way to determine slice timing is by referencing the timing information for each slice under "MosaicRefAcqTimes" ([ms], ordered corresponding to the slice numbering (section 1)) in vendor private field of the DICOM header. This slice-by-slice timing information is generic (transparent to the multiband factor) for any protocol.

Example: multiband>=2, n_{shots}=10, TR=750ms

```
MosaicRefAcqTimes
  0.00000000        (Slice_0)
372.50000000
 75.00000001
447.50000001
149.99999999
522.50000002
225.00000001
597.50000000
300.00000002
672.50000002
  0.00000000        (Slice_10)
372.50000000
 75.00000001
   …
```

Known Bug: The DICOM acquisition time parameters are incorrect for the first MB repetition.