Cluster EFW, Application of Calibrations

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February 3, 2000

Document Status Sheet			
1. Document Title: **EFW: Application of Calibrations**			
2. Document Reference Number: **EFW-IRFU-TN-0004**			
3. Issue	4. Revision	5. Date	6. Reason for Change
Draft	0	96 Mar 01	New document
Draft	1	3 Feb 2000	First draft for Cluster II

Contents

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1 Introduction

1.1 Background

The electric field and wave experiment (EFW) of the Cluster project is designed to measure the electric field and plasma density.

The instrument is designed to measure the wave and quasi-static electric fields in the spin plane of the four Cluster spacecraft with high time resolution. Voltage/current sweeps can also be made to measure electron temperature and density. The three magnetic field signals from the STAFF SC search coil sensors are also available to the EFW experiment.

The sensors consist of 16 spherical probes, four for each of the four spacecraft. The probes can be operated in pairs to measure the voltage between probes or the voltage between a single probe and the spacecraft can be measureed. The probes can also be used as low impedance probes (Ampère meter) to measure the current between the plasma and the probe.

1.2 Scope of the Document

This document describes or gives reference to other documents describing the use (application) of the EFW calibration products. The document also summarizes the requirements on the calibration products imposed by the plans for the application of the calibration products.

1.3 Related Documents

1. The scientific user requirements on the EFW instrument are described in [Ref. 2], part 1, page 8, *Scientific capabilities*.
2. An overview of the EFW calibrations is given in [Ref. 3].
3. The analog calibrations are described in [Ref. 1].
4. The *digital calibrations* reference document is [Ref. 7].
5. The description of the *stimuli box* is found in [Ref. 11].
6. The calibrations of the *stimuli box* are described in [Ref. 10].

1.4 Definitions and Acronyms

See the corresponding section of [Ref. 1].

2 Needs of EFW Calibrations and Corrections

The formal instrument requirements are specified in [Ref. 2]. In this section, we give the background to the actual plans to apply the EFW calibration products described in sections 5 and 6. For clarity we summarize the requirements imposed by the applications of the calibration products.

2.1 General Requirements

2.1.1 Calibration product requirements

For all EFW data analysis the following calibration items are required:

EFWCR-01 Time tag to UT conversion algorithms for all relevant instrument modes including the internal burst memory.

EFWCR-02 Boom lengths. This is required to convert from voltage to fields as well as for all spatially dependent measurements.

EFWCR-03 TM to physical units conversion factors for all relevant instrument modes. In combination with *WCR-01* and *WCR-02* the complete instrument response function should be provided.

EFWCR-04 A final EFW calibration product should adhere to the specifications given in [Ref. 9].

2.1.2 Software requirements

The general EFW data analysis software requirements are given in [Ref. 5]. Of special relevance to the calibration are: UR-WEC-105, UR-WEC-114a.

2.2 Quasi-Static Electric Field

There are no special calibration product requirements in addition to the general requirements.

2.3 Wave Fields

2.3.1 Calibration product requirements

The basic calibration products needed for the wave field analysis are phase and amplitude response as a function of amplitude, TM to physical units conversions and timing information. The requirements can be summarized as follows:

WCR-01 Amplitude response as a function of frequency for all relevant measurement modes. The response shall represent the complete *instrument* and all *models*. The combined WCR-01, WCR-02, and EFWCR-03 should provide the complete instrument response functions.

WCR-02 Phase response as a function of frequency for all relevant measurement modes. The response shall represent the complete *instrument* and all *models*. The combined WCR-01, WCR-02, and EFWCR-03 should provide the complete instrument response functions.

WCR-03 The products described in WCR-01 available as fitted polynomials for use in software.

WCR-04 The products described in WCR-02 available as fitted polynoms for use in software.

WCR-05 Instrument input impedance for the relevant frequency ranges and measurement modes. This is needed for estimation of the probe-plasma coupling.

WCR-06 Instrument saturation and non-linearity limits. This should be given both in terms of current and voltage for the relevant measurement modes and frequency ranges. This is of importance for studies of non-linear wave phenomena.

2.3.2 Analysis software requirements

It should also be possible to access several calibration parameters interactively when running the analysis software. For example, having the possibility to plot the instrument phase and amplitude response in every spectrum will help to reduce the risk of misinterpretation of data. In summary, the following software requirements in addition to the general requirements are identified:

WSR-01 The calibration value used for the conversion from TM to physical units.

WSR-02 Boom length, filter 3 dB damping points, bit resolution, input impedances, sampling frequency, and similar key parameters for the instrument performance should be easily available.

WSR-03 Linear response as a function of frequency. (Available as amplitude and phase response). These should be accessible as function calls, where the input is an array of frequencies and the output is the response at these frequencies. This facility is necessary for inversion of filter characteristics.

WSR-04 The software should be prepared for the swift plotting of response functions. Having plotted a spectrum, it should be possible to have the amplitude and phase response functions drawn in the same plot routinely.

2.4 Plasma Parameters

There are no special requirements associated with the plasma parameters.

3 Derivation of the ultimate EFW calibration file

3.1 Basic EFW calibration Products

The EFW calibration products consist of:

1. Analog calibrations described in [Ref. 1].
2. Digital calibrations described in [Ref. 8].
3. Mechanical mounting documentation in [Ref. 12]. Based on these primary products, an ultimate *EFW calibration File* is derived. It follows a syntax described in [Ref. 9]. The details of the derivation and the specific format of the *EFW calibration file* is described in section 3.2.

3.2 The EFW calibration file

The *EFW Calibration File* is derived from the *digital calibrations*, [Ref. 7] and the *analog calibrations* [Ref. 1].

3.3 Format of the EFW calibration file

The general format of the *EFW Calibration File* is found in [Ref. 9] and the EFW specific format is described in [Ref. 7].

4 Archiving of EFW Calibration Products

The EFW calibration files will be archived with the WEC calibration files [Ref. 9].

5 Application of EFW Calibration Products in the Software

All major EFW calibration product applications take place within the ISDAT EFW server module. The implementation is described in the description of the WEC/ISDAT WEC architectural design document [Ref. 6].

6 Plans for Post-Launch Maintenance and Derivation of Corrections

6.1 Maintenance Requirements

The main formal driver of the calibration maintenance requirements is the committment to produce EFW parameters for the CSDS data bases. This is done at the CSDS Scandinavian Data Centree, SDC, at KTH, Stockholm. The CSDS requirements are described in [Ref. 4].

6.2 Maintenance Procedures

The main calibration maintenance will take place within the SDC activities in close coordination with the CSDS data base production. The integrated CSDS production and maintenance is therefore described in some detail in section 6.2.1.

6.2.1 SDC Activities

This section concerns the calibration and data reduction to be done at the Scandinavian Data Centre (SDC) to produce the Prime Parameter Data Base (PPDB), the Summary Parameter Data Base (SPDB) and the Summary Plots (SP) for the Cluster EFW instrument. The detailed analysis of the EFW data is not covered. Basically, all the software should be available in and from the SDC, and the whole processing chain will be tested out in the SDC. The routine processing will also take place at the SDC.

```
Basic input sources:
  RDM       Raw Data Media from ESOC
  CDDS      Cluster Data Disposition System at ESOC

Final output from EFW:
  Ex        Sunward electric field
  Ey        Duskward electric field
  Vsp       Satellite potential
  Ip        Probe current (measures total electron density)

Included in PPDB (Prime Parameter Data Base):
  Ex, Ey, Vsp, Ip
  All 4 satellites
  1 point/spin (4 seconds)

Included in SPDB (Summary Parameter Data Base):
  Ex, Ey, Vsp, Ip
  Only 1 satellite
  1 point/minute

Included in SP (Summary Plots):
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```
  Same as in SPDB

Auxiliary data needed from other experiments:
  ASPOC:    Ii  Ion current
  EDI:      Ex  Sunward electric field
        Ey  Duskward electric field
        Ie  Electron current
  WHISPER:  on/off  On/off flag
        ne  Electron density
  FGM:      B   Magnetic field vector (3 components)
  CIS:      ni  Ion density
        Ti  Ion temperature
        vi  Ion bulk speed (3 components)
  PEACE:    ne  Electron density
        Te  Electron temperature
        ve  Electron bulk speed (3 components)

Other auxiliary data needed from satellite:
  Orbital elements and satellite position and velocity
  Attitude
  Spin phase
  Other housekeeping data, experiment status, TM rate, etc.
```

The flow of data processing is roughly as follows:

Each numbered item is a process, creating output from a given input. Input needed from the outside world is marked at the left with an "i", and output available to the outside world is marked with an "o".

```
1. Unpack the WEC data packets from the total satellite raw data
i Input: "RDM" or "CDDS"
  Output: "WEC data"

2. Unpack the auxiliary satellite data from the total satellite raw data
i Input: "RDM" or "CDDS"
  Output: "AUX", containing satellite velocity, spin phase, etc.

3. Unpack the EFW data from the WEC data
  Input: "WEC data"
  Output: "EFW data"

4. Extract the EFW housekeeping data
  Input: "EFW data"
  Output: "EFW HK", the EFW housekeeping data

5. Extract the EFW raw electric field data
  Input "EFW data"
  Output: "EFW raw"

6. Remove bad data when WHISPER is on. This may or may not be necessary.
```

```
  Input: "EFW raw"
  Output: "EFW good"

7. Extract the satellite potential, and the probe current
  Input: "EFW good"
  Output: "Vsp", "Ip"

8. Extract the Langmuir probe sweeps for later use in determining the
   correction factors
  Input: "EFW good"
  Output: "EFW sweeps"

9. Compute the electric field in the satellite frame of reference
  Input: "EFW good"
i        "EFW conv", the conversion factors for the electric field
                     instrument. These are provided by the EFW
                     experiment team.
  Output: "Esat", E1 and E2, two components of the electric field vector
                  in the spin plane

10. Subtract the electric field induced by the satellite motion, and
    despin the data into the Geocentric Solar Ecliptic (GSE) coordinate
    system.
  Input: "Esat"
i        "FGM B", the magnetic field vector from the FGM instrument
         "AUX", including the satellite velocity, attitude, and spin
                phase
  Output: "Egse"

11. Compute the correction factors for the EFW electric field data.
    This is a complicated and time-consuming process, which needs much
    human intervention.
  Input: "Egse", the electric field in the GSE frame
         "Vsp", the satellite potential
         "Ip", the probe current
         "EFW sweeps", the Langmuir probe sweeps
         "EFW HK", EFW housekeeping data
i        "ASPOC Iion", the ion current from the ASPOC instrument
i        "EDI Ex, Ey, Ielectr", the electric field and the electron
                                current from the EDI instrument
i        "WHISPER ne", the electron density from the WHISPER instrument
i        "FGM B", the magnetic field vector from the FGM instrument
i        "CIS ni, Ti, vi", the ion density, ion temperature and ion bulk
                           flow speed (3 components) from the CIS
                           instrument
i        "PEACE ne, Te, ve", the electron density, temperature and bulk
                             flow speed (3 components) from the PEACE
                             instrument
o Output: "EFW calib", correction factors for the EFW electric field
```

```
                        data

12. Calibrate the electric field data in the GSE frame
  Input: "Egse"
         "EFW calib"
  Output: "Ex", "Ey", calibrated data in the GSE frame

13. Merge EFW data to create the PPDB
  Input: "Ex", "Ey", "Vsp", "Ip"
o Output "EFW PPDB", the EFW part of the PPDB, with data from all 4
                     satellites, one point per spin (4 seconds)

14. Reduce data to the SPDB resolution
  Input: "EFW PPDB"
o Output: "EFW SPDB", the EFW part of the SPDB, with data from one
                      satellite, one point per minute

15. Plot the data
  Input: "EFW SPDB"
o Output: "EFW SP", the EFW part of the Summary Plots

16. Merge with the other French data
  Input: "EFW SP"
         "CIS SP", the CIS part of the SP
         "STAFF SP", the STAFF part of the SP
         "WHISPER SP", the WHISPER part of the SP
o Output: "WEC + CIS SP", two pages of summary plot for WEC and CIS, as
                          suggested in the CSDS final report
```

Note that there is a difference in our concept between conversion factors and correction factors. The conversion factors are known to a certain accuracy in advance, such as Volts/bit in an ADC, the boom lengths etc. The correction factors are not known at all in advance, and would not be necessary for an ideal instrument. They are necessary because of unforeseen effects on the instrument of photoelectrons, surface work function differences, contact potential drops, etc. The determination of the correction factors is a major effort during the initial phase of the mission, and as can be seen above, it involves the use of data from a number of other instruments.

6.2.2 Detailed data analysis

The regular calibration maintenance will take place within the CSDS SDC activity as described in section 6.2.1. Occasionally detected anomalies will be handled within the ISDAT error reporting procedure via http://www.irfu.se/isdat.

6.3 Reference Documents

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