

LWA Interferometer Observing Procedure and Associated File Formats Ver. 1

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1 Introduction

This memo documents the observing procedures and associated file formats for the LWA interferometer. This document should be viewed as a companion to [3] which details the procedure for a single LWA station.

2 Definitions

The terminology used for the LWA interferometer is designed to be slightly different than that used for single station observations in order to make it easier to quickly distinguish between the two observing styles. Generally, observations with the interferometer are grouped into *projects*, *runs*, and *scans*. The relationship between these is that a *project* consists of one or more *runs*, with each *run* composed of one or more *scans*. The formal definitions are:

- Similar to single station observations in [3], a **project** is a set of observations that further a specific scientific goal. These correspond to approved LWA proposals.
- A **run** is a subset of *scans* that uses exactly one of the LWA interferometer beams and is contiguous in time. The lengths of these are typically one or three hours.
- An **scan** is a continuous block of data from the interferometer that has a single set of observing parameters. These should be considered as “atomic” units for scheduling purposes by observers. In addition to specifying the pointing center for the array, a *scan* can also have multiple *alternate phase centers* that can be correlated as well.
- An **alternate phase center** specifies additional phase centers for correlation within a single station beam. This provides a way to observe a target and a phase calibrator within the same station beam and have the data correlated separately.

A scan is run on the LWA interferometer in one of three **observing modes**:

- RA/DEC Tracking (TRK_RADEC). This is an interferometer mode in which the array beam tracks a specified right ascension (RA) and declination (DEC). The TRK_RADEC mode also supports proper motion corrections for the pointing center as a function of the epoch of observation.
- Solar Tracking (TRK_SOL). This is an interferometer mode in which the array beam tracks the Sun.
- Jupiter Tracking (TRK_JOV). This is an interferometer mode in which the array beam tracks Jupiter.

See the appendices for examples of runs and scans.

3 Procedure

This section outlines the process of creating, scheduling, and conducting LWA interferometer observations from the stand point of an observer.

1. The PI creates an *interferometer definition file* (IDF). An IDF is a text file which defines the run and its constituent *scans*. The format of an IDF is specified in Section 4.

2. The PI submits the IDF file to the “LWA Observing File Validator and Submission Tool”¹. From this webpage the IDF is:
 - (a) First validated. All valid files are then used to generate *session definition files* for each station (see [3]).
 - (b) The SDFs generated above are then automatically transferred to the stations and scheduled using the HAL systems [2].
3. The run is observed and the resulting data files and station level metadata are automatically aggregated onto the LWA Users Compute Facility [1] for correlation.
4. The station level metadata is parsed to generate the correlator configuration files by the correlator operator and the data are correlated. The resulting FITS IDI files [4] are then transferred to the LWA Data Archive² where they can be accessed by the PI [5].

4 Format of an Interferometer Definition File

Interferometer Definition Files (IDFs) are human-readable text files that are structured to be similar to the Session Definition Files (SDFs; [3]) used for single station LWA observations. See the example provided in Appendix A.

IDFs consist of lines, with each line having the following structure:

- A keyword identifying a parameter
- At least one whitespace character
- Data intended to be assigned to the parameter
- Newline (line terminator)

A line may be up to 4096 characters long. Lines which are empty lines (i.e., containing only the newline character) are allowed, ignored, and encouraged as a way to improve the readability. The “data” field contains only alphanumeric characters (including space) plus standard punctuation and common symbols, but not special/invisible characters. Note that any whitespace between the end of the intended data and the newline is significant.

Generally, IDFs have three or more parts. The first part is a set of lines identifying the PI and project. The second part is a set of lines identifying the run, including parameters that apply throughout the run. The third part is a set of lines identifying the first scan, including parameters that apply to that scan. Each additional scan is defined by repeating the third part with the desired modifications. Only parameters which are different from the previous scan need to be defined for subsequent scans.

The following is a list of defined parameters, in the order in which it is required that they appear in the IDF. In each case, we give the identifying keyword, followed by information on valid values. We begin with parameters identifying the PI and project which are identical to those used in SDFs:

- **PI.ID:** PI Identification. This is intended to enable concise, unambiguous identification of the PI. PI identification codes should be assigned and maintained by the LWA Project Office. It is recommended that this be a sequentially-assigned integer.

¹<https://fornax.phys.unm.edu/lwa/validator/index.html>

²<https://lda10g.alliance.unm.edu/ldadb/>

- **PI_NAME:** PI Name. This is redundant information given **PI_ID**, but is included primarily for user convenience. The recommended format is Last Name, First Name Middle Initial(s).
- **PROJECT_ID:** Project Identification. This is a string of no more than 8 characters. This is intended to enable concise, unambiguous identification of the project. Project identification codes should be assigned and maintained by the LWA Project Office. Since this is used as part of the filename of some files, it is strongly recommended that these be minimum length, free of whitespace, and constructed to be easy to sort; for example “E00037” where “E” identifies a class of projects and “00037” means the 37th project in this class.
- **PROJECT_TITLE:** This is redundant information given **PROJECT_ID**, but is included primarily for user convenience.
- **PROJECT_REMPI:** Remarks from the PI on the project. This is intended to convey information that might not be present or obvious through other session definition file parameters.
- **PROJECT_REMPO:** Remarks from the LWA Project Office on the project. This is intended to convey information that might not be present or obvious through other IDF parameters.

Next, keywords identifying the run:

- **RUN_ID:** Run Identification. This is intended to enable concise, unambiguous (in combination with **PROJECT_ID**) identification of the run. Run identification codes are sequentially-assigned integers, beginning with 1.
- **RUN_TITLE:** This is redundant information given **RUN_ID**, but is included primarily for user convenience.
- **RUN_STATIONS:** List of LWA stations to use. This is intended to allow users to specify which LWA stations to use as part of the array through a comma separated list of two-letter station identifiers. If all stations are needed then the special value “all” can be provided.
- **RUN_CHANNELS:** Channel count. This is intended to relate how the data are to be channelized during the correlation process. Allowed values are even integers between 16 and 32,768, inclusive.
- **RUN_INTTIME:** Integration time. This is intended to relate the desired time resolution in seconds of the visibilities. Allowed values are between 0.1 and 10 s, inclusive.
- **RUN_BASIS:** Polarization basis. This is intended to relate the desired polarization basis of the visibilities. Allowed values are “linear” for the data to be left in its native basis, “circular” for it to be converted to RR/LL/RL/LR, or “stokes” for it to be converted to Stokes I, Q, U, and V. Currently the “stokes” basis is not recommended.
- **SESSION|_REMPI:** Remarks from the PI on the run. This is intended to convey information that might not be present or obvious through other IDF parameters.
- **SESSION_REMPO:** Remarks from the LWA Project Office on the run. This is intended to convey information that might not be present or obvious through other IDF parameters.

Finally, required keywords defining a scan:

- **SCAN_ID:** Scan Identification. This is intended to enable concise, unambiguous (in combination with **PROJECT_ID** and **RUN_ID**) identification of the scan. Scan identification codes are sequentially-assigned integers, beginning with 1.

SCAN_BW	Sample Rate
1	0.25 MS/s
2	0.50 MS/s
3	1.00 MS/s
4	2.00 MS/s
5	4.90 MS/s
6	9.80 MS/s
7	19.6 MS/s

Table 1: Allowed values for `SCAN_BW` and the corresponding sample rates.

- `SCAN_TARGET`: This is intended to provide a convenient, standard place to indicate the intended “target” of the scan. This field is provided for the convenience of the observer only, and no specific format is required. It should be noted that this field is only used by the correlator to populate the `SOURCE` table in the FITS IDI file.
- `SCAN_INTENT`: Scan intent. This is intended to convey the purpose of the scan, i.e., whether or not it is a calibrator source. Allowed values are “fluxcal” for flux density and bandpass calibration sources (`CALCODE K`), “phasecal” for complex gain calibration sources (`CALCODE D`), “target” for target sources, and “dummy” for dummy scans. Dummy scans are not correlated but are useful for observations where there are multiple alternate phase centers and the station beam is pointing at some location in between them to maximize sensitivity of the ensemble.
- `SCAN_REMPI`: Remarks from the PI on the scan. This intended to convey information that might not be present or obvious through other IDF parameters. Optional.
- `SCAN_REMPO`: Remarks from the LWA Project Office on the scan. This intended to convey information that might not be present or obvious through other session definition file parameters. Optional.
- `SCAN_START_MJD`: Modified julian day (MJD) on which the scan is to start. Coordinated Universal Time (UTC) is assumed.
- `SCAN_START_MPM`: Time of day at which the scan is to start, written as integer milliseconds past UTC midnight (MPM). The range of values is 0 through 86399999; or, for days containing a leap second, 0 through 86400999.
- `SCAN_START`: Start time of the scan written in a format of the PI’s choice. This is redundant information given `SCAN_START_MJD` and `SCAN_START_MPM`, but is included for user convenience. The suggested format is “UTC yyyy mm dd hh:mm:ss.sss”. This parameter is not used for scheduling purposes.
- `SCAN_DUR`: The duration of the observation in integer milliseconds.
- `SCAN_DUR+`: The duration of the observation written in a format of the PIs choice. This is redundant information given `SCAN_DUR` and is ignored for scheduling purposes, but is included for user convenience.
- `SCAN_MODE`: Observing mode, as explained in Section 2. Allowed values are “`TRK_RADEC`”, “`TRK_SOL`”, and “`TRK_JOV`”.
- `SCAN_RA`: RA (decimal hours) for beam pointing, epoch J2000. Meaningful only if `SCAN_MODE` is `TRK_RADEC`; otherwise this parameter is ignored.
- `SCAN_DEC`: DEC (decimal degrees) for beam pointing, epoch J2000. Meaningful only if `SCAN_MODE` is `TRK_RADEC`; otherwise this parameter is ignored.

- `SCAN_PM_RA`: Proper motion in RA (decimal mas/yr) for the beam pointing, epoch J2000. Meaningful only if `SCAN_MODE` is `TRK_RADEC`; otherwise this parameter is ignored. Optional.
- `SCAN_PM_DEC`: Proper motion in DEC (decimal mas/yr) for the beam pointing, epoch J2000. Meaningful only if `SCAN_MODE` is `TRK_RADEC`; otherwise this parameter is ignored. Optional.
- `SCAN_FREQ1`: Center frequency for the first DRX tuning, expressed as an integer “tuning word”. The center frequency will be $\text{SCAN_FREQ1} \times 192/2^{32}$ MHz. For example, a `SCAN_FREQ1` of 1073741824 corresponds to a center frequency of 49.000000 MHz. The valid range is 219130984 (≈ 5.6 MHz) through 1928352663 (93 MHz).
- `SCAN_FREQ1+`: Center frequency for the first DRX tuning, expressed in a format of the PIs choice. This is redundant information given `SCAN_FREQ1` and is ignored for the purpose of scheduling, but is included primarily for user convenience. The suggested format is “xx.xxxxxx MHz”. Optional.
- `SCAN_FREQ2`: Center frequency for the second DRX tuning, expressed as an integer “tuning word”. See `SCAN_FREQ1` for additional details.
- `SCAN_FREQ2+`: Center frequency for the second DRX tuning, expressed in a format of the PIs choice. See `SCAN_FREQ1+` for additional details. Optional.
- `SCAN_BW`: Bandwidth, expressed as an integer between 1 and 7. Refer to Table 1 for more information³.
- `SCAN_BW+`: Bandwidth, expressed in a format of the PIs choice. This is redundant information given `SCAN_BW` and is ignored for scheduling purposes, but is included primarily for user convenience.

Each scan may also have up to ten alternate phase centers associated with it. For these the following keywords control the centers:

- `SCAN_ALT_N`: Number of alternate phase centers, as an integer. $0 \leq \text{SCAN_ALT_N} \leq 10$.
- `SCAN_ALT_TARGET[n]`: Target name. $1 \leq n \leq \text{SCAN_ALT_N}$.
- `SCAN_ALT_INTENT[n]`: Intent. Allowed values are “fluxcal” for flux density and bandpass calibration sources (`CALCODE K`), “phasecal” for complex gain calibration sources (`CALCODE D`) and “target” for target sources. $1 \leq n \leq \text{SCAN_ALT_N}$.
- `SCAN_ALT_RA[n]`: RA (decimal hours) for alternate pointing, epoch J2000. $1 \leq n \leq \text{SCAN_ALT_N}$.
- `SCAN_ALT_DEC[n]`: DEC (decimal degrees.) for alternate pointing, epoch J2000. $1 \leq n \leq \text{SCAN_ALT_N}$.
- `SCAN_ALT_PM_RA[n]`: Proper motion in RA (decimal mas/yr) for the beam pointing, epoch J2000. $1 \leq n \leq \text{SCAN_ALT_N}$. Optional.
- `SCAN_ALT_PM_DEC[n]`: Proper motion in DEC (decimal mas/yr) for the beam pointing, epoch J2000. $1 \leq n \leq \text{SCAN_ALT_N}$. Optional.

The following scan parameters are optional, but allow additional control over the observation which may be useful in certain cases. If not specified, an attempt will be made to assign reasonable values.

- `SCAN_ASP_FLT`: Selects the “filter setting” for the ARX. Allowed values are “0” for “split”, “1” for “full”, “2” for “reduced”, and “-1” = “MCS decides” (this is the value used if not specified).

³As of the time of the document a `SCAN_BW` value of 7 is not supported.

- **SCAN_DRX_GAIN**: This corresponds to the DP/ADP DRX command parameter DRX GAIN. This is an integer value between 0 and 12, or “-1” = “MCS decides” (this is the value used if not specified).

A Example Interferometer Definition File

Below is shown the contents of an sample interferometer definition file.

```
PI_ID          99
PI_NAME        Dowell, Jayce

PROJECT_ID     COMJD
PROJECT_TITLE  Commissioning data
PROJECT_REMPI  None provided
PROJECT_REMPO  None

RUN_ID        5
RUN_TITLE     Test Run of the LWA Single Baseline Interferometer
RUN_STATIONS  VL,SV
RUN_CHANNELS  256
RUN_INTTIME   1.000
RUN_BASIS     linear

SCAN_ID       1
SCAN_TARGET   3C295
SCAN_INTENT   FluxCal
SCAN_REMPI    None provided
SCAN_REMPO    Estimated data volume for this scan is 11.04 GB
SCAN_START_MJD 58513
SCAN_START_MPM 36000000
SCAN_START    UTC 2019 01 30 10:00:00.000
SCAN_DUR      300000
SCAN_DUR+     00:05:00.000
SCAN_MODE     TRK_RADEC
SCAN_RA       14.189016667
SCAN_DEC      +52.202638889
SCAN_FREQ1    920350135
SCAN_FREQ1+   42.000000007 MHz
SCAN_FREQ2    1621569285
SCAN_FREQ2+   73.999999990 MHz
SCAN_BW       6
SCAN_BW+     9.800 MHz

SCAN_ID       2
SCAN_TARGET   3C286
SCAN_INTENT   Target
SCAN_REMPI    None provided
SCAN_REMPO    Estimated data volume for this scan is 44.15 GB
SCAN_START_MJD 58513
SCAN_START_MPM 36300000
SCAN_START    UTC 2019 01 30 10:05:00.000
SCAN_DUR      1200000
SCAN_DUR+     00:20:00.000
SCAN_MODE     TRK_RADEC
SCAN_RA       13.518966667
SCAN_DEC      +30.509138889
SCAN_FREQ1    920350135
```


SCAN_FREQ1+	42.00000007 MHz
SCAN_FREQ2	1621569285
SCAN_FREQ2+	73.999999990 MHz
SCAN_BW	6
SCAN_BW+	9.800 MHz

B Document History

- Version 1 (Aug 20, 2019): First version.

References

- [1] J. Dowell, “The LWA1 User Computing Facility,” Ver. 3, Long Wavelength Array Memo 193, Dec 21, 2018. [online] <http://www.phys.unm.edu/~lwa/memos/index.html>.
- [2] J. Dowell and G. B. Taylor, “The Swarm Telescope Concept,” 2018, Journal of Astronomical Instrumentation, 7, 1850006.
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- [4] E. W. Greisen, “The FITS Interferometry Data Interchange Convention Revised,” AIPS Memo 114, Feb 16, 2016. [online] <http://www.aips.nrao.edu/FITS-IDI.html>.
- [5] G. Taylor, J. Dowell, Y. Pihlstrom, and J. Craig, “LWA Data Management,” Ver. 4.0, Long Wavelength Array Memo 177, Jan 3, 2019. [online] <http://www.phys.unm.edu/~lwa/memos/index.html>.