Cluster EFW Analog Calibrations

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Contents

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 EFW instrument is described in [Ref. 4].

The instrument will 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 both electron temperature and density. The three magnetic field signals from the search coil sensors are also available in 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. The probes can also be used as low impedance probes (Ampère meter) to measure the current between the plasma and the probe.

The EFW electronics can be divided into an analog part (from sensors to ADCs) and a digital part (from ADCs onwards). Many aspects of the complete system are investigated in the digital calibrations [Ref. 5]. However, a detailed investigation of the behaviour of the absolute phase of a signal can only be achieved through an analog calibration, where the effect of the instrument to the applied stimulus is observed before the ADCs. In addition, several other Cluster instruments (STAFF SA, WHISPER, WBD) sample the analog signal from EFW. A separate calibration of the analog part is therefore clearly needed.

From the analog testing point of view, the instrument consists of the *sub-units* :

1. the contact surface between probe and plasma
2. the pre-amplifier in the puck
3. the buffers that distribute the signal
4. attenuators
5. multiplexors
6. filters
7. analog to digital converters

1.2 Purpose of the analog calibrations

The purpose of the EFW analog calibrations is: (see section 1.7 for definitions of *unit* and *instrument*)

1. to verify the instrument performance with respect to the user requirements.
2. to provide phase response as needed for the scientific data analysis.

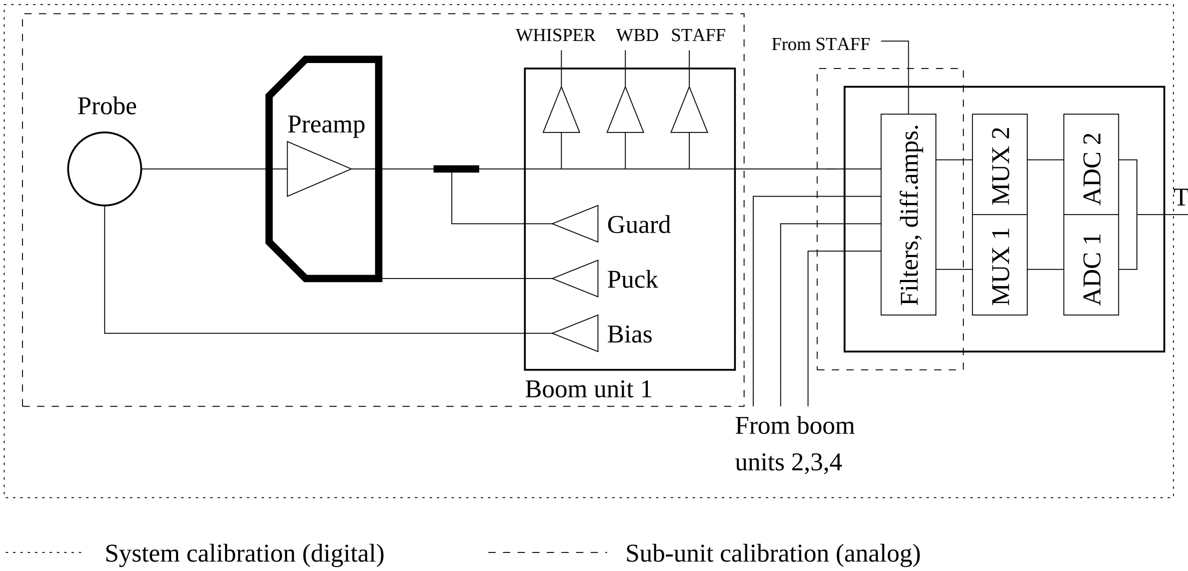

Figure 1: EFW calibration block diagram

3. to verify the amplitude response derived from the digital calibrations.

1.3 Scope of the analog calibration

The scope of the *analog calibration* is to cover the electronics from the probe amplifiers to the "analog side" of the multiplexors. This is schematically illustrated in Figure 1. As it clearly is impossible to access all the system, including the ADCs, in the *analog tests*, these are implemented as *sub-unit* tests of the EFW boom packages and the EFW WEC-5 electronics (Figure 1). To get results for any complete unit, the results for the two sub-units concerned should be combined. System tests, as shown in Figure 1, are performed for the digital calibrations [Ref. 5].

1.4 Responsibilities

The responsibility for the performance of the analog test, and thereby of the *analog calibrations*, lies with the EFW technical manager, Lennart Åhlén.

1.5 Scope of the Document

This document constitutes the reference document for the *analog calibrations* of the Cluster EFW instruments.

1.6 Related Documents

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

1.7 Definitions and Acronyms

The following definitions are used:

Analog calibration see section 1.3.

Digital calibration See [Ref. 5].

instrument A complete EFW electronics and boom package. An instrument consist of five *units* (see below). *instrument* is used as the generic expression and *model* (see below) is used for the *specific* instrument.

model A specific *instrument* (see above). The following models exist (Cluster II):

- Four flight models: **F5 (or F9), F6, F7, F8**
- A flight spare model: **FS**
- An engineering model: **EM**

sub-unit A sub-set of a *unit* (see below).

system The complete instrument as indicated in Figure 1.

unit A part of the *instrument*. The following *units* exist:

WEC1/4 boom package unit (see Figure 1).

WEC5 the electronics package (see Figure 1).

The actual unit configuration within each model, as well as which model flies on which spacecraft, is described in [Ref. 8]. At the time of writing this, the intended configuration is as follows: The specific *WEC1/4* units are numbered 201 - 216 for the flight units and 15 and 16 for the spare units, e.g. WEC1/4-201, WEC1/4-202, etc. The specific *WEC5* units are numbered 5 - 9, with 5 being the spare and 6 - 9 the flight units, i.e. WEC5-9, WEC5-6, WEC5-7, WEC5-8, WEC5-5. **This information is preliminary only: reference document is [Ref. 8].**

The acronyms and abbrieviations are listed in Table 1.

Acronym	Meaning
AC	Alternating Current
ADC	Analog to Digital Converter
DC	Direct Current
EFW	Electric Field and Waves
EM	Electromagnetic model
EPS	Encapulated Postscript (file)
FM1	Flight Model 1
FM2	Flight Model 2
FM3	Flight Model 3
FM4	Flight Model 4
FS	Flight Spare model
GIF	a graphics file format
IRF-U	Institutet för Rymdfysik, Uppsalaavdelningen
MUX	MUltipleXor
NA	TBD
PI	Principal Investigator
psd	TBD
Psim	TBD
SN	TBD
SR	Scientific requirements
TBA	TBD
TBD	To Be Defined
TBW	To Be Written
TM	Telemetry
TR	Technical Requirement
WEC	Wave Experiment Consortium

Table 1: Acronyms and abbrieviations

2 Applicable user requirements

The *EFW tests* are concerned with the following requirements:

Scientific Requirements, SR described in the EFW proposal to ESA, [Ref. 3] Part 1, page 8.

EFW Calibration Requirements, EFWCR described in [Ref. 1].

Wave Calibration Requirements, WCR described in [Ref. 1].

The requirements applicable to the *analog calibrations* are indicated in Table 2. The complete list of requirements, and the compliance to them, is found in [Ref. 1].

Requirement ID	Description	Compliance	Remarks
SR-A	E Dynamic range and time resolution		
SR-B	N dynamic range		
SR-C	dN dynamic range and time resolution		
SR-D	Electrostatic shocks		
SR-E	Wave ranges		
SR-F	Time accuracy		
SR-G	Measuring spacecraft potential		
WCR-01	Amplitude response		
WCR-02	Phase response		
WCR-04	Analytical function (phase)		
WCR-06	Saturation and non-linear response		

Table 2: Requirements applicable to the analog calibrations.

3 Test and Data Description

3.1 Test setup

As each test corresponds to a certain data file, the tests are described in Section 3.2.1 below.

3.2 Data structure

3.2.1 Data archiving

The data is presently stored on an interim CD prepared by Lennart Åhlén, who will organize the data on a final analog test data CD into a directory structure with standardized file names. The directory structure and file name conventions, which directly reflect how the tests were done, will be described here.

3.2.2 Data formats

The output from the *analog tests* is put into data files, named and organized as in Section 3.2.1, specifying the amplitude and phase response (in dB and degrees, respectively) as a function of frequency. The parameters normally plotted are:

- Amplitude response A [dB]: With U_{in} being the input signal, and U_{out} the output signal, this parameter is defined b $A = 10\ {}^{10}\log(U_{\mathrm{out}}/U_{\mathrm{in}})$.
- Phase response ϕ [deg]: The phase lag of U_{out} as compared to U_{in}.
- Group delay time τ_{g} [s]: $\tau_{\mathrm{g}} = -\mathrm{d}\phi(f)/\mathrm{d}(2\pi f)$.

3.3 Plans for post-launch tests

The philosophy of tuning *sub-units*, *units*, and *instruments* to a high level of similarity implies that it will be possible to use the spare and EM units for post launch trouble shooting.

4 Test results

4.1 Presentation of selected test data

This section presents a subset of the test data, the complete set of which is listed in Section 3.2.1.

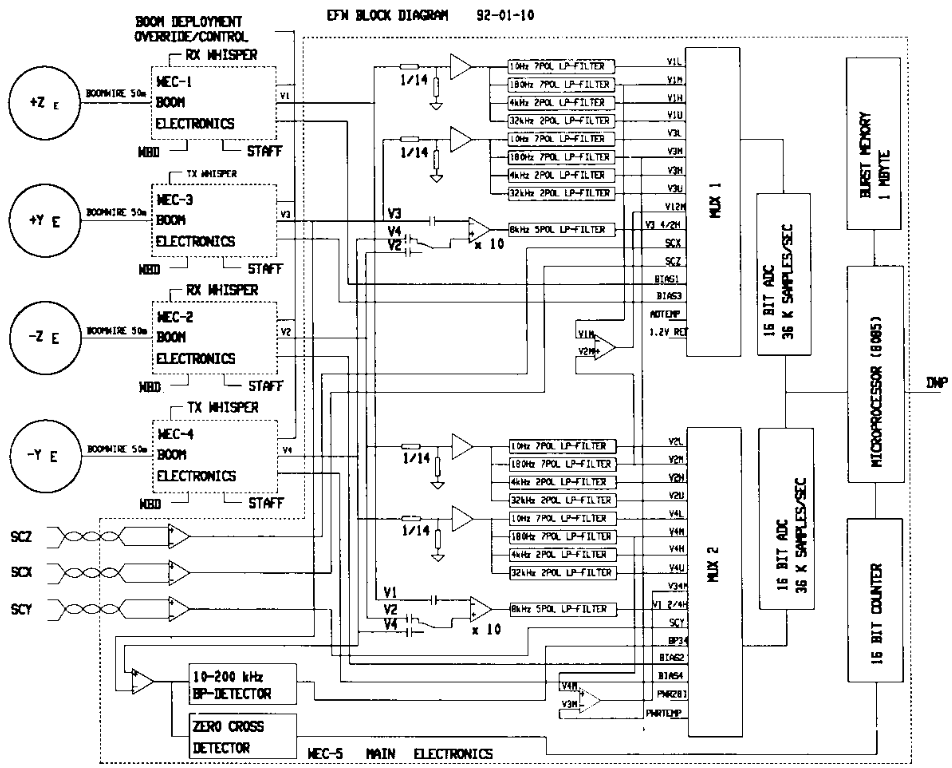

Figure 2: Block diagram of the Cluster EFW instruments.

To understand the selection of test results, it is suitable to consider the block diagram in Figure 2, showing the logical structure of the EFW instrument [Ref. 4]. To the left of the multiplexors (MUX1 and MUX2), names of different signals are shown. These signals naturally form the following groups:

1. Lowest-frequency band, single-probe signals: V1L, V2L, V3L, V4L
2. Medium-frequency band signals:
   - (a) : single-probe signals: V1M, V2M, V3M, V4M
   - (b) : double-probe signals: V12M, V34M
3. Higher-frequency band signals:
   - (a) : single-probe signals: V1H, V2H, V3H, V4H
   - (b) : double-probe signals: V12H, V34H, V14H, V23H

4. Highest-frequency band, single-probe signals: V1U, V2U, V3U, V4U
5. Signals from STAFF SC: SCX, SCY, SCZ

The electronics are designed so as to minimize the differences between the handling of signals in the same group, and between different satellites. Two main tasks for the calibrations are (i) to find out to what degree the signals within each group are identical, and (ii) to determine the characteristics for each group of signals.

For task (i), one can either compare the output from the analog (or, for amplitude response, digital) tests for two selected channels, or use the common mode response (CMM) which has been directly measured in the analog tests for some signal combinations (see Section 3.2.1. If two signal paths were identical, the CMM would be zero, so this quantity is an indirect indication of differences.

For task (ii), the phase response is only available from the analog calibrations. The results presented here are therefore the principal source of information on phase response and group delay time. We also present results on the amplitude response, so as to verify the results from the digital calibration.

Analog calibration data for each of the groups above are presented below. We show digitization plots for the amplitude and phase response, and occasionally also the group delay time. In some cases, the common mode response (CMM) is also presented.

4.1.1 V1L, V2L, V3L, V4L

These signals are to be sampled at 25 samples/s, and are therefore low pass filtered at 10 Hz.

Figure 3: Measured phase and amplitude response.

Figure 4: Example of V4L−V3L common mode response.

4.1.2 V1M, V2M, V3M, V4M

These signals are to be sampled at 450 samples/s, and are therefore low pass filtered at 180 Hz.

Figure 5: Measured phase and amplitude response.

Figure 6: Example of V4M−V3M common mode response.

4.1.3 V12M, V34M

These signals are to be sampled at 450 samples/s, and are therefore low pass filtered at 180 Hz.

Figure 7: Measured phase and amplitude response.

Figure 8: Example of V12M common mode response.

Figure 9: Example of V34M common mode response.

4.1.4 V1H, V2H, V3H, V4H

These signals are to be sampled at 9 ksamples/s, and are therefore low pass filtered at 4 kHz.

Figure 10: Measured phase and amplitude response.

4.1.5 V12H, V34H, V14H, V23H

These signals are to be sampled at 18 ksamples/s, and are therefore low pass filtered at 8 kHz. In addition, they are high pass filtered and amplified, to facilitate studies of small-amplitude waves.

Figure 11: Measured phase and amplitude response.

Figure 12: Example of V12H common mode response.

Figure 13: Example of V34H common mode response.

4.1.6 V1U, V2U, V3U, V4U

These signals are to be sampled at 36 ksamples/s, and are low pass filtered at 32 kHz.

Figure 14: Measured amplitude and phase response.

4.1.7 SCX, SCY, SCZ

Figure 15: Measured amplitude and phase response.

Figure 16: Measured group delay and amplitude response.

Figure 17: Example of SCX common mode response.

Figure 18: Example of SCY common mode response.

Figure 19: Example of SCZ common mode response.

Instrument Proposal			Calibration				
Measured quantity		Frequency range	Measured range (Digital)	Analog calibration passband	Analog calibration rejectband	Digital calibration (3dB freq)/10	Digital calibration Noise psd
D C Electric Field	VxL	0-10Hz	0-50Hz	<± 0.2 dB <± 3 deg	<± 0.5 dB <± 6 deg	± 2 %	<0.03 psd
	VxM	0-180Hz	10-800Hz			± 0.4 %	
	VxyM	0-180Hz	10-900Hz			± 0.2 %	
	VxH	0-4kHz	.2-47.25kHz			± 0.4 %	
	VxU	0-32kHz	.7-189kHz			± 1.6 %	
Range 0.1 to 700mV/m				<0.03 psd ~ 12 dB SN			
AC Electric Field	VxyH	.01-8kHz	.4-32kHz	<± 0.2 dB <± 3 deg	<± 0.5 dB <± 6 deg	± 3.1 %	
Range 3µV/m-50mV/m				<0.03 psd ~ 6-26 dB SN depending on the freq.			
Plasma density fluctuations	VxL	0-10Hz		<± 0.2 dB <± 3 deg	<± 0.5 dB <± 6 deg	± 2 %	NA
	VxM	0-180Hz				± 0.4 %	
	VxH	0-4kHz				± 0.4 %	
Psim 5pF	VxH	0-4kHz	.2-47.25kHz			±2.9 %	
Psim 5pf	V12H	0-4kHz	.4-32kHz			± 3.3 %	
Range 1 to 100 cm^-3 = 40dB				> 60 dB			
HF power filter	BPxy	10-200kHz	.001-10V	± 4 %		TBA	NA

Figure 20: EFW results obtained from the acceptance test for Cluster I. To be updated for Cluster II: see text for comments.

5 Conclusions

5.1 Compliance with requirements

The results of the acceptance tests will be summarized in this section in a table such as found in Figure 20, which was applicable to Cluster I. The corresponding Cluster II table is under preparation by Lennart Åhlén. No significant changes are expected.

5.2 Transfer Functions

Amplitude and frequency response curves have been presented in this report. These are further discussed in [Ref. 2], where the derivation of polynomials describing the transfer functions also is described.

5.3 Use of analog calibrations in scientific analysis

The application of the calibrations are described in [Ref. 1].

5.4 Reference Documents

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[5] B. Lybekk and M. Thomsen. Digital calibration of cluster EFW. Technical Report EFW-UIO-TN-0202, Institute of Physics, University of Oslo, September 1999. Replaces EFW-IRFU-TN-0003.

[6] T. A. Sten. Calibration of the Cluster EFW stimuli box. Technical Report EFW-UIO-TN-0001, Institute of Physics, University of Oslo, March 1992.

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