# MFMC file specification, version 1.2

## Summary of main changes since version 1.1

* Specification changed to enable single file to hold multiple Multi-frame Full Matrix Capture (MFMC) sequences if desired.
* Dimensions of MFMC dataset for each sequence changed from 2D to 3D to reflect logical structure, with (expandable) 3rd dimension corresponding to the frames in the sequence.
* Explicit requirement for each frame in an MFMC sequence to have common parameters for everything except the probe position.
* Redundant datasets (e.g. describing sizes and types of other datasets) removed if information is available implicitly in the HDF5 format.
* Description of array probes moved to root level in the file, enabling probe descriptions to be re-used for different MFMC sequences within the file.
* Individual array elements are referenced by [probe, element] rather than defining global element numbers.
* Change to way element size and orientation is specified as previous one did not generalise to 3D.
* Requirement to include a firing index for each A-scan for each frame of each MFMC sequence. Probe position information must be provided for each firing index in the sequence (this removes a previous ambiguity about how probe position should be interpreted for each frame).
* Change to way probe orientation is specified to use vectors rather than rotations.

## Change log for this document

#### Changes made

* Probe and sequence numbers implemented by naming locations “/PROBE<p>” and “/MFMC<m>” where p and m are the respective numbers.
* Structure altered such that FMC data is a special case of generic case, rather file being specific to FMC data with added functionality for other cases. Specifically, {TRANSMIT/RECEIVER}\_{PROBE/ELEMENT} vectors replaced with {TRANSMIT/RECEIVE}\_ LAW\_INDEX vectors which index into mandatory LAW<l> structures. These replace current optional {TRANSMIT/RECEIVE}\_FOCAL\_LAW<{t/r}> structures. The minimum mandatory content in LAW<l> is PROBE and ELEMENT which for FMC data contain only single values.
* Changed PROBE\_DIRECTION1 and PROBE\_DIRECTION2 to PROBE\_X\_DIRECTION and PROBE\_Y\_DIRECTION for clarity.
* Changed ELEMENT\_PERIM1 and ELEMENT\_PERIM2 to ELEMENT\_MINOR and ELEMENT\_MAJOR for clarity and changed definition for consistency with way overall probe orientation is defined. ELEMENT\_{MINOR/MAJOR} are now defined as vectors in PCS from ELEMENT\_POSITION to relevant element mid-side points (not as absolute position vectors in PCS which they were previously). For rectangular element in linear array, element width is given by 2x|ELEMENT\_POSITION–ELEMENT\_MINOR|.
* Singular used for all location names (e.g. DEAD\_ELEMENT, RECEIVE\_FOCAL\_LAW, TRANSMIT\_FOCAL\_LAW).
* COUPLANT\_VELOCITIES changed to WEDGE\_VELOCITY for consistency with WEDGE usage in probe definitions.
* and renamed as and due to earlier use of for something else.
* Issue of multiple probes in same sequence resolved by adding new FIRING\_INDEX matrix to /MFMC<m> and changing dimensions of PROBE\_POSITION and PROBE\_{X/Y}\_DIRECTION from to where is the number of probes in use in sequence. Also element vector PROBE\_INDEX added to /MFMC(m)/COMMON to cross-reference this dimension with probe numbers. Note that in cases where a single probe is used and PROBE\_INDEX will just contain single number, which is the index of probe in use.
* Optional MFMC\_DATA\_IM field added that has exactly same properties and size as MFMC\_DATA and contains imaginary components of FMC data if they exist (HDF does not have a native complex datatype).
* Added optional attribute fields OPERATOR, TIME\_AND\_DATE and FILTER\_DESCRIPTION to /MFMC<m>/COMMON.

#### Changes still to be made

* Give clear statement of purpose and scope of file in introduction.
* State exactly how version is specified in “VERSION”, e.g. “MFMC 1.2”.
* String encoding should be specified (ASCII or UTF-8).
* Specify how dimensions are ordered - row or column major.
* Specify that indices start at 1 not 0.
* Improve explanation of FIRING\_INDEX.
* State what file extension should be, e.g. “\*.mfmc”.
* State that order of A-scans in a frames in a sequence should not be assumed – it should always be based on using indices in {TRANSMIT/RECEIVE}\_{PROBE/ELEMENT} in /MFMC/COMMON.

#### Issues resolved without change

* Changes recommended by Christopher Woods:
  + Change ./USER fields to ./EXT (extension), for consistency with other formats. Idea is that common functionality evolves within ./EXT over time, and later file versions see fields moved out of here and into file specification. ***Decided to remove explicit user fields completely as it is easy to identify these by listing fields that are not part of specification.***
  + Trying to write a future-proof generic template that covers all eventualities is difficult; preferred solution is to provide version-specific checking functions as part of library along with basic function set. ***Decided to proceed with generic template for the moment as most of necessary functionality is already written and other changes made according to CW’s suggestions actually make remaining checks simpler.***
* Should either replace START\_TIME, TIME\_STEP with TIME vector or add TIME\_POINTS value, otherwise MFCM data cannot be initialised without data from which time dimension can be deduced? ***Not necessary – can be initialised when first frame is added.***
* Decide if chunking is officially part of file specification, or simply a recommendation. ***It is a requirement if infinite maximum dimension specified for dataset. Set chunk to size of single frame.***

## Specification of file structure

The underlying file is HDF5, which allows a grouped hierarchy of data. The data in the group structure is either in the form of multi-dimensional datasets or attributes. The overall structure for the MFMC common file format is summarised in Fig. 1.

Fig. 1 Overall file structure. User-specified groups and datasets can be added as necessary at any level.

For multi-dimensional dataset, the order of dimensions has been chosen to generally go from smallest to largest. If a dataset is intended to be expandable (e.g. as new frames of FMC data are added to a sequence) the expandable dimension is always the last one. The sizes of the dimensions of datasets are fixed when created unless stated as being expandable.

The units used for physical quantities should be SI. In particular: distance in metres; time in seconds; frequency in Hertz (not radians per second); velocity in metres per second. Also note that gains are specified as linear ratios, not decibels (i.e. that value of 100 should be used not 40 dB).

Small, fixed-size items containing less than four elements are stored as attributes rather than datasets, as the storage overhead for these is lower. Table 1 defines some variables used to explain and relate the sizes of the dimensions of datasets and Table 2 summarises the structure of the file.

|  |  |
| --- | --- |
| **Variable** | **Description** |
|  | Number of probes (expandable) |
|  | Number of MFMC sequences in file (expandable) |
|  | Number of elements in probe |
|  | Number of FMC frames in sequence of MFMC data (expandable) |
|  | Number of time points per A-scan in sequence |
|  | Number of A-scans per frame in sequence |
|  | Number of firing events sequence |
|  | Number of focal laws associated with each frame in sequence |
|  | Number of probe/element combinations used in focal law in sequence |
|  | Probe number |
|  | MFMC sequence number |
|  | Transmit focal law number |
|  | Receive focal law number |

Table 1 List of variables used in file structure description. The general notation is that lower case indicates a counter, e.g. probe number , that has a range of values from to .

| **Location** | **M/O** | **D/A** | **Data-type** | **Dimensions** | **Notes** |
| --- | --- | --- | --- | --- | --- |
| **/Root** | | | | | | |
| /VERSION | M | A | String |  | This also defines the name of part of the \*.json template file to be used for checking |
| /TEMPLATE\_FILENAME | M | A | String |  |  |
| /PROBE (see below) | M | D | Group |  | One group per probe |
| /MFMC (see below) | M | D | Group |  | One group per sequence of MFMC data |
| /USER | O | D | Group |  | Top-level user parameters |
| **/PROBE<p>** | **M** | **Description of array probe** | | | | |
| ./ELEMENT\_POSITION | M | D | Float |  | Coordinates (in PCS) of centre of each element |
| ./ELEMENT\_MINOR | M | D | Float |  | Vector in in PCS between element centre and end of minor axis of element, i.e. the mid-point of longer side for rectangular element. Element normal is defined by vector normal to both ELEMENT\_MINOR and ELEMENT\_MAJOR vectors |
| ./ELEMENT\_MAJOR | M | D | Float |  | Vector in in PCS between element centre and end of major axis of element, i.e. the mid-point of shorter side for rectangular element. Element normal is defined by vector normal to both ELEMENT\_MINOR and ELEMENT\_MAJOR vectors |
| ./ELEMENT\_SHAPE | M | D | Integer |  | Integer specifying shape of each element (0 = elliptical, 1 = rectangular, 2 = other) |
| ./ELEMENT\_RADIUS\_OF\_CURVATURE | O | D | Float |  | Radius of curvature of each element for spherically or cylindrically-focussed curved elements. The centre of curvature is assumed to lie on a line normal to the element (see above for how this is determined) that passes through ELEMENT\_POSITION |
| ./ELEMENT\_AXIS\_OF\_CURVATURE | O | D | Float |  | Direction vector (in PCS) specifying direction of axis of curvature through centre of curvature for cylindrically-focused elements. If this vector is not parallel to the plane of the element (i.e. normal to the element normal direction), then its component parallel to the plane of the element is used. If this field is absent and ELEMENT\_RADIUS\_OF\_CURVATURE is present then elements are assumed to be spherically-focused |
| ./WEDGE\_SURFACE\_POINT | O | A | Float |  | Coordinates (in PCS) of one point on surface of planar wedge |
| ./WEDGE\_SURFACE\_NORMAL | O | A | Float |  | Vector (in PCS) of surface normal of planar wedge. Together with WEDGE\_SURFACE\_POINT, this is sufficient to describe the position of the planar surface of a wedge in the PCS |
| ./DEAD\_ELEMENT | O | D | Integer |  | 1 = dead, 0 = OK |
| ./CENTRE\_FREQUENCY | O | A | Float |  |  |
| ./BANDWIDTH | O | A | Float |  |  |
| ./PROBE\_MANUFACTURER | O | A | String |  |  |
| ./PROBE\_SERIAL\_NUMBER | O | A | String |  |  |
| ./PROBE\_TAG | O | A | String |  |  |
| ./WEDGE\_MANUFACTURER | O | A | String |  |  |
| ./ WEDGE\_SERIAL\_NUMBER | O | A | String |  |  |
| ./ WEDGE\_TAG | O | A | String |  |  |
| ./USER | O | D | Group |  | For probe-specific user-defined parameters |
| **/MFMC<m>** | **M** | **The MFMC sequence** | | | | |
| ./COMMON (see below) | M | D | Group |  | For everything that is common to all frames in MFMC sequence (by definition, everything except probe position) |
| ./MFMC\_DATA | M | D | Float or integer |  | Raw FMC or other array data. Expandable in number of frames dimension |
| ./MFMC\_DATA\_IM | O | D | Float or integer |  | Imaginary component of raw FMC or other array data if data is complex. Expandable in number of frames dimension |
| ./FIRING\_INDEX | M | D | Integer |  | Firing index for each A-scan in each frame, which indexes into ./PROBE\_POSITION and ./PROBE\_{X/Y}\_DIRECTION. Expandable in number of frames dimension |
| ./PROBE\_POSITION | M | D | Float |  | Coordinates of PCS origin in global coordinate system (GCS) for each firing position. Expandable in number of firing positions dimension |
| ./PROBE\_X\_DIRECTION | M | D | Float |  | Direction vector for x-axis of PCS in GCS for each firing position. Expandable in number of firing positions dimension |
| ./PROBE\_Y\_DIRECTION | M | D | Float |  | Direction vector for y-axis of PCS in GCS for each frame. If vector not orthogonal to PROBE\_X\_DIRECTION, orthogonal component will be used. Expandable in number of frames dimension |
| **/MFMC<m>/COMMON** | **M** | **Common parameters for MFMC sequence** | | | | |
| ./TRANSMIT\_LAW\_INDEX | M | D | Integer |  | Transmit law number for each A-scan in MFMC sequence |
| ./RECEIVE\_LAW\_INDEX | M | D | Integer |  | Receive law number for each A-scan in MFMC sequence |
| ./PROBE\_INDEX | M | D | Integer |  | Probe index used associated with dimension of ./PROBE\_POSITION and ./PROBE\_{X/Y}\_DIRECTION in MFMC sequence. |
| ./TIME\_STEP | M | A | Float |  | Time interval between sample points in each A-scan in frame |
| ./START\_TIME | M | A | Float |  | Time (relative to time of transmitted signal) of first sample point in each A-scan in frame |
| ./SPECIMEN\_VELOCITY | M | A | Float |  | Shear and longitudinal velocities in specimen. For fluid set shear velocity to NaN |
| ./LAW<L> (see below) | O | D | Group |  | Description of focal laws |
| ./WEDGE\_VELOCITY | O | A | Float |  | Shear and longitudinal velocities in couplant. For fluid set shear velocity to NaN |
| ./TAG | O | A | String |  |  |
| ./DAC\_CURVE | O | D | Float |  | Distance amplitude correction values (linear scale, not dB) that have been applied to A-scans prior to digitsation |
| ./RECEIVER\_AMPLIFIER\_GAIN | O | A | Float |  | Total gain (linear scale, not dB) applied to A-scans excluding DAC (if applicable) prior to digitssation |
| ./FILTER\_TYPE | O | A | Integer |  | 0 = no filter, 1 = low pass, 2 = high-pass, 3 = band pass, 4 = other filter |
| ./FILTER\_PARAMETERS | O | D | Float | , , or | Cut-off frequencies for low, high or bandpass filters, array of frequencies and values describing frequency response for other filter |
| ./FILTER\_DESCRIPTION | O | A | String |  | Written description of filter |
| ./USER | O | D | Group |  | For MFMC-sequence-specific user-defined parameters |
| ./OPERATOR | O | A | String |  | Operator’s name or ID |
| ./DATE\_AND\_TIME | O | A | String |  | Time and date at start of sequence in format DD-MMM-YYY HH:MM:SS, e.g. “'23-Nov-2018 16:20:43'” |
| **/MFMC<m>/COMMON/LAW<l>** | **M** | **Group for specifying focal law in MFMC sequence** | | | | |
| ./PROBE | M | D | Integer |  | Probe number of [probe, element] |
| ./ELEMENT | M | D | Integer |  | Element number of [probe, element] |
| ./DELAY | O | D | Float |  | Delay associated with [probe, element] |
| ./WEIGHTING | O | D | Float |  | Weighting associated with [probe, element] |

Table 2 Structure of the file. Abbreviations: M/O = Mandatory / Optional; D/A = Dataset / Attribute; PCS = Probe Coordinate System; GCS = Global Coordinate System. Mandatory / Optional is applicable to children if parent dataset exists, i.e. a mandatory parameter in an optional group is mandatory if the group exists.