# 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 sequence index for each MFMC sequence. For each frame, probe position must be provided for each firing 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\_DIRECTION2 – vector describes direction of y axis (not x axis) of probe.
* 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 extra dimension to /MFMC(m)/PROBE\_POSITION etc. so dimensions go from to where is the number of probes in use in sequence. Also element dataset added as /MFMC(m)/COMMON/PROBE\_LIST to cross-reference this dimension with probe numbers. Note that in most cases where a single probe is used and /MFMC(m)/COMMON/PROBE\_LIST just contains number of probe in use.
* Probe and sequence numbers implemented by naming locations “/PROBE<p>” and “/MFMC<m>” where p and m are the respective numbers
* 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)
* Changed ELEMENT\_PERIM1 and ELEMENT\_PERIM2 to ELEMENT\_MINOR and ELEMENT\_MAJOR for clarity which are 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); this is for consistency with way probe orientation is defined. For rectangular element in linear array, element width is given by 2x|ELEMENT\_POSITION–ELEMENT\_MINOR|
* Changed PROBE\_DIRECTION1 and PROBE\_DIRECTION2 to PROBE\_X\_DIRECTION and PROBE\_Y\_DIRECTION for clarity
* Added optional attribute fields OPERATOR, TIME\_AND\_DATE and FILTER\_DESCRIPTION to MFMC<m>

#### Changes still to be made

* 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”

#### Issues resolved without change

* 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. Each level also provides the opportunity for user-specified groups and datasets.

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 per frame in sequence |
|  | Number of transmit focal laws associated with each frame in sequence |
|  | Number of receive focal laws associated with each frame in sequence |
|  | Number of probe/element combinations used in transmit focal law in sequence |
|  | Number of probe/element combinations used in receive 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 |  |  |
| /TEMPLATE\_FILENAME | M | A | String |  | Name of \*.json file |
| /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 |
| ./PROBE\_POSITION | M | D | Float |  | Coordinates of PCS origin in global coordinate system (GCS) for each frame. Expandable in number of frames dimension |
| ./PROBE\_X\_DIRECTION | M | D | Float |  | Direction vector for x-axis of PCS in GCS for each frame. Expandable in number of frames 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\_ELEMENT | M | D | Integer |  | Transmitter element number or transmit focal law number for each A-scan in MFMC sequence |
| ./TRANSMIT\_PROBE | M | D | Integer |  | Transmitter probe number for each A-scan in MFMC sequence. Zero values are interpreted to mean that TRANSMIT\_ELEMENT refers to transmit focal law number rather than transmitter element number |
| ./RECEIVE\_ELEMENT | M | D | Integer |  | Receiver element number or receive focal law number for each A-scan in MFMC sequence |
| ./RECEIVE \_PROBE | M | D | Integer |  | Receiver probe number for each A-scan in MFMC sequence. Zero values are interpreted to mean that RECEIVE\_ELEMENT refers to receive focal law number rather than receiver element number |
| ./FIRING\_INDEX | M | D | Integer |  | Firing index associated with each A-scan in frame |
| ./PROBE\_LIST | M | D | Integer |  | Probes (referenced by indices) used 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 |
| ./TRANSMIT\_FOCAL\_LAW<t> (see below) | O | D | Group |  | Description of transmit focal laws |
| ./RECEIVE\_FOCAL\_LAW<m> (see below) | O | D | Group |  | Description of receive 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/TRANSMIT\_FOCAL\_LAW<t>** | **O** | **Optional group for specifying transmit focal law in MFMC sequence if not using single transmitters** | | | | |
| ./PROBE | M | D | Integer |  | Probe number of transmit [probe, element] |
| ./ELEMENT | M | D | Integer |  | Element number of transmit [probe, element] |
| ./DELAY | O | D | Float |  | Delay associated with transmit [probe, element] |
| ./WEIGHTING | O | D | Float |  | Weighting associated with transmit [probe, element] |
| **/MFMC<m>/COMMON/RECEIVE\_FOCAL\_LAW<r>** | **O** | **Optional group for specifying receive focal law in MFMC sequence if not using single receivers** | | | | |
| ./PROBE | M | D | Integer |  | Probe number of receive [probe, element] |
| ./ELEMENT | M | D | Integer |  | Element number of receive [probe, element] |
| ./DELAY | O | D | Float |  | Delay associated with receive [probe, element] |
| ./WEIGHTING | O | D | Float |  | Weighting associated with receive [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 exisits, i.e. a mandatory parameter in an optional group is mandatory if the group exists (e.g. /MFMC<m>/COMMON/TRANSMIT\_FOCAL\_LAW<t>/ELEMENT in /MFMC<m>/COMMON/TRANSMIT\_FOCAL\_LAW<t>).