WEC Instrument User Manual for Cluster II

Prepared by
The University of Sheffield
on behalf of the
Cluster II WEC
Principal Investigators

Document Reference	CL-WEC-UM-002 Issue:1.03
Prepared by:	Ieuan Willis, Keith Yearby, Cecilia Harvey, Hugo Alleyne and others
Release Date	23rd August 2000

Document Control

Document title:	**WEC User Manual Document**		
Reference:	**CL-WEC-UM-002**		
Issue:	***Revision***	***Date***	***Reason for Change***
1.03	**0**	**24-Aug-00**	**Minor corrections and ammendments to Issue 1.02**
1.02	**0**	**01-Dec-99**	**Minor corrections and ammendments to Issue 1.01**
1.01	**0**	**30-Jul-99**	**Minor corrections to Issue 1.00**
1.00	**0**	**28-May-99**	**Updates to Draft edition**
Draft	**0**	**26-Mar-99**	**CL-WEC-UM-001 rewritten for Cluster 2**

Abstract

Abstract:	**This document is the complete description of the in orbit operation of the Cluster 2 WEC instruments**
Prepared by:	**Ieuan Willis, Keith Yearby, Cecilia Harvey, Hugo Alleyne and the WEC PIs, TMs and others. The preparation of chapter 5 was coordinated by Michel Parrot.**
Reference:	**CL-WEC-UM-002**
Status:	**Issue 1.02**
Approved by:	
Released: ***Issue:1.02***	***See cover***

Distribution:	**WEC Chair and previous Chairs** **WEC PIs** **WEC TMs** **WEC Operations Group** **Estec ...P. Escoubet** **Esoc ... P.Ferri** **JSOC ... M Hapgood**

WEC INSTRUMENT USER MANUAL

CHAPTER 1

INSTRUMENT DESCRIPTION

Table of Contents

Acronyms

AGC	Automatic Gain Control
AIT	Assembly Integration and Test
AOCMS	Attitude and Orbit Control and Measurement System
ASPOC	Active Spacecraft POtential Control
BM	Burst Mode
bps	bits per second
bpw	bits per word
CDDS	Cluster Data Disposition System
CDMU	Central Data Management Unit
CIS	Cluster Ion Spectroscopy
CRRES	Combined Release and Radiation Effects Satellite
CTU	Central Terminal Unit
DAC	Digital Analogue Converter
DMA	Direct Memory Access
DPU	Digital Processing Unit
DSN	Deep Space Network
DSP	Digital Signal Processing
DWP	Digital Wave Processor
EDI	Electron Drift Experiment
EEPROM	Electrically Erasable Programmable Read Only Memory
EFW	Electric Fields Waves
EGSE	Electrical Ground Support Equipment
EID	Experiment Interface Document
EM	Emergency Mode
EMC	ElectroMagnetic Compatibility
EMI	ElectroMagnetic Interferometer
ESA	European Space Agency
ESIS	European Space Information System
ESOC	European Space Operation Centre
ESTEC	European Space Technology Centre
FDM	Fast Digital Monitor

FFT	Fast Fourier Transform
FGM	FluxGate Magnetometer
FM	Fast Mode
HBR	High Bit Rate
HK	HouseKeeping
IBMD	Instrument Baseline Mode Definition
IEL	Inter Experiment Link
ISEE	International Sun Earth Explorer
JSOC	Joint Science Operation Centre
LCA	Listen, Calibration or Average
LCL	Latching Current Limiter
LSB	Least Significant Bit
MHD	MagntoHydroDynamics
MSB	Most Significant Bit
MWF	Magnetic Wave Form
NASA	National Aeronautics and Space Agency
NBR	Normal Bit Rate
NM	Normal Mode
OBDH	On Board Data Handling
OSTB	One Second Timing Boundary
PCB	Printed Circuit Board
PDU	Power Distribution Unit
PEACE	Plasma Electron And Current Experiment
PI	Principal Investigator
PRI	Primary
PWR	PoWeR
RAPID	Research with Adaptive Particle Imaging Detectors
RED	Redundant
rms	root mean square
RTU	Remote Terminal Unit
SA	Spectrum Analyser
SC	Search Coil
SDT	Serial Digital Telemetry
SEU	Single Event Upset
SM	Special Mode
sp	spin period
STAFF	Spatio-Temporal Analysis of Field Fluctuations Experiment
SWT	Science Working Team
SYNC	Synchronisation

TBC	To Be confirmed
TBD	To Be Decided
TM	TeleMetry
TRP	Temperature Reference Point
TX	Transmit(ter)
USO	Ultra Stable Oscillator
VCXO	Voltage Controlled Crystal Oscillator
VLBI	Very Long Baseline Interferometer
VSP	Vector Signal Processor
WBD	Wide Band Data
WCMW	Whisper ComMand Word
WEC	Wave Experiment Consortium
WHISPER	Waves of HIgh frequency and Sounder for the Probing of Electron density by Relaxation
WHSS	WHisper Sample Synchronisation
WPW	Whisper Processing Word

1.1 EXPERIMENT OVERVIEW

1.1.1 Summary on the experiment purpose :

1.1.1.1 Objectives

In the magnetohydrodynamic (MHD) view of a collisionless plasma, magnetic field lines are "frozen" in the plasma; two plasma elements which are initially on the same field line will remain on it. Hence, in the MHD limit, the magnetic field topology is conserved in a collisionless plasma. Most of astrophysical plasmas surrounding planets are "collisionless", yet the magnetic topology is not conserved everywhere. For instance, we know, from past space missions, that the interaction between the solar wind and the Earth magnetic field leads to the formation of critical layers, or discontinuities, with a small transverse thickness, where magnetic topology is not conserved. In the absence of binary collisions, plasma waves must ensure the "anomalous" (i.e. wave driven) diffusion of magnetic field lines through these layers. Similarly, there is a need for plasma waves to ensure thermalisation of the solar wind bulk motion in the collisionless bow shock, in front of the Earth magnetosphere. The same need also exists in order to account for electron and ion parallel acceleration in plasmas where parallel electric field cannot be supported by collisions. Taking advantage of the new capabilities offered by Cluster II, the coordinated study, which will be conducted by the WEC, is expected to really improve our understanding of the "anomalous" behaviour of plasmas. While the electric and magnetic fluctuations play a key role in determining the behaviour of critical layers, they are extremely difficult to study because:

(i) they develop in spatially limited regions which are seldom crossed,
(ii) the corresponding structures moves at fast speed with respect to the spacecraft,
(iii) their amplitudes are so large that the use of a linear dispersion relation to help characterising them is useless.

Given the above requirements, the scientific objectives the WEC are:

a/ Characterisation of non-linear electrostatic structures. This will be achieved by high resolution time domain studies.
b/ Unambiguous determination of the parameters which characterise plasma turbulence (distribution in the k vectors) and small-scale field-aligned current structures (geometry, current density,...) from inter spacecraft correlations of field fluctuations.
c/ Evaluation of magnetic vorticity, charge separation voltages,...
d/ Assessment of the role played by electric and magnetic fluctuations in the "anomalous" behaviour of critical layers.

e/ Wave-particle interactions, via correlations performed onboard between wave and particle measurements.
f/ Determination of source locations from the wave vector measured at various spacecraft positions.
g/ Role of high frequency waves. Study of their fine structure and its bearings on non-linear wave particle interactions, from wide band data.
h/ Measurement of the quasistatic E field in the spin plane and of density fluctuations.
i/ Measurement of plasma density and assessment of its spatial variations.
j/ Evaluation of spacecraft potential.

1.1.1.2 Program of activities to attain the objectives

Although most of the WEC objectives can be reached for distances between satellites of the order of a few hundreds of km to a few R_E, what we qualify of intermediate scale, several objectives require smaller or larger distances.

- small scales (< 100 km), small spatial and temporal structures are important because they provide the necessary dissipation in the various magnetospheric boundary regions, they are equally important from the point of view of basic plasma physics since they represent the non-linear state of the plasma under various conditions;

- intermediate scales studies include MHD turbulence in the solar wind, magnetosheath and cusp, instabilities driven by velocity shears, waves associated with quasi-parallel shocks, transfer events, impulsive penetration of plasma in the magnetosphere, slow-mode shocks in the near tail in association with reconnection, instantaneous auroral electrodynamics;

- large scales (several R_E) studies include processes such as steady-state reconnection at the magnetopause, convection in the "quiet" magnetotail, and the formation of a near-earth neutral line.

Priority will be given at the crossing of the boundary regions : foreshock, bow shock, magnetosheath, magnetopause and low-latitude boundary layer, cusp, plasmasheet.

The STAFF experiment needs a time synchronisation of 200 µs between the 4 satellites.

The extremely high (microsecond) time resolution provided by the WBD measurements makes it possible to utilise the signals from two or more spacecraft to perform Very-Long-Baseline-Interferometer (VLBI) measurements.

Real time WBD data require direct acquisition by a NASA Deep Space Network (DSN) receiving station.

1.2 AREAS OF INTEREST

The WEC modes of operations have been constructed to share resources in the electrical power available for the experiments (11.75 Watts have been allocated but 14 Watts would be necessary) and above all , telemetry (5217 bits/s in Normal Bit Rate, 43.898 kbits/s in Burst mode 1, BM1, 91.26315 kbits/s in Burst mode 2, BM2, and 29.45836 kbits/s in Burst mode 3, BM3). Each mode corresponds to priority on one or two of the experiments, the others being in a degraded mode. DWP is responsible for coordinating all WEC operations. To do so it uses "macro commands" and "switches". Macro commands are command sequences which are expected to be commonly used. They provide a "skeleton" for each WEC mode. Switches are changes to a WEC instrument which do not alter the quantity and format of the data being produced by that instrument. Examples of switches could be bias current variation to the EFW sensors or changing parameters passed to WBD.

Most of the WEC objectives can be pursued by the basic WEC modes : NBR-BASIC, NBR-LOW RECURRENCE, HBR-BASIC and HBR-LOW RECURRENCE, which are expected to be run about 75% of the time, in all geophysical regions : solar wind, bow shock, magnetosheath, magnetopause and low latitude boundary layers, cusp, plasmasheet and its boundary layer. etc. However, subject to agreements between WEC experimenters and SWT, more specific WEC modes can be used, whatever the geophysical region :

- NBR-LANGMUIR, HBR-LANGMUIR or HBR-EFW, will be used, over full orbits, to allow EFW to operate the electric antennas in Langmuir mode (1 antenna, at the best, being available for electric fields wave measurements),

- NBR-SPIN SYNCHRONISED, NBR-CONTINUOUSLY ACTIVE, HBR SPIN SYNCHRONISED GLIDING, or HBR CONTINUOUSLY ACTIVE will be used over limited time intervals to allow WHISPER active modes,

- NBR-WBD or HBR-WBD will be used for specific WBD science objectives during 10% of the NASA Deep Space Network (DSN) real-time coverage,

- STAFF and WHISPER CALIBRATION modes have to be forecast, on a strategy to be defined by the Science Operations Working Group. It should be telecommanded at the beginning of some of the data acquisition periods (typically once per orbit in different plasma regions). STAFF calibration will be most of the time in NBR (6 minutes) but sometimes in HBR (2 minutes).

HBR-WHISPER has been specifically designed for studies of fine structures, with WHISPER being most of the time in a passive mode.

BM2-WBD is for use when DWP takes WBD data and the s/c is in BM2 mode.

BM3-EFW allows EFW to dump its memory.

1.3 INSTRUMENTS DESCRIPTION

1.3.1 EFW instrumentation

1.3.1.1 Brief Experiment Description

The electric field and wave experiment (EFW) on Cluster II is designed to measure the electric field and density fluctuations with sampling rates, on some occasions, up to 36000 samples/s in two channels. Langmuir sweeps can also be made to determine the electron density and temperature. Among the more interesting objectives of the experiment is to study non-linear processes that result in acceleration of plasma. Large scale phenomena where all four spacecraft are needed will also be studied.

To meet the scientific objectives the electric field instrument will be capable of measuring, in various modes;

- Instantaneous spin plane components of the electric field vector, over a dynamic range of 0.1 to 700 mV/m, and with variable time resolution down to 0.1 ms.
- The low energy plasma density, over a dynamic range at least 1 to 100 cm^{-3};
- Electric fields and density fluctuations of small amplitude in double layers, over dynamic ranges of 0.1 to 50 mV/m for the fields and 1 to 50 % for the relative density fluctuations, and with a time resolution of 0.1 ms on some occasions;
- Electric fields and density fluctuations in electrostatic shocks or double layers of large amplitude, over dynamic ranges of 0.1 to 700 mV/m for the fields and 1 to 50 % for the relative density fluctuations, and with a time resolution of 0.1 ms on some occasions;
- Waves, ranging from electrostatic ion cyclotron emissions having amplitudes as large as 60 mV/m at frequencies as low as 50 mHz, to lower hybrid emissions at several hundred Hertz and with amplitudes as small as a few µV/m;
- Time delays between signals from up to four different antenna elements on the same spacecraft, with a time resolution of 30 µs on some occasions.
- The spacecraft potential.

The detector of the instrument consists of four orthogonal spherical sensors deployed from 50 meter cables in the spin plane of the spacecraft, four deployment units, and a separate main electronics unit as shown in the block diagram in Figure 3 of ESA SP-1159. The instrument has several important features. The potential drop between two opposing spherical sensors can be measured to provide an electric field measurement. The instrument can also be operated as a Langmuir Probe and biased to provide the Langmuir current-voltage curve and, thus, the electron temperature and density. The potentials of the spherical sensor and nearby conductors are controlled by the microprocessor in order to minimise errors associated with photoelectron fluxes to and from the spheres. The output signals from the spherical sensor preamplifiers are provided to the wave instruments for analysis of high frequency wave phenomena. The instrument has a 1-megabyte burst memory and two fast A/D conversion circuits for recording electric field wave forms for time resolutions up to 10 kHz. Data gathered in the burst memory will be played back through the telemetry stream allocated to the electric field experiment by pre-empting a portion of the real time data gathered by the instrument. On board calculations of least square fits to the electric field data over one spacecraft spin period (4 seconds) will provide a baseline of high quality two dimensional electric field components that are always present in the telemetry stream. Incoming data is continuously monitored using algorithms in software to determine if conditions are appropriate for triggering a burst collection playback.

The Cluster II instrument has been modified as compared to the original Cluster instrument. Instead of housing the preamplifier in the spherical sensor, the preamplifier has been moved to a separate housing called the "hockey puck". The hockey puck and the sphere are connected by an extremely thin cable, which minimises the disturbance from photoelectrons on the measurement made by the sphere.

1.3.1.2 Analogue Electronics

The hockey puck adjacent to each puck houses a preamplifier which measures the potential difference between the sphere surface and the spacecraft analogue ground. Since the plasma has high source impedance (10^7 to 10^{10} Ω) and a capacitance of 5 pF due to the 8 cm diameter sphere, the preamplifier must have a low leakage current (<10 pA) and low input capacitance (<8 pF) to avoid the attenuation of input signals. Since the potential of a biased sphere can differ from that of the spacecraft by 5-30 V in the absence of an electric field, and fields as large as 500 mV/m have been observed, the dynamic range of the preamplifier and associated sensor electronics is ±70 V from DC to 200 Hz. The small signal response exists to 600 kHz for use by the AC electric field instrument.

The 50-meter boom cable between the deployment unit and the puck sensors contains eight wires and one coaxial cable. These wires carry the power to the preamplifier in the sphere, the biasing voltages on the puck and guard surfaces, and the biasing voltage to the bias resistor. The wires and coaxial cable are surrounded by a kevlar braid which provides mechanical support against the centrifugal stresses on the cable. The outer surface of the cable is a conductor which is tied to the spacecraft EFW main ground chassis.

In order to limit and control the flux of photo-electrons from the booms to the spherical sensors and minimise error sources in the potentials of puck and guard surfaces are forced to follow the potential of the sphere with an adjustable DC offset. The DC offset is determined by 8 bit microprocessor-controlled digital-to-analogue converters located in the digital section of the main electronics box. The puck voltage follows the sphere voltage with an offset which can range between -1.26 and +1.26 V in 256 steps. The guard voltage follows the sphere potential with an offset between -39. and +39. V in 256 steps.

The sphere potential is determined by the balance of plasma thermal currents, photoemission current, and a bias current to the sphere whose magnitude is controlled by on-board electronics to minimise the sheath impedance. This is accomplished by controlling the potential drop across a 75 MΩ bias resistor with bias control circuitry (see Figure 1.2/2.1 of EID-B). One end of the bias resistor is tied to the sphere surface. The other end of the resistor is driven by the bias control circuitry which operates in one of the two modes as determined by the state of a bias relay. If the instrument is measuring electric fields, the relay is set so that the bias control circuit follows the output of the sphere with a DC offset determined by the DAC. The potential drop across the resistor is the DAC determined value and the injected current is this value divided by the value of the resistance. This current can vary from -0.5 to +0.5 μA in 256 steps. These values are large enough to balance the maximum possible photoelectron flux from the spheres.

The spherical sensors can also be operated as current collecting Langmuir probes to provide information on the plasma density and electron temperature. In this mode, relays in each of the four deployment units are flipped so that the microprocessor controlled bias circuits are referenced to the satellite rather than the output of the sphere preamplifier.

The output of each sphere preamplifier is filtered by anti-aliasing filters with frequencies at 10 Hz, 180 Hz, 4 kHz and 8 kHz. A simple frequency counter is included for the range 10-200 kHz. The low frequency filter data will be utilised for direct transmission of data. The 180 Hz signal will be stored on the on-board tape recorder. The highest frequency data will be recorded in the internal burst memory and played out at slower telemetry rates.

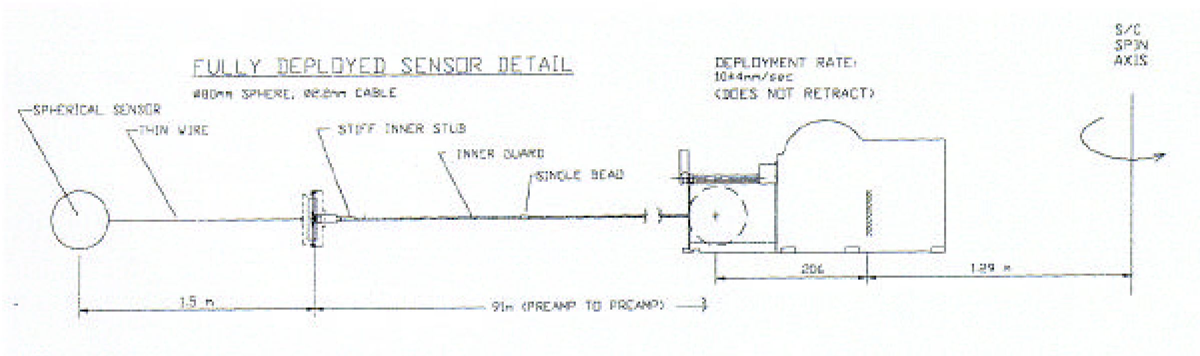
1.3.1.3 Digital Electronics

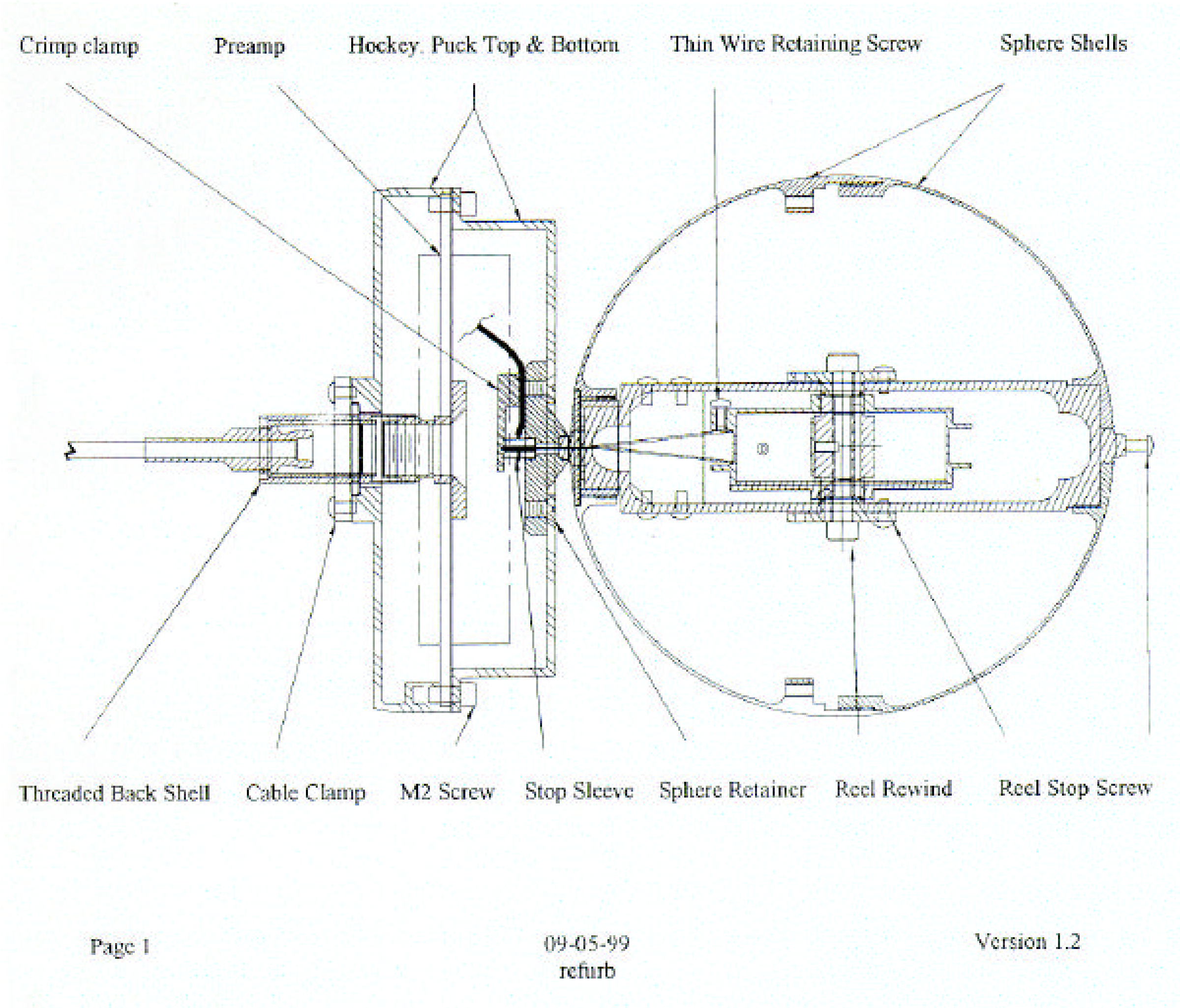
The digital electronics contain two very fast analogue-to-digital system, a set of digital-to-analogue converters for biasing, a single 8-bit radiation-hard microprocessor, and a large burst memory. Extensive software functions increase the instrument's capabilities and data coverage.

The strategy for measuring the sphere voltages over a range of ± 700 mV/m to a relative accuracy of 3μV/m can be achieved in a number of ways. With a 16-bit converter, the single ended measurements of sphere voltage (V1 through V4) will be measurable from 700 mV/m to 30 μV/m. Differential measurements V1-V2/4H and V3-V4/2H will have a gain factor of ten and thus be measurable to about 3 µV/m taking the system noise into account (the one bit resolution is 0.15 µV/m) but will only have a range to 10 mV/m. The variation of the sensitivity with frequency of the instrument is shown in Figure 5 of ESA-SP.

1.3.1.4 Boom Deployment Mechanism

Each DC Electric Fields Deployment Unit is a small, self-contained package containing a motor driven mechanism that deploys a multiconductor cable and tip mounted spherical sensor in the spin plane of the Cluster II satellites. In orbit, each opposing pair of cables will be symmetrically deployed to a tip-to-tip distance of approximately 100 m,except during commissioning .when various tip to tip distances will be tested. The assembly consists of two major components: a deployment mechanism, and the cable with sensor. The mechanism design has evolved from a series of successful satellite experiments including S3-2, S3-3, ISEE, Viking, and CRRES. The deployment unit contains a rotating cable spool assembly, a brush DC gear motor, an over-tension and end-of-cable indicator, an analogue cable length indicator, a pyrotechnic-released spherical sensor housing, and a cable oscillation Coulomb damper through which the cable exits the mechanism. The possibility that the satellite control deploys the booms is also built into the system. The figures below show a drawings of the modified design for Cluster II, with the sphere/hockey puck configuration.





1.3.1.5 Measured quantities

Three main parameters will be measured.

- The quasi static Electric Field.
- The Wave Electric Fields
- The plasma Density and the relative Density Fluctuations

Measured quantity	Frequency range	Dynamic range
DC Electric Field (2 components)	0 - 10 Hz 0 - 180 Hz 0 - 4000 Hz 0 - 32000 Hz	700 mV/m - 0.1 mV/m 700 mV/m - 0.1 mV/m 700 mV/m - 0.1 mV/m 700 mV/m - 0.1 mV/m
AC Electric Field (2 components)	10 - 8000 Hz	10 mV/m - 3 μV/m See note.
Plasma density fluctuations	0 - 10 Hz 0 - 180 Hz 0 - 4000 Hz	1 - 100 cm-3 1 - 100 cm-3 1 - 100 cm-3
Frequency counter	10-200 kHz	
Density and Temperature (Langmuir sweeps)		1 - 100 cm-3 eV range

Table 1.3.1.1 Data rates:

Nominal telemetry rate Tape loading mode data rate Burst memory loading mode data rate	1440 bits/sec 15.1, 22.5, 29.4 kbit/sec < or = 1152 kbit/sec

Table 1.3.1.2 Physical Data:

Item	Mass (kg)	Power (W)
Main Electronic Box Wire Booms units	1.80 13.60	3.7

Table 1.3.1.3 A block diagram of EFW is given in figure 1.2/2.1.a of EID-B.

1.3.1.6 EFW operational modes

The EFW instrument has a large number of possible sampling modes. The main parameters to be selected in each case are: probe bias, probe mode, filter frequency, telemetry rate and internal memory use. Several of the parameters are interrelated which limits the possible number of combinations, the telemetry rate is also dependent on other instruments in the wave consortium. The combinations of probes and telemetry is shown in a schematic way in Figure 1.3.1.6.1. (cf ESA-SP-1159 Fig 6).

The four probes can all be biased relative to the satellite, and may be operated individually either in voltage mode or current mode, see Figure 1.3.1.6.1. (ESA-SP Fig 6). When operated in voltage mode, to measure the electric field, the current bias can be varied from -500 nA to +500 nA. When operated in current mode, to measure density/temperature variations, the voltage bias may be varied from -30 V to +30 V. In some combinations voltages are measured from probe to satellite and in some cases differentially between the probes.

In addition, diagnostic sweeps in either voltage mode or current mode may be performed at regular intervals. The number of voltage or current steps in each sweep is up to 256. The time for each step in a sweep may be varied between 1/150 seconds and 255/150 seconds. The time between sweeps may be varied between 32 seconds and 136 minutes in increments of 32 seconds. The start level, the bias increment, the time on each step, the time between sweeps and the sun angle at the start of a sweep can be controlled by commands. Sweeps can only be carried out on a pair of booms and only one pair at a time. Typical values for the sweep duration and repetition rate are 1 second and 30 minutes, respectively.

A bit in the telemetry will indicate the occurrence of the sweep. The spacecraft potential is flagged as not valid during sweeps. STAFF/PEACE will get a disturbed signal on the two probes that are sweeping.

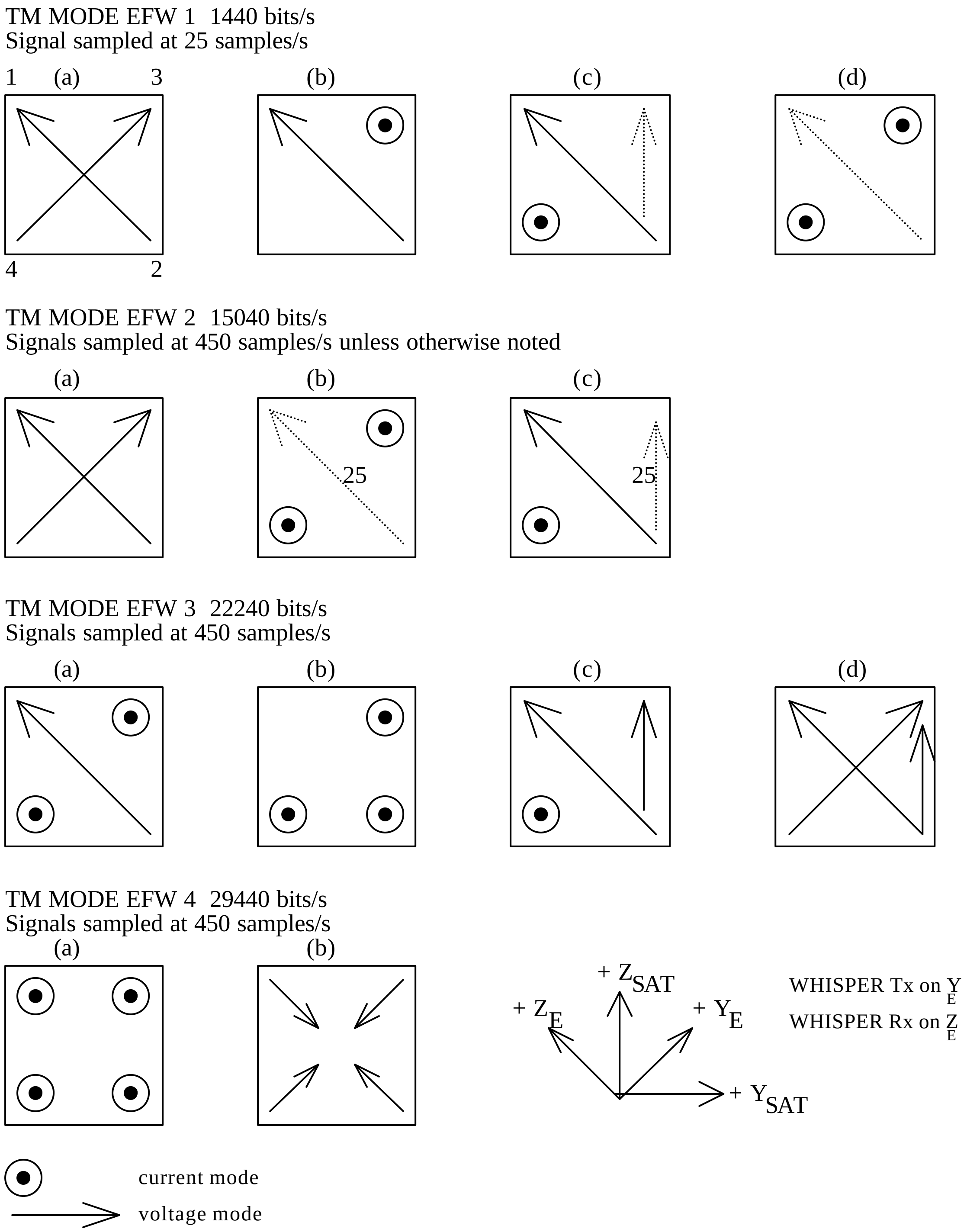
The signals from the Search Coil are also available in the EFW instrument with a bandwidth of 4 kHz, and can be sampled and stored in the internal EFW burst memory.

Each probe signal is transferred through an anti-aliasing filter and sampled by one of the two A/D converters. Low pass filters at 10 Hz, 180 Hz, 4 kHz, or about 32 kHz, or a bandpass filter for 50 Hz to 8 kHz are available. The telemetry limits the direct transmission to 10 Hz (25 samples/sec) and the transmission to the tape recorder to 180 Hz (450 samples/ sec.). Frequencies above that may be recorded with the internal burst memory. There is also a simple frequency counter and an rms detector for 10-200 kHz available to detect the plasma frequency.

Figure

1.3.1.6.1

EFW PROBE CONFIGURATION



The software and hardware has been made to accommodate the probe combinations shown in each of the boxes in the figure. The broken lines indicate that the modes imply some compromise regarding the content of the telemetry format to get sufficient place.

The data transfer from EFW to telemetry goes via DWP and can be made at four different rates 1440, 15040, 22240, or 29440 bits/s.
The main probe combinations for each of the EFW data modes are shown in Figure 1.3.1.6.1. (ESA-SP1159 fig 6). Each square of the figure shows one combination of probes for a particular data transmission rate, shown as one row . As an example, mode EFW1a corresponds to two perpendicular vector measurements of the electric field giving a total data rate of 1440 bits/sec.. After gaining experience with the instrument in orbit the number of combinations may be reduced. There is also a possibility, not shown in Figure 1.3.1.6.1. , to measure two parallel electric field vectors separated in space in mode EFW2a.

EFW carries out onboard estimates of the spacecraft potential that are sent to DWP for distribution to other instruments. For this calculation at least two probes operated in the voltage mode are required which is not the case when 3 or 4 probes are operated in current mode. EFW also has the capability to make onboard preliminary estimates of the DC electric field by means of spin fit calculations.

The EFW internal memory storage will be used to register signals from the filters with frequencies 0-4 kHz, 50 Hz to 8 kHz and 0-32 kHz, as data from these frequencies cannot be transmitted in real time due to telemetry limitations. The 4, 8, and 32 kHz signals are sampled at 9, 18, 36 ksamples/s, respectively and stored in the internal memory. The triggering of the internal memory can be made by ground commands or by an internal algorithm based on EFW data or on flux gate magnetometer data via DWP.

1.3.2 STAFF instrumentation

The STAFF experiment comprises two main parts, the measurement of the magnetic components of the waves up to 4 kHz by means of three orthogonal search coil sensors, and onboard data handling, which consists in transmitting the 3 magnetic wave forms up to either 10 Hz or 180 Hz on the one hand, and the calculation of the 25 coefficients of the spectral matrix (2 x E + 3 x B) up to 4 kHz on the other hand. The share of task inside STAFF is given in table 1 of ESA SP-1159.

1.3.2.1 The search coil sensors and the preamplifier

Three orthogonal sensors are mounted on a rigid boom away from the spacecraft body (see ESA-SP1159 Fig 4). Two sensors, By and Bz, are in the spin plane, while the third one is parallel to the spacecraft spin axis. Each sensor consists of a high permeability core embedded inside two solenoids. The main winding has a very large number of turns, its resonant frequency is within the expected 3 dB bandwidth. The frequency response of the main winding is flattened by a secondary winding through a flux feedback effect, in the frequency range 40-4000 Hz. Furthermore, the secondary winding is used as a calibration loop on which an external ac signal is applied through a calibration network included in the preamplifiers. The transfer function and the experiment sensitivity are given in figure 5 of ESA-SP1159.

The 3 channel preamplifier unit is located on the spacecraft deck. The low power consumption preamplifiers have a low noise input stage and high input impedance since they are connected to the magnetic sensors which are characterised by a low DC resistance and a very high impedance in the vicinity of the resonant frequency. The dynamic range of the preamplifiers is about 100 dB, which allows to withstand the large voltage signals induced by the rotation of the spacecraft in the DC magnetic field, as well as the weak signals to be measured. A new preamplifier using hybrid technology has been developed that has been flown for the first time on CASSINI. This technique has the advantage to include protections against radiations, together with the possibility of a thermal control of the preamplifier (when located outside the spacecraft body, which is not the case of Cluster II). Moreover, these preamplifiers are lighter than traditional ones.

The output signals of the magnetic preamplifiers are sent to:

(i) the magnetic waveform unit for analysis up to 180 Hz,
(ii) the spectrum analyser up to 4 kHz,
(iii) the Wide Band Data unit, also up to 4 kHz,
(iv) the EFW experiment for the fast event detector,
(v) it has also been requested by the Electron Drift Experiment (EDI).

1.3.2.2 The magnetic wave form unit

The magnetic wave form unit is made of three sections in order to fulfil different filtering and wave form digitalisation, output interface and onboard calibration.

The three magnetic components Bx, By, Bz, at the output of the search coil preamplifier are filtered simultaneously in either of the two bandwidths 0-10 Hz and 0-180 Hz.

The low pass filters are 7th order. They are specified with an accuracy of 1% in amplitude and 1 degree in absolute phase. The sampling frequency is equal to 2.5 times the 3dB point frequency of the filters. So, the rejection of the aliasing components is at least 40 dB. The filters are the same as those used in the E-field experiment in order to improve the E/B correlation.

The filtered signals are applied, after the selection of the bandwidth, to three sampling and hold devices synchronised by DWP, then digitalised and sent to the DWP experiment. The same synchronisation signal is sent to EFW. The selection between the two bandwidths is made by the DWP DPU according to the telemetry rate. The filtered signals are simultaneously sampled in a large dynamic range within a very short sampling time of about 10 microseconds in order to guarantee a relative error less than one degree at 180 Hz between the three components. The sampling signal, provided by DWP, is common between STAFF and EFW experiment to allow the best simultaneous analysis of the 5 available components of the electromagnetic waves.

Then the samples are digitised by a real 16 bit analogue to digital converter and transmitted to the DWP experiment through one parallel interface.

The advantage of a digitalisation at 16 bit consists in the simultaneous analysis of natural waves of a few pT Hz-1/2 and the large signal induced by the rotation of the spacecraft in the environmental DC field, up to 100 nT at 0.25 Hz. With such a dynamic, there is no trouble shoot to expect at the inversion of the DC magnetic field at the magnetopause.

Due to the telemetry limitation, a reduction of the dynamic data range from 16 to 12 bits is performed inside DWP. The principle is to transmit at the beginning of each telemetry packet the full 16 bits word, and then the difference between the successive samples, coded on 12 bits in such a way that the dynamic of the experiment should be preserved even at boundary crossings. Conservative back up solutions can be selected by telecommand, being either a more crude compression, or no compression at all.

The output interface unit distributes the analogue magnetic signals Bx, By and Bz to the other customers of the Wave Consortium and to EDI experiment, over the 4 kHz range of the search coils.

1.3.2.3 The spectrum analyser

The spectrum analyser is designed to perform the complete auto and cross correlation matrix of 5 sensor channels over a frequency range of more than 9 octaves at a high rate.

The "front-end" of the analyser is analogue. It consists of 15 variable-gain amplifiers and 15 anti-aliasing filters. The analysis band of 8 - 4000 Hz is divided into 3 logarithmically distributed frequency sub-bands, each with the maximum frequency 8 times the minimum frequency. For each of the 3 sub-bands and for each of the 5 sensor channels there is separate band pass filtering. For each sub-band there are 3 controlled-gain amplifiers (AGC): one for Bx channel and one for each couple of spinning components (By, B and Ey, Ez respectively). The AGC amplifiers normalise the output signals to an optimum level for digitisation. For spin-plane sensors (Ey, Ez, By, Bz) the total power from the 2 sensors is used for the normalisation because the sensor outputs will have to be "de-spin" later (see below).

The dynamic range of the normalisation is 80 dB, which, combined with the 45-50 dB dynamic range of the digital processing, gives a total instrument dynamic range of the order of 120 dB. Separate high-pass and low-pass filters insure that the gain normalisation is only performed for signal components with frequencies within the sub-band which will be further analysed digitally, and more important, will prevent "aliasing", i.e. unwanted contribution from frequency components above the Nyquist frequency (sample frequency/2).

The 15 amplifier outputs are multiplexed together to a single 8-bit flash A/D converter. They are digitised in a rapid-fire mode by groups of 5 or 10, as needed at a 16 kHz rate. The 9 AGC gain-control signals are digitised separately to be included in the telemetry packets, as a multiplicative factor for the results of the subsequent digital filtering.

For digital processing see section 1.4.2

1.3.2.4 In flight calibration

One sequence of calibration can be commanded by the DWP to calibrate in flight the STAFF experiment (the magnetic wave sensors, the wave form unit and the spectrum analyser), either at normal bit rate or at high bit rate.

STAFF calibrations will take place, once per orbit, at the beginning of data collection periods. The duration of the calibration sequence is about 6 minutes at normal bit rate and 2 minutes at high bit rate.

Two kinds of calibration signals are generated in the magnetic wave form unit: a sinusoidal signal at about 7 Hz and 100 Hz. and a pseudo random noise signal covering 4 kHz bandwidth. Eight different steps in amplitude are available to cover a 80 dB range. The calibration signal called REF is transmitted in the telemetry packets, together with the signals coming from the output of the STAFF analysers. It is used as a reference signal for the phase measurements between the different channels. It permits to identify the origin of an anomally and thus to recalibrate the experiment.

1.3.2.5 Operational modes

Different operational modes are foreseen, mainly depending on the bit rate. A short description of these modes, for both the waveform and the spectrum analyser is given below. For more details, see the tables below (ESA-SP1159, Tables 3 and 4). The STAFF mode are commanded by DWP. The STAFF modes are part of the WEC modes that are monitored by DWP.

NORMAL MODE 1: NM1 (3 x B + 2 x E), secondary power = 1.75 W

Band	AUTO resolution	b/s	CROSS resolution	b/s	AGC resolution	b/s
A: 8-64 Hz	1.s	360	4.s	180	1.s	24
B: 64-512 Hz	1.s	360	4.s	180	1.s	24
C: 512-4096 Hz	1.s	360	4.s	180	1.s	24

Table 1.3.2.1 Total: 1696 bps (including status)

NORMAL MODES 1': NM1'b (3 x B) or NM1'e (2 x E + Bx), secondary power = 1.75 W

Band	AUTO resolution	b/s	CROSS resolution	b/s	AGC resolution	b/s
A: 8-64 Hz	1.s	216	4.s	54	1.s	16
B: 64-512 Hz	1.s	216	4.s	54	1.s	16
C: 512-4096 Hz	1.s	216	4.s	54	1.s	16

Table 1.3.2.2 Total: 864 bps (including status)

NORMAL MODES 2: NM2 b (3 x B) or NM2 e (2 x E + Bx), secondary power = 1.75 W

Band	AUTO resolution	b/s	CROSS resolution	b/s	AGC resolution	b/s
A: 8-64 Hz	1.s	216	4.s	216	1.s	16
B: 64-512 Hz	0.5s	432	4.s	216	0.5s	32
C: 512-4096 Hz	0.5s	432	4.s	216	0.5s	32

NOTE: The low power mode no longer exists. It is an ECR agreed by the project. But normal mode 2 still exists.

Table 1.3.2.3 Total: 1840 bps (including status)

SPECIAL MODE: SM (3 x B + 2 x E), secondary power = 1.75 W

Band	AUTO resolution	b/s	CROSS resolution	b/s	AGC resolution	b/s
A: 8-64 Hz	1.s	360	2.s	360	1.s	24
B: 64-512 Hz	0.5s	720	2.s	360	0.5s	48
C: 512-4096 Hz	0.5s	720	2.s	360	0.5s	48

Table 1.3.2.4 Total: 3032 bps (including status)

EMERGENCY MODE: EM (3 x B + 2 x E), secondary power = 1.75 W

Band	AUTO resolution	b/s	CROSS resolution	b/s	AGC resolution	b/s
A: 8-64 Hz	2.s	180	4.s	180	2.s	12
B: 64-512 Hz	2.s	180	4.s	180	2.s	12
C: 512-4096 Hz	2.s	180	4.s	180	2.s	12

Table 1.3.2.5 Total: 1120 bps (including status)

FAST MODE 1: FM1 (3 x B + 2 x E), secondary power = 1.50 W

Band	AUTO resolution	b/s	CROSS resolution	b/s	AGC resolution	b/s
B: 64-512 Hz	0.125s	2880	1.s	720	0.125s	192
C: 512-4096 Hz	0.125s	2880	1.s	720	0.125s	192

Table 1.3.2.6 Total: 7600 bps (including status)

FAST MODE 2: FM2 (3 x B + 2 x E), secondary power = 1.50 W

Band	AUTO resolution	b/s	CROSS resolution	b/s	AGC resolution	b/s
B: 64-512 Hz	0.25s	1440	1.s	720	0.25s	96
C: 512-4096 Hz	0.25s	1440	1.s	720	0.25s	96

Table 1.3.2.7 Total: 4528 bps (including status)

FAST MODES 3: FM3 b (3 x B) or FM3 e (2 x E + Bx), secondary power = 1.5 W

Band	AUTO resolution	b/s	CROSS resolution	b/s	AGC resolution	b/s
B: 64-512 Hz	0.125s	1728	1.s	216	0.125s	128
C: 512-4096 Hz	0.125s	1728	1.s	216	0.125s	128

Table 1.3.2.8 Total: 4160 bps (including status)**- STAFF Spectrum Analyser Normal Bite Rate Operation modes**

The principle is to cover the full STAFF frequency range in all modes, but the means are different depending on the bit rate. In Normal bit rate, the wave form data cover the 0.1 - 10 Hz frequency range, whereas the Spectrum Analyser covers the frequency range 8 Hz - 4 kHz, working in its 3 frequency bands. In High bit rate, the waveform data covers the 0.1 - 180 Hz frequency range, then in order to spare telemetry, the Spectrum Analyser only operates in its 2 upper frequency bands, from 64 Hz to 4 kHz.

For the waveform data, 2 combinations of commands can be sent, one is the sampling frequency rate which is a STAFF command, the other is the application or not of a compression algorithm. This is an application software in the DWP experiment. The sampling frequency is either 25 Hz, with the 10 Hz low pass filter, in normal bit rate, or, 450 Hz, with the 180 Hz filter in high bit rate. One constraint is that STAFF and EFW must use the same sampling frequency as they are synchronised by DWP.

The STAFF waveform words are 16 bits. Normally, due to telemetry limitations, DWP applies a compression algorithm to get 12 bits words (giving 912 bits per second). In emergency mode the 16 bit words are telemetered (see tables above), ESA-SP1159 table 2). The principle is the same in high bit rate; with compression the needed telemetry is then 16320 bps.

Mode	Bit rate	Compression	b/s
NM	Normal	Yes (12 bits)	928
BM	High Bit Rate	Yes (12 bits)	16480
EM NBR	Normal	No (16 bits)	1216
EMHBR	High Bit Rate	No (16 bits)	21760

Table 1.3.2.9 - STAFF Wave Form data Modes (Search Coil)

For the Spectrum Analyser, the different modes are the combination of 3 parameters, the time resolution, the number of frequencies computed, the number of wave components considered. Then each mode is a combination of these different parameters. The modes are defined to fulfil different scientific objectives, in the framework of two constraints, first the telemetry limitation, second the total WEC power limitation.

The "Normal Mode 1" is the basic mode in normal bit rate. The auto-spectra are averaged over 1s, and the complete matrix over 4s for 5 components (25 coefficients). The other modes are variations of this.

In Normal Mode 1', the calculation is performed for only 3 components, either 3 x B or Bx and 2x E (NM1'e). Only 9 elements of the spectral matrix are computed (instead of 25). This mode is used in time sharing with NM1, during active Whisper modes. It allows saving telemetry.

In the Normal Modes 2, three of the five wave components are selected. The time resolution is 0.5 or 1s for the auto spectra and 1s for the cross spectra. Modes NM2b and NM2e are used in time sharing.

In the Special Mode the time resolution is improved.

In the Emergency Mode, the 5 components are taken into account, with a lower time resolution, 2 and 4 seconds for the auto and cross spectra respectively. This reduction in time resolution, and thus in telemetry is intended to compensate for the increase due to the non compression of the wave form data.

In high bit rate, only the 2 highest frequency bands are analysed. In the Fast Modes the time resolution is 1s for the cross spectra and either 0.125 s or 0.25s for the auto spectra. Here again 5 or 3 components can be considered (see table 13.2/4, ESA-SP1159 table 4). The different constraints, telemetry, Whisper active and low power are considered in the choice of the modes.

The calibration mode calibrates both parts of the experiment. The different SA modes are tested during this sequence. Operation of the calibration mode is expected to be no more than once a day, but rather once per orbit and preferentially at the beginning of a data acquisition sequence.

1.3.3 WHISPER instrumentation

1.3.3.1 Principle of the measurements

The WHISPER experiment is part of a package, the Wave Experiment Consortium, or WEC, which investigates in a comprehensive way the characteristics of waves and related quantities relevant to the CLUSTER II mission. Inside this package, the WHISPER instrument ensures two specific functions:

1/ the measurement of the total density through the identification of the plasma frequency,
2/ the continuous survey of the natural noise recorded by the electrical sensors in the high frequency range, from 4 to 80 kHz.

The method chosen, a relaxation sounder including a spectrum analyser, is an experienced one. Its principle is the active triggering of plasma resonances via the transmission in the plasma of a short pulse of sine wave, and the listening of the electric field present in the medium, following the transmission period. Plasma resonances are identified if the received signal displays peaks which are not present in the passive level preceding the pulse transmission, and which decay with time. The analysis of their frequency position provides the absolute value of the total electron density. Natural wave measurements are recorded in parallel or in the absence of active sounding. The extensive use of digital techniques permits to meet the specific constraints of CLUSTER II, notably a time resolution (of the order of a second) sufficient to observe the main plasma boundaries, including the transition region, within limited TM rate allocations.

1.3.3.2 Instrumentation

The relaxation sounder instrument on CLUSTER II consists of three main parts:

(i) a sensitive double sphere antenna, measuring the AC electric field. This device is part of the Electric Field Wave (EFW) Experiment. From the WHISPER view point, it is a passive system;

(ii) a transmitter, a receiver, a digital spectrum analyser and a controller unit, which forms the WHISPER experiment stricto sensu;

(iii) commands and data processing systems, which are part of the Data Wave Processing (DWP) Experiment.

The last-mentioned device also takes care of the control of telecommand and telemetry for the entire WEC unit. The block diagram of the electronic boards is detailed in Figure 1.3.3.2.1 (ESA-SP1159 Fig WHI1).

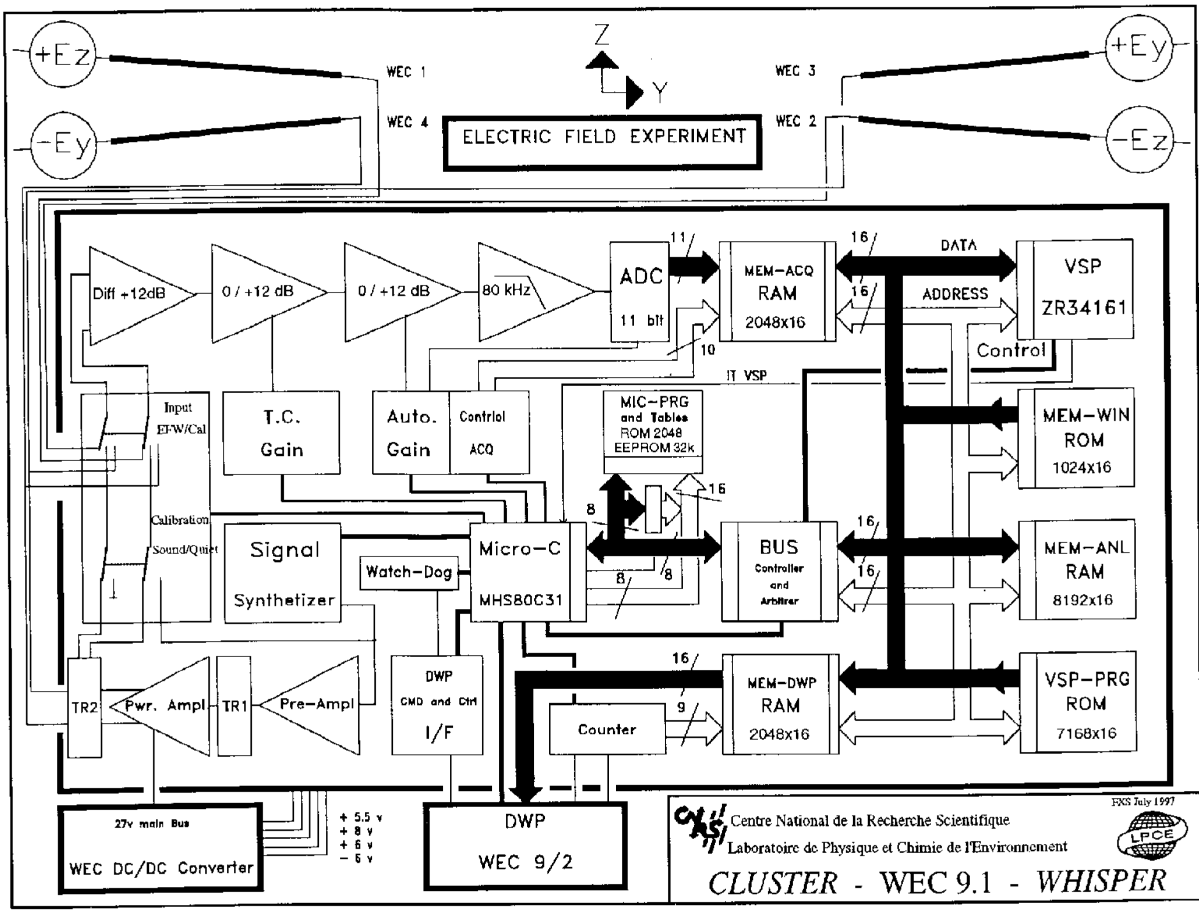


Figure 1.3.3.2.1

The transmitter is connected to the shields of one electric wire boom pair, Ey, through the EFW experiment module. For the measurement of natural noise only (natural modes), it stays inactivated. In sounding modes, a pulse of sine waves is transmitted during 1 ms (or 0.5 ms) inside a blanking period of 3 ms at a frequency set by the micro controller in the range from 4 kHz to 80 kHz, according to a command word transmitted via DWP. This corresponds, in the frequency domain, to a slice of 1 kHz (or 2 kHz) where eventual resonances can be triggered. The total frequency range, adjustable, will be covered by a number of frequency steps of equal duration. A step is formed by the transmitting period and a longer listening period. Different levels can be selected e.g.: 50, 100, 200 volts peak to peak. The WHISPER transmitter should not cause interference either directly or by varying the spacecraft potential. This has been tested on the ground but will require further tests in orbit. The sequencing of WHISPER transmissions is insured by the blanking signal transmitted to WHISPER by DWP. In particular, the synchronisation with EFW sampling is always achieved. The period of the blanking signal is usually a multiple of 13.33 ms, the duration of the basic time structure of WHISPER internal operations. In special modes, the blanking signal is spin synchronised, for a better cohabitation with the particle instruments in their low energy range.

The receiver is connected to one of the double sphere dipole probes, Ez or Ey, through the electric field module, and is operated after the transmission of the pulse on Ey braids (the receiver is inhibited during the pulse). The signal is measured on each of the 13.33ms time structure, with a sensitivity better than 5 $nVrms.m^{-1}.Hz^{-1/2}$. It is amplified by a stepped gain amplifier with three 12 dB steps. The gain will be fixed or automatically adjusted, by telecommand. The automatic adjustment selects one of two consecutive stepped gains. It responds to the characteristics (number of overflows) of a short sampling taken before the real acquisition, placed in the second part of the time structure. After an analogue to digital (A/D) conversion, the signal is analysed in frequency. The device used is a Zoran Vector Signal Processor (VSP) which performs an FFT, and delivers 64 to 512 useful bins (amplitudes in 16 bit words) in the range 0-80 kHz. The 512 bins option is always chosen in sounding modes, which require a good frequency resolution. The A/D converter and VSP combination yields to an absolute dynamic range larger than 80 dB (90 dB at best) for the 512 bins FFT option. The spacing between two frequency bins is then 160 Hz. However the actual measurable frequency separation is of about 320 Hz, since windowing of the time signal is necessary. The chosen window (Blackmann-Harris) leads to an actual 70 dB dynamic range between the highest spike of the spectrum and the level of the lowest measurable signal located 2.5 bins apart. The total duration of the basic operations cover three time structures of 13.33 ms: one for the acquisition, one for the FFT calculation, one for the transfer of FFT frames to DWP. The details of operations are managed by the micro controller.

1.3.3.3 Output of the WHISPER instrument

The data output from the VSP analyser, a frame of 64 to 512 words of 16 bits, are organised by WHISPER in such a way that the lowest frequency bins, non significant owing to the filtering in the band 2-80 kHz, are overwritten by status information and by the energy (of time samples) data.

1.3.3.4 Operational modes

(see 1.4.3 for description of on-board data processing)

A given WHISPER operational mode is defined by two pieces of telecommand information, which transit through DWP: the WHISPER command word (WCMW), and the WHISPER processing word (WPW). The WCMW completely defines the operations internal to the WHISPER module. It is partly decoded by DWP, which needs the information concerning the sequencing it has to operate, the FFT size defining the size of WHISPER output frame, and the instrument responsible of on-board data compression, WHISPER or DWP. The WCMW is passed to the WHISPER module, which takes the required configuration and operates in sequence with the transmitted DWP clocks: the 13.33 ms period clock and the blanking pulse. The WPW is used only by DWP. It defines the application options this instrument has to apply, if it is in charge of the on-board data compression.

The WCMW defines the following adjustable parameters:

- mode, i.e. natural, sounding, calibration, contingency or troubleshooting;
- FFT size;
- step duration (sounding mode), alternatively the number of FFT frames to accumulate (natural mode);
- instrument for data compression (DWP or WHISPER);
- pulse characteristics, duration and level;
- gain characteristics (fixed or automatic, threshold for the automatic gain change);
- Whisper receiver connected antennae (Ez or Ey);
- frequency table, applicable in sounding mode;
- a repetition factor, indicating the number of the cycles defined above to be repeated to form a mode.

The frequency table parameter defines the bottom frequency and the size of the range to explore. It allows the micro controller to compute the frequencies it needs for driving the synthesiser. It is interpreted differently according to the pulse-duration value (40 frequency values are needed with a pulse 0.5 ms wide, when 80 values are needed with a pulse 1 ms wide). A few fixed tables, for which the pulse duration command is ignored, are stored in the micro controller memory. They divide the frequency domain into two ranges. The transmission pulses are 0.5 ms wide in the high-frequency range (where the resonances are thought to need less energy to be triggered) and 1 ms wide in the low-frequency range.

The WCMW defines completely the duration of a WHISPER mode. In natural mode, this duration is mainly a multiple of 13.33 ms by the number of accumulated spectra and the repetition factor. In sounding modes, it is the step duration by the number of steps and the repetition factor. Additional time has to be included for the set-up phase in both cases. Moreover, some margin has to be included in sounding modes at the end of each sweep, for DWP to do the requested calculations without loosing any useful WHISPER frames.

The WHISPER processing word (WPW) is applicable for three options of the WCMW 'mode' parameter: natural, sounding, and gliding, a special mode which alternates short sounding sweeps and natural modes in spin synchronisation. The WPW word, has to be interpreted differently according to the WCMW 'mode' parameter. In all cases, the WPW defines the characteristics of the quasi-logarithmic word compression: fixed or dynamic level range, 6 or 8 bits per word. In natural modes, the additional adjustable parameters are the energy averaging option, and the rate of selection of the spectra included in the TM flow. In sounding modes, the additional adjustable parameters define the strategy of compression: bin-selection rate, passive-bin reduction, presence of active-to-passive ratios. In gliding mode, the WPW contains one byte defining the processing of the sounding mode part of the operations; the other byte completes the definition for the processing of the natural mode part.

The WPW option, combined with the WCMW option, defines completely the volume of data output from a WHISPER mode. Examples of typical resulting TM rates are given in tables below. (cf ESA-SP1159 Fig. WHI2).

The natural modes are based on 3 durations in time: 25, 100 ,and 13s for respectively the WEL1, WEL2 and WEL3 elements. (An element is defined as any mode of the same type, natural or sounding, of a given duration). The option (letter indication) inside the element corresponds mainly to:

(i) different choices in FFTs, leading to different frequency resolutions;
(ii) the size of the words (bpw, for bit per word);
(iii)options in the accumulation and selection of spectra, leading to different time resolutions and TM rates.

As explained above, the frequency bin separation goes from 160 Hz for the 512-bin FFT option, to 640 Hz for the 128-bin FFT option. The achievable frequency resolution is twice these figures.

The sounding-mode elements are of different types. WEL4 and WEL5, which are intended to give punctual density measurements, are installed in the two main WEC time structures, of respective basic durations 28 and 104s. Two consecutive active sweeps are run, for redundancy. These elements will be used in conjunction with natural-mode elements, completing the WEC mode sequence. WEL6 and WEL7 elements operate continuous density measurements, respectively under HBR (high bit rate) and NBR (normal bit rate) TM conditions. Passive information, reduced or complete, taken during the active sweeps must be filed to the TM flow for those elements. The WEL8 element corresponds to spin synchronised transmissions, 32 times per spin in standard functioning, which is the recurrence of particle energy sweeps. The WEL10 element is the gliding mode, also spin synchronised.

Element	Duration	FFT	bpw	Δt (s)	TM rate (bps)
WEL1-a	25	256	6	2.15	813
WEL1-b		256	6	0.32	5721
WEL1-c		256	6	0.65	3337
WEL1-d		512	8	1.30	3076
WEL1-e		256	6	0.85	1875
WEL1-f		512	8	0.65	6265
WEL1-g		128	6	0.107	8761
WEL1-h		512	6	0.107	28806
WEL1-i		256		0.32	5721
WEL2-a	100	256	6	2.6	631
WEL2-b		512	8	2.6	1567
WEL2-c		256	8	3.41	608
WEL2-d		256	8	2.6	818
WEL3-a	13	512	6	0.43	6820
WEL3-c		256		0.107	6382
WEL3-d		128		0.107	6633

Table 1.3.3.1 - WHISPER NATURAL MODES

Element	Duration (s)	Steps/sweep	step duration (ms)	Frequency range	bpw-bin selection	Passive	Δt (s)	TM rate (bps)
WEL4-a	3	52	26	4-80 kHz	8-1/2	reduced	1.5	2283
WEL4-b		52	26	4-80 kHz	8	full	1.5	5195
WEL4-		32	40	4-80 kHz	8	reduced	1.5	2080
WEL4-		32	40	4-80 kHz	8	full	1.5	2891
WEL5-a	4	71	26	4-70 kHz	8-1/2	reduced	2.	1544
WEL5-b					8	reduced	2.	2064
WEL5-c					6-1/2	absent	2.	1032
WEL5-d					8	full	2.	3480
WEL6-a	185	52	16	4-80 kHz	8	full	1.44	5392
WEL7-a	104	79	40	4-80 kHz	8	reduced	3.25	1408
WEL7-b					6-1/2	reduced	3.25	852
WEL8-a	516	32	125	4-68 kHz	8	reduced	4.	936
WEL8-c					6-1/2	reduced	4.	564
WEL8-d					6	reduced	4.	708
WEL10	580	32	13	4-68 kHz	8	full	4.5	4452

Table 1.3.3.2 - WHISPER SOUNDING MODES

1.3.3.5 Output of the instrument:

see section 1.4.3.2, on-board processing software.

1.3.4 WBD Instrumentation

1.3.4.1 General Description

A simplified block diagram of the WBD design is provided in Figure 3 of ESA-SP. The instrument processes signals from one of four sensors which can be chosen via an antenna selection switch located at the receiver input. The four selectable inputs consist of two electric field signals, and two magnetic field signals. These inputs are provided by the electric field (EFW) and magnetic field (STAFF) experiments.

In the WBD design, input bandpass filters limit the incoming signal to one of four possible frequency bands ranging from baseband to 500 kHz. The band-limited signal then goes to a single-sideband frequency conversion stage which determines the range of frequencies to be received. Under this scheme, the filtered input signal is mixed with conversion frequencies f and f (phase quadrature). The input signals are thereby converted to baseband with upper and lower sidebands superposed and with a phase difference of 180 degrees. A quadrature phase shift network shifts one converted signal by an additional 90° so that when the converted signals are summed, the upper sideband components add and lower sideband components cancel. The output of the conversion stage then goes to one of a set of three bandpass filters which determines the bandwidth of the output waveform. Because of the large dynamic range of the input signal, and in order to maintain a high signal-to-noise ratio for the processed signal, an incremental automatic gain control (AGC) amplifies the signal to the proper level in steps of 5 dB over a range of 0 dB to 75 dB. The output from the gain select then goes to an analogue-to-digital converter which provides 1-bit, 4-bit, or 8-bit resolution for a selection of sample rates. Finally, a format generator organises the digitised waveform data into a data frame suitable for the spacecraft telemetry system. The digitised wideband data is transferred to the spacecraft data system in either a real-time data mode at 220 kbs which requires direct acquisition by a NASA DSN ground station, or a burst-data mode at 73 kbs which provides data to the spacecraft tape recorder via the WEC data processing unit (DWP). This latter mode provides the capability for acquiring data when the spacecraft cannot be tracked by a DSN station, and also provides capability for collecting data from more than one spacecraft at a time. Commanding of the WBD instrument is managed by the DWP. A summary of WBD instrument parameters is given in Table 2 of ESA-SP. Individual aspects of the wideband receiver system are discussed in detail in the following sections.

1.3.4.2 Sensors and Sensor Interfaces

The Cluster II plasma wave sensors consist of two orthogonal spherical electric antennas located in the spin plane of the spacecraft, and a triaxial search coil magnetometer oriented with two measurement axes in the spin plane and the third measurement axis oriented parallel to the spacecraft spin axis. The electric antennas, designated E^y and Ez, are provided by the EFW investigation and, after full deployment, have sphere-to-sphere separations of about 100 m. The spheres each contain a high-impedance preamplifier which provides signals to the EFW main electronics, and to WBD and other wave instruments via buffer amplifiers. The EFW/WBD buffer amplifier is a low-noise, low-power design which meets WBD frequency/amplitude response requirements, particularly the need to maintain a flat response up to about 600 kHz. The three orthogonal search coils (Bx, By, and Bz) are part of the STAFF instrumentation, and provide magnetic field signals up to 4 kHz.

The WBD instrument has the capability of processing signals from one of four sensors which may be selected by spacecraft command. Under the control of DWP, WBD can be switched to either the Ey or Ez sensor, to a spin-plane search coil (By), or to the spin-axis search coil (Bx).

1.3.4.3 Frequency Bands

The input frequency range of the wideband receiver can be shifted by a frequency converter to any one of four frequency ranges, where the conversion frequency f determines the lower edge of the frequency range to be received. The conversion frequency is obtained by dividing a 14-MHz reference oscillator. To maintain phase stability in the entire system, this internal oscillator is synchronised to a 220.752 kHz high frequency clock, which is the spacecraft's Ultra Stable Oscillator (USO) divided by 38.

A spacecraft command to select a particular frequency band causes DWP to switch the wideband receiver to the appropriate input bandpass filter and to select conversion frequencies of 0, 125, 250, or 500 kHz. If baseband (f=0) is selected, the mixing stage is bypassed so that the signal is routed directly to the output bandpass stage with no frequency conversion.

The bandwidth of the WBD instrument's output waveform is determined by one of three bandpass filters selected in combination with a given output mode. Conversion frequencies and bandpass filter ranges are summarised in Table 2 of ESA-SP1159.

1.3.4.4 Gain Control

The gain select of the wideband receiver employs a set of dual-gain amplifiers which may be selected to provide gain control in increments of 5 dB. This programmable amplifier stage consists of amplifiers having gains of 0/5 dB, 0/10 dB, 0/20 dB, and 0/40 dB.

In manual gain select mode, the total receiver gain can be set to one of the sixteen levels (from 0 dB to 75 dB) by the appropriate spacecraft command.

Additionally, WBD has the capability of auto-ranging through the gain steps. The auto-ranging mode is enabled by command and allows the instrument to automatically manage large changes in signal intensity. In this operational mode, the output from the programmable amplifier is compared to a pair of reference amplitudes. If the criteria for changing the gain are met, the gain state is either increased by one step (5 dB) or decreased by one step, accordingly. In order to avoid excessive toggling between gain steps, a commandable threshold must be exceeded, thereby introducing hysteresis in the AGC control loop. The gain is updated (if required) at a rate determined by the gain update clock, which is a DWP function selected by spacecraft command. The period of the clock is programmable from 0.1 to 10 seconds in increments of 0.1 second. The actual gain change takes place at the beginning of the next WBD major frame.

1.3.4.5 A/D Converter and Format Generator

The output analogue waveform is sampled by an 8-bit analogue to digital converter which provides the sampling resolution and data output rates listed in Table 3 of ESA-SP1159.

For sample rates where the bit rate exceeds the spacecraft telemetry data rate (220 kbits/sec), the digitised wideband data is buffered by the format generator and read out at a reduced average bit rate of 220 kbits/sec. The format generator organises the digitised waveform data into a 1096-byte output frame, which includes appropriate timing and status information.

1.3.4.6 WBD Data

Interfaces The WBD instrument utilises two separate paths for transferring frames of digitised data to the spacecraft data handling system. The primary path supports real-time acquisition of WBD data by the NASA DSN. The second data path supports burst data acquisition via an onboard tape recorder.

Real-Time Data Acquisition

A special serial data interface between the WEC (originating at WBD) and the spacecraft's Central Data Management Unit (CDMU) supplies the primary path for data from the WBD instrument. Interface functions consisting of 220 kHz sampling clock, timing pulse, and data output are redundantly implemented. Data are present on this interface (at 220 kbs) whenever WBD is powered. During real-time data acquisition, the WBD data appears on a dedicated virtual telemetry channel (VC5), embedded in the 1096-byte data field of the standard 1279-byte transfer frame. The WBD transfer frames are acquired by a DSN receiving station.

Burst Data Acquisition

A second path for WBD data is provided by a serial interface between WBD and DWP. This interface supports a special burst mode (BM2) dedicated to WBD. When the BM2 operational mode is enabled, WBD data are transferred to DWP at 220 kbs, and the DWP, in turn, reduces the wideband data by a factor of three either by digital filtering or duty cycling (accepting only one out of three frames). At the new average bit rate of 73 kbs, the WBD data are transferred to the OBDH system for recording and subsequent playback.

1.3.5 DWP Instrumentation

The scientific data generated by DWP (as opposed to the data handled and processed by DWP) come from a particle correlator. This takes a data input from the PEACE instrument via the IEL and performs correlations as described in ESA SP-1159. The correlator studies the regions of electron phase space in which there are significant frequencies present as an indicator of wave-particle interactions.

The basic architecture of the DWP is shown in Figure 3 of ESA-SP1159. Each of the WEC instruments is provided with a dedicated interface to the common instrument bus. A redundant interface to the spacecraft on-board data handling (OBDH) system is also included. Three processor modules are provided, interconnected by links to provide inter-process communications and interfaced to the instrument bus to provide for instrument and spacecraft communication.

The Engineering Model is shown in a semi-assembled form in Figure 4 of ESA-SP1159. In this photograph the pcb's are attached to a backplane for testing out of their mechanical housing. Table 2 of ESA-SP1159 gives an approximate mass breakdown and outline specification of the DWP.

1.3.5.1 The processor module

A T225 transputer with 32 Kbytes of external RAM (the internal memory is disabled to provide increased radiation tolerance) and 32 Kbytes of PROM forms the core of each module. In addition each has a HS82C37A DMA controller, event multiplexer and instrument bus interface. A 16-bit transputer is the microprocessor of choice rather than a 32-bit device. The main reasons for this are that fewer RAM and ROM chips are accessed in one cycle, thus reducing power consumption, and most instruments use a 16-bit data length. A programme of test irradiation of the T225 transputer was carried out using the facilities at ESTEC. The results established the viability of the T225 for the Cluster II mission.

Power-down circuitry enables processor modules to be switched off to conserve power. Series resistors or tri-state buffers are employed to ensure that the inputs of powered-down circuits are not driven. Processor modules are powered down by a hardware decoded command from the OBDH interface.

The design of the DWP allows the transputers to be operated at input clock frequencies of 2.5 or 5 MHz, the lower rate requiring less power. The clock frequency select signal is applied to the transputer link speed input (as well as to the clock divider) in such a way that the links always operate at the standard speed of 10 Mbits/s. This allows processor modules operating at different speeds to communicate. Speed selection is made by hardware command from the OBDH interface.

1.3.5.2 The instrument bus and interfaces

The instrument bus allows 16-bit parallel communication between the processor modules and the instrument interfaces. Events and DMA transfers are also requested over this bus. Only one transputer (chosen at boot time) is allowed access to the instrument bus. This removes the requirement for any complex instrument bus arbitration logic. However, simple logic is provided to prevent damage to DWP if, owing to some fault, more than one processor does try to drive the instrument bus simultaneously.

A variety of interfaces are used to control and obtain data from the instruments of the wave consortium. Interfaces with a relatively low data rate employ registers allocated one of the 16 instrument bus addresses and in some cases an event request line. High data rate interfaces use the DMA channels.

1.3.5.3 The spacecraft OBDH interface

The OBDH (on board data handling) interface contains telemetry, telecommand and service signal circuitry, duplicated for telemetry and telecommand to provide redundancy in case of failure. The telemetry interface is the route for all data leaving the DWP. A DMA channel is used to provide high data throughput. Data may be output on either of the redundant interfaces, as requested by the spacecraft OBDH.

The telecommand interface enables the DWP software to receive commands from the spacecraft OBDH. Separate command registers and interrupt request lines are assigned to the two redundant parts of this interface. An extension of this interface (hardware commands) allows the OBDH to directly command parts of the DWP hardware without software intervention (processor speed and power on/off).

1.3.5.4 Watchdog timer

Watchdog timer hardware is interfaced to the instrument bus. The kernel process should signal the watchdog at regular intervals; if it fails to do so for any reason the watchdog will reset all three processors. The reset inputs to the processor modules are edge-sensitive to ensure that DWP could still function if the watchdog failed with its output in the active state.

1.3.5.5 Particle Correlator

The scientific data generated by DWP (as opposed to the data handled and processed by DWP) comes from the particle correlator. The DWP particle correlator detects modulations and short time particle bursts in the electron population as an indicator of wave-particle interactions. The modulation amplitude is measured as a function of the wave frequency and electron energy . The particle correlator takes input from the Cluster PEACE HEEA electron sensor via the PEACE-to-DWP Inter Experiment Link (IEL). The detection technique used is to construct ACFs (Auto Correlation Functions, which maintain frequency information but remove phase information) from a time series of electron counts measured over a particular correlator energy band by the PEACE HEEA electron instrument. The ACFs are constructed in 1 of 15 correlator electron energy bands which correspond to either two or four PEACE energy levels. The actual energy range of the correlator energy bands 1-15 in units of eV corresponds to that scanned by the PEACE HEEA

detector which is determined by the PEACE-HEEA instrument energy preset value and sweep mode. Constraints of processing and WEC telemetry allows
ACFs for only 2 of the possible 15 energy bands to be processed at any particular time. One of these energy bands is pre-selected while the other available band steps through the remaining 14 energies.

Individual ACFs are constructed within separate 1.111 millisecond DWP clock cycles. The time series of electron counts is of duration 732 microseconds and comprises 61 “count bins” of 12 microsecond duration. Each 12 microsecond count bin has an associated dead-time of approximatly 1.6 microseconds, leading to an effective count bin interval of approximately 10.4 microseconds. A basis section of the first 30 samples is shifted, multplied and summed against subsequent sections of the time series of electron counts to produce the ACF amplitude at incrementing lags. The integer lag value corresponds to the shift of the 30 sample basis in units of 12 microsecond count bins. Zero to 31 lags are performed on each individual time series to produce a 32-point ACF with the following characteristics:
Frequency range: 1.4 to 41 .6 KHz in 32 frequency bands (covering typical f_{pe}, f_{ce} ranges in the magnetosphere), and DC to 4 Hz by time series of the extracted Zero – Lags.
Energy range: 0.6 eV to 26 KeV in 15 energy bands (PEACE mode dependent)
Amplitude range: “Offset and scale” compression $\Longrightarrow$ 64 bands for modulated part and DC offset (=Zero Lag) sent with full count precision.

The ACFs, for a particular energy band, are summed on board prior to transmission to the ground so as to increase the signal-to noise ratio for any modulations present and also to fit within WEC telemetry constraints. Further ACF accumulation results from the PEACE instrument performing multiple energy sweeps within a spacecraft spin. The number of ACFs summed is sent with other correlator status information (e.g. energy band number).

1.4 ON-BOARD SOFTWARE

1.4.1 EFW software

1.4.1.1 Data handling

The Cluster II EFW instrument communicates with DWP by a single 38.4 kbits/s serial link. EFW accepts commands, telemetry codes and flux gate magnetometer data (8 vectors/s) from the DWP unit, and transmits telemetry data to DWP.

The EFW software co-ordinates Real-Time sampling along with Burst (high sampling rate) data collections using an 80 element sampling buffer. The total A/D rate is 36000 sample-pairs per second which fills 450 buffers per second.

EFW software must allocate samples out of this total collection rate between real-time samples, burst samples, boom monitoring, sweep collection points, etc. The user controls how much of the samples that may be used for real-time and non-burst versus how many can be used by bursts.

There are four "sample" modes available: Normal, Split, Hx only and Null. In the Normal mode, all real-time and monitoring samples are allowed while Burst operations are limited to 9000 sample-quadruples per second.

The Split mode allows the user to push the burst data sampling to 18000 sample pairs. In this mode, the real-time samples are taken 1/18000th second apart instead of 1/36000th.

The Null mode turns off real-time and monitoring and allows the burst to take all 36000 sample-pairs, the telemetry is undefined in this case.

The Hx only mode is a variation of the Null mode. The burst data can take all 80 elements of the sampling buffer but V12 and V34 data is available to telemetry every 40 sample-quadruplets.

1.4.1.2 Telemetry Description

The EFW instrument sends telemetry data in blocks to DWP. Each of the four data rates has its own blocking format as shown in Figure 7 of ESA-SP1159. Basically, data is blocked up for transmission differently depending on the mode. In mode EFW1(1440 bits/sec), data is transferred in a single block once per second. For modes EFW2-4, 10 blocks per second are sent to DWP, making up one format

Fast digital monitor

The purpose of the Fast Digital Monitor (FDM) is to indicate relatively fast mode transitions and status of the telemetry stages. For example, playbacks of recorded data are indicated by a playback bit in the FDM. See Figure 7 of ESA-SP1159 and description below for the bit structure.

p	playback indicator 0 - off 1 - playback in progress
bbb	burst internal state 000 - off 001 - compiling list 010 - turning on 011 - searching 100 - collecting 101 - closing the file 110 - playback wait 111 - playing back
x	main/burst playback 0 - burst playback 1 - main playback
r	whisper pulses present if set
w	sweep in progress if set
c	command counter mismatch if set
ss	sampling mode 00 - NORMAL 01 - SPLIT 10 - HXONLY 11 - NULL
q	interferometric mode if set
iiiii	digital subcom index
aaaaaaaa	sun angle
eeee	voltage/current mode for each probe (4,3,2,1) 0 - voltage mode 1 - current mode
mmmm	motor on/off status for each boom unit (4,3,2,1) 0 - off 1 - on

Table 1.4.1.1

1.4.1.3 Spin fit data

The EFW instrument calculates the E-field vector by taking 32 points at equal angles and fitting a sine wave least squares fit to the data. The resulting values are represented as 3-byte floating point values.

1.4.1.4 Digital subcom data

The digital subcom data is a 256-byte table which is intended to telemeter very slow instrument status, verify commanding, etc. For each format 8 bytes of digital subcom data is sent which means that it takes 32 formats (32 seconds) to build the table.

1.4.1.5 LX data Low rate data

In the normal case this area is used for the V1L, V2L, V3L and V4L quantities sampled at 5 samples/s. Other quantities and burst playback data can also be routed through this section. All values are little endian 16-bit 2's complement numbers.

1.4.1.6 HX data High rate data

In TM mode EFW 1, this section contains 25 samples each of V12L and V34L by default. The content can be changed to other quantities and burst playback data by command. All values are little endian 16-bit 2's complement numbers.

1.4.2 STAFF Spectrum Analyser Software

The digital processing of the sampled inputs is performed in 3 distinct steps:

1/ de-spin of the spin-plane sensor outputs,
2/ determination of the complex Fourier coefficients,
3/ calculation of the correlation matrices (see Fig. 6 of ESA-SP1159).

1.4.2.1 Despin system

The de-spinning operation involves processing of the two signals received by a pair of spinning dipole or search coils to make them appear as signals received by non-rotating sensors. This transformation is necessary because the spin period is generally not long compared to the measurement times. Each time samples are taken of the spinning sensor outputs; they will undergo the following calculations:

$$Va = Vy*Cos(m) + Vz*Sin(m)$$
$$Vb = Vz*Cos(m) - Vy*Sin(m)$$

where Vy and Vz are the spinning outputs, m the instantaneous angular position of the Vy sensor, and Va and Vb the expected outputs for non-spinning antennas at m=0° and m=90°. It is foreseen that the reference for m will be the sun pulse and that m will be derived from the spin rate signals, both spacecraft-supplied on board.

1.4.2.2 Fourier Coefficients

The determination of the Fourier coefficients is performed using appropriate algorithms which are extensions of the Remez exchange algorithm. Each of the 3 sub-bands are divided into 9 logarithmically- spaced channels. The relative (3 dB) bandwidth of each is 26 %.

The required analysis times are variable, depending on the frequency sub-bands, ranging from 0.016 to 1.0 s.

1.4.2.3 Correlation matrices

The auto and cross-spectra are calculated by complex multiplication of the Fourier coefficients and accumulation of the products. The analyser stores all of the results during one measurement cycle of 4 s (in normal operating mode). 540 auto-spectral coefficients are stored. This corresponds to 5 real sensor amplitudes per frequency, 27 frequencies, and 4 sub-cycles of 1s each. The number of stored cross-spectral coefficients is 540, i.e., 20 off-diagonal matrix elements and 27 frequencies. Only one set of cross-correlation components are transmitted each 4 s in the normal mode.

All of these numbers are stored in the analyser as 40-bit numbers, representing power. Out of these 40 bits 24 are significant in the final results of the auto-spectrum calculations. They represent a dynamic range of 10*log10(2**24)=72dB. For better use of the telemetry bit rate allotment and to simplify interfaces with the DWP, the 24 bit amplitudes are log-compressed by software in the wave analyser before transfer to the DWP. The result of this compression for an amplitude Nin is

$$Nin = 2**(E-3) * (8+M)$$

where 5 bits are used to represent the exponent E and 3 bits for the mantissa M. The total possible dynamic range for this data presentation is 96 dB, while the average relative amplitude resolution is 0.38 dB.

The cross-spectral coefficients are sent to the DWP with the same compression technique. But only 4 bits will be put into the telemetry bit stream.

1.4.3 WHISPER software

1.4.3.1 Software for operating the instrument

The WHISPER instrument includes two on board software. One of them is used by the VSP for performing the calculation of:

- the energy contained in the received time samples;
- the various FFTs;
- the module of the complex bin data delivered by the FFT;
- the bin to bin accumulation of spectra when a WHISPER internaldata compression is requested, and the instrument is in natural mode.

The other software is used by the microcontroller. Its main functions are:

- to set-up the experiment according to the WHISPER command word;
- to load the needed FFT program into the VSP internal Ram;
- to generate and control the transmitted wave;
- to run a "watch dog" program against the radiation effects;
- to reshape the data output from the analyser, a table of 64 to 512 FFT words, before they are transferred to DWP. A few bins corresponding to the lowest part of the frequency range are overwritten by status words and by the energy (of time sample) data. If a WHISPER internal data compression is requested in sounding modes, the table contains the succession of active bins;
- to run the calibration modes.

Two calibrations modes with two different forms of processing are implemented in order to allow for the verification of the transfer function of both the receiver and the transmitter. The first one, called 'passive calibration' does not activate the transmitter. The inputs of the receiver are connected to the internal synthetiser. In the second one, called 'active calibration', the transmitter is running while connected to the inputs of the receiver. In both calibrations, 10 frequency values, all the gain steps and all the output levels are swept. A total of 132 steps are performed. Both calibrations can be executed with two different forms of processing:

- No processing where the 132 data frames are transmitted via DWP for ground analysis (duration 212 seconds);
- WHISPER processing (duration 0.7 second) where the result of the 132 steps are compared with an internal table. Only one frame including an error level table is transmitted. This mode can be used as a WHISPER go/no-go test mode along the integration phases.

1.4.3.2 Software for on-board processing for WHISPER

This task is performed by DWP in nominal functioning, by WHISPER with inferior performances, if a back up is needed.

Natural modes

The high compression needed is obtained in three main phases. First, the useful part of the successively available spectra (480 bins in the 512-bin FFT option) is accumulated bin by bin to form a single 'accumulated' spectrum. The energy information can optionally be treated in the same way. When it is not accumulated, this data flow provides information about the variability of high-frequency emissions, at a time resolution of 13.33 ms (up to 30 Hz in the frequency domain). In a second phase, each accumulated bin level, which comprises 32 bits of data (24 bits useful), is compressed in a quasi-logarithmic way, within a word of 6 or 8 bits. The compression may be fixed or dynamically adjusted. In the fixed compression case, the bit numbers for coding respectively an exponent part and a fraction part of a word are fixed (in the 8 bits word case, the exponent part of the word is coded on 5 bits, the fraction part on 3). The 8-bit data word option induces an uncertainty of 1 dB on the signal level (1 part over 8), which is negligible with respect to the overall uncertainty in the tranfer function (about 2.5 dB). The 6-bit data word option induces an uncertainty of 3.5 dB. In the dynamic compression case, the exponent part is adjusted to the size of the words in the treated data set, i.e. in the accumulated spectrum, in which case the uncertainty due to compression can be considerably reduced, depending of the variability of the signal over the data set. The energy information, 32 bits of data, is compressed on 8 bits according to a similar algorithm. The third phase consists simply in throwing out accumulated spectra, according to a selection factor. The status (command words, number of overflows, gain changes...), treated separately, are part of the WHISPER science data flow.

The internal WHISPER processing in natural mode reflects the first phase only: it is the bin-to-bin averaging of 8 (256-bin FFT option) or 16 (128-bin FFT option) spectra.

Sounding modes

In sounding modes, we want to measure both the 'active' bins, and the 'passive' bins. The active to passive level ratio at a given bin is an important clue for the identification of resonances. An active FFT bin is one from an FFT acquired immediately after a sounding at that bins frequency. Depending on the sounding bandwidth (1 or 2 kHz), there are either six or twelve active bins per sounding. The corresponding passive FFT bins must show the undisturbed plasma at the same frequencies. They are the ones from the FFT acquired immediately before the sounding at those bins bandwidth. This ensures that they are measured at a time which is as long as possible (one sweep duration) after the last sounding at that frequency and as near as possible (13.33 ms) to the next active data for those frequency bins.

The first phase of the processing is to sort out the 'active' and 'passive' bins. A large part of the FFT WHISPER frames is thus thrown out. A second phase of the processing is optional. It consists in grouping the bins in packets of 2 or 4 consecutive in frequency. One bin (the largest one) is selected in each group. If this option is chosen, the position of the bin in the group, and also the active-to-passive ratio, coded on 4 bits, are included in the data flow. The third phase is similar to what is done in natural mode. The active-bin levels (after selection) are compressed from a 32-bit data word to a 6- or 8-bit data word. A fourth phase is optional. It consists in the reduction of the passive information: 6 bins consecutive in frequency are accumulated. A final phase takes place when the passive information is transmitted. It consists in the same quasi-logarithmic compression of passive levels as that to which active levels are subjected. The resulting data are called the 'passive reduced' information, or simply the passive information. The status (command words, number of overflows, gain changes...) are treated separately and are included in the data flow. No energy information is transmitted.

The WHISPER internal processing is available only for one specific sounding mode (fixed frequency table and step duration). It performs the first phase of the compression, only for the active bins.

1.4.4 WBD software

See Gain Control in section 1.3.4.4.
See A/D Converter and Format Generator in section 1.3.4.5.

1.4.5 DWP software

1.4.5.1 Data compression

A problem common to most space instruments is due to restrictions on the available telemetry bandwidth. This can be particularly severe for wave experiments where the mismatch between information and telemetry bandwidths can be several orders of magnitude. In order to optimise the use of available telemetry, data compression techniques are employed in the DWP instrument.

Data compression allows more useful information to be transmitted over a given telemetry system than would otherwise be possible. This is achieved by removing redundant information from the data. Various data compression methods are currently implemented within the WEC and DWP. To simplify allocation of telemetry bandwidth these are restricted to methods providing a fixed degree of compression independent of the variability of the data. The methods are:

(i) Wideband instrument - digital filtering with resampling
(ii) STAFF Search Coil (MWF) - differential encoding

(iii) WHISPER - data selection followed by pseudo-logarithmic compression and
(iv) Correlator - averaging.

The compressions obtained (in high bit rate mode) are listed in Table 1 of ESA-SP.

1.4.5.2 WEC Operations

DWP is responsible for coordinating WEC operations at several levels. At the lowest level DWP provides electrical signals to synchronise instrument sampling. At higher levels DWP time tags data in a consistent manner and provides a facility for constructing more complex WEC modes by means of macros. These facilities are briefly described in the following sections where the normal acronyms or abbreviated instrument titles are used.

1.4.5.3 EFW and STAFF Search Coil (MWF)

DWP has an internal clock running at a fixed 900 Hz frequency. Pulses of this clock are counted by software which derives either a 25 Hz or a 450 Hz signal known as the WEC Sample Sync (WECSS). This controls STAFF Magnetic Waveform Analyser (MWF) and EFW electric field sampling and ensures that sample taking is synchronised to this clock. The WECSS clock is not synchronous with spin of the spacecraft.

DWP has direct digital control of STAFF MWF by means of a number of control signals that allow DWP to select the Bx, By or Bz field components and to control the analogue to digital converter, ADC. DWP reads Bx,By,Bz values to 16-bit resolution at the frequency of WECSS and assembles the values in a buffer within DWP. By contrast EFW has its own microprocessor that fills a sampling buffer within EFW and, once per second, outputs a data packet to DWP through a serial interface (uart). To enable easy time correlation of EFW and STAFF MWF data, DWP samples one second's worth of MWF data before outputting it to the spacecraft. Furthermore, DWP controls the start of EFW sampling (by means of the transmission of a synchronisation character) so that EFW and MWF sampling start at the same time and both generate a complete packet of data one second later. DWP ensures that both of these packets carry the same time tag so as to aid subsequent correlative studies.

It can be seen that for EFW and STAFF operations there is a one second period where sample buffers are being filled before they are output. DWP delays any telecommanded mode changes for EFW and MWF until the sample buffers have been flushed of the samples taken during the last second. This point is termed the One Second Timing Boundary (OSTB), and it will be shown later that all WEC instrument mode changes are synchronised to OSTBs to ensure continuous time coverage in known instrument modes.

1.4.5.4 STAFF Spectrum Analyser

The STAFF Spectrum Analyser (SA) instrument contains a digital signal processing, or DSP, chip and has its own analogue interfaces to the STAFF search coils and EFW. DWP can be programmed to start an SA analysis at set intervals. These analyses usually take one second or multiples thereof. DWP can then read the results of the analysis whilst SA does analysis on the next interval of data.

DWP transmits Start Analysis commands to SA synchronous with the OSTBs. Thus synchronisation with STAFF MWF and EFW is guaranteed.

1.4.5.5 WHISPER

Sampling by the WHISPER instrument is controlled by the WHISPER Sample Synchronisation (WHSS) signal which is generated by DWP and is a 75 Hz signal synchronous with the WECSS. On every pulse of this signal WHISPER may take up to 1024 samples and uses a dedicated DSP to perform FFTs over these samples and to compute the modulus of FFTs. This can result in a maximum data rate to DWP of 75 frames of 512 16-bit values per second which is equivalent to 600 kbps.

When WHISPER is in a sounding mode, DWP controls the timing of the resonance sounder transmission by means of a Blanking Pulse signal synchronous with the WHSS. This signal is also transmitted across the IEL interface and to other WEC instruments to warn them that WHISPER sounding is taking place. This may be useful in the event that electromagnetic interference from the sounder transmitter is suspected. DWP can also synchronise WHISPER sounding with the spacecraft spin if required. The significance of spin synchronisation is that this is used by the particle experiments to obtain a full plasma distribution function. WHISPER synchronisation in this way may be used to minimise any possible interference. However, this imposes limitations on WHISPER operations and is not the nominal mode. WHISPER mode changes (e.g. passive to sounding) are synchronised with OSTBs to ensure synchronisation with EFW and STAFF.

1.4.5.6 Wideband

Wideband has direct connections to the spacecraft data handling system and this is the path that is usually used for data transmission. Sampling and output is not controlled by DWP. Wideband data also may be routed to one of the two spacecraft tape recorders through the DWP interface to the spacecraft. To reduce the bit-rate to fit within the WEC science telemetry allocation, DWP reduces the data rate by a factor of three by applying a digital filtering algorithm to and then resampling this data stream.

1.4.5.7 Correlator

The data flow tasks implemented by the correlator software is illustrated in Figure a) while the associated correlator processing control is illustrated in Figure b)

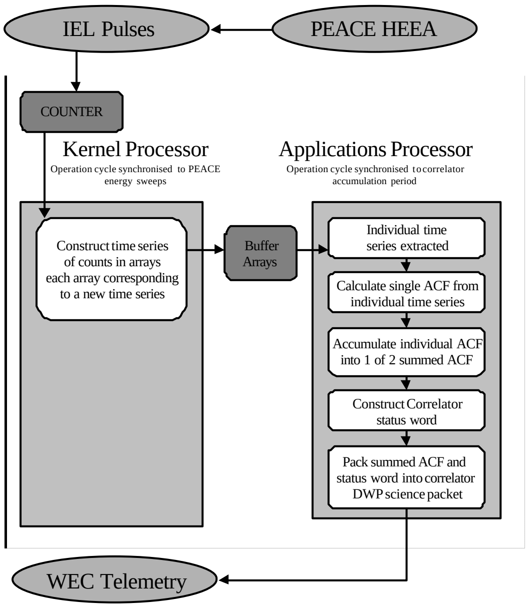


Figure a) Overview of DWP Particle Correlator Data Flow

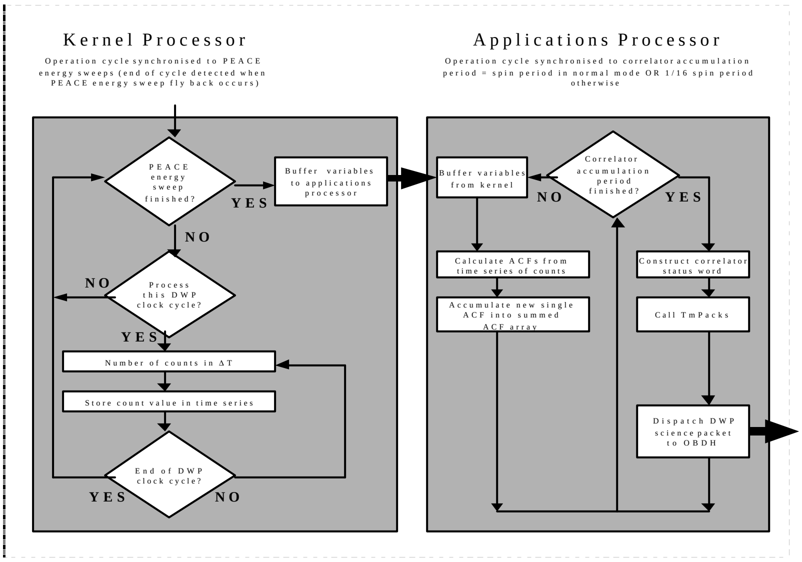


Figure b) Overview of DWP Particle Correlator Processing Control

1.4.5.8 WEC Macros

An area of DWP memory is allocated as a buffer for WEC macros. The WEC macro buffer can hold a number of command sequences that can be invoked with a single telecommand from the spacecraft. The WEC macros exist for two main reasons:

(i) the number of telecommands that can be uplinked to the spacecraft in any orbit is limited. By storing the most commonly used sequences of commands in the macro buffer, efficient use can be made of the spacecraft telecommanding allocation,

(ii) commands can be inserted into the macro buffer to enable features such as looping and timed delays to implement automatic WEC instrument mode switching. These allow the construction of more scientifically interesting WEC modes.

DWP holds 256 instrument commands in a part of the program PROM. Table 3 of ESA-SP shows the initial content of the FM ROMs showing which WEC modes are located in ROM. When DWP is powered on in flight, these are copied into the DWP volatile RAM. These sequences may be modified at any time by telecommand. When DWP is powered off, any modified macro sequences in volatile memory are lost. This buffer space is currently divided into 32 slots of 8 commands (although the command set allows up to 64 slots of 16 commands if enough resources were available within DWP!). A macro command sequence must start at the beginning of a slot, but may overrun into following slots. Macro primitives are available as listed in Table 4 of ESA-SP. With these primitives it is possible to build nested loops and timed delays.

A description of WEC macro commands is given in chapter 3.6.

To give an example of the application of WEC macros, the implementation of a proposed nominal WEC mode when a high telemetry bit rate to the spacecraft is available is described below. To provide clarity the sequence of commands is simplified slightly.

This mode has a repeating cycle of 28 seconds. For the first 2.85 seconds of this cycle, WHISPER is performing a sounding sweep measuring induced plasma resonances. For the last 25 seconds WHISPER is in passive mode in which it acts as a receiver measuring the natural emissions. Whilst WHISPER is sounding, SA performs a single spectrum analysis (duration four seconds) with three magnetic field components. Whilst WHISPER is passive, SA performs a five component (2 electric and 3 magnetic) spectrum analysis. As can be seen from this example which is detailed in Table 5 of ESA-SP, the macro will run indefinitely or until the Terminate Macro command is received. An important point to note is that any time whilst a macro command is executing, additional telecommands may be transmitted to DWP from the spacecraft. It is assumed that the command sequence will be vetted before transmission to ensure that it will not conflict with the execution of the macro (e.g. turning off one of the instruments in use). If this were to occur, DWP will flag warning messages in the WEC housekeeping data. The sorts of telecommands that are likely to be useful are those which adjust operational parameters such as bias current or gain settings (these are referred to later in this paper as switches).

To summarise, the WEC macros provide a skeleton for each WEC mode which can be adjusted by additional telecommands transmitted from the spacecraft as may be required for any particular campaign.

The previous section outlined the implementation of macros, and their usefulness. It may be worth mentioning a few of the limitations.

In theory, many more DWP hard coded operations could be implemented in macros. This would provide ultimate flexibility for reprogramming operations at a high level. However, macros are only executed at a fixed rate (currently one per 50 milliseconds) as a simple mechanism to prevent overloading of DWP. This would give unacceptable response times to external events. Even if the execution rate were to be reduced to one millisecond, there would then be a number of commands that would require explicit delay instructions (e.g. wait 13.3 ms) before execution of the next could be accepted, and this would cause the size of the macro command sequences to grow rapidly.

Asynchronous events would require a supplementary macro sequence running in parallel with the main macro sequence. This is starting to add too much complexity for the limited resources available within DWP and is thus not practical.

Late in mission life when scientific objectives may be altered, or radiation damage may have disabled some instruments, reprogramming WEC macro sequences will enable some work-around solutions to be formed and executed, but these will need to be uplinked after each DWP power off and on cycle.

1.4.5.9 Power-on Default

A power-on default (and emergency) mode is defined. This mode will not be the normal scientific mode but will yield a reasonable set of scientific data in the event of any of four possible worst case or emergency situations :

(i) low spacecraft bit-rate (a safe assumption)
(ii) spacecraft power limited (again a safe assumption)
(iii) no command link into DWP (perhaps due to a failure) and
(iv) DWP capabilities limited (perhaps due to radiation damage).

If these emergency conditions do not apply it should be possible to command the WEC experiments into other modes which take into account the actual circumstances.

1.4.5.10 Fault tolerance

During operational life there are two main sources of problems - the first is collisions with micro meteoroids and space debris (which, for the orbit of Cluster II, is a small problem), the second is radiation damage. The latter can have three consequences; latch-up followed rapidly by thermal run-away and destruction of a device; a single event upset (SEU) which causes the value of a register to be reversed (this is a non-permanent effect); and premature ageing. Of these three, SEUs are the hardest to combat by circuit design and component selection, especially in the case of volatile memory devices. Since the executing program and data are stored in such devices, this constitutes a potentially serious problem. In the next section we explore software techniques to deal with SEUs. A similar effect will be met in many industrial environments due to electrical noise or electromagnetic interference, (EMI). Indeed, one way to test for the effect of SEUs is to inject EMI into open wiring harnesses. The two main errors which are considered in this work are SEUs, or transient errors, and premature ageing which leads to a permanent failure of a device. Repairs to permanent failures are not possible.

Designing for reliability

Conventionally, the techniques for reliability design consider hardware and software as distinct topics. Hardware reliability design uses techniques such as FMECA to identify critical areas (often these are single point failures). Software reliability frequently uses exception handling and related concepts. Of course both concentrate on good design and implementation practice as well (for example de-rating components, high quality manufacturing and modular software). We have attempted to consider the system reliability and functionality independently of the hardware and software in which it is implemented, although the traditional approaches have been used as well.

Possible faults, whatever their cause, may conveniently be classified according to the required recovery procedure. Five classes were identified and are discussed below.

Faults that may be ignored

Faults that fall into this class may be caused by SEUs or some software bugs. The corruption, by an SEU or bug, of a memory word that contains only sampled science data will cause no upset in operation to be observed and have no serious consequences if only a single word is corrupted.

Software protectable faults

Faults that fall into this class may again be caused by SEUs, some software bugs and faults in other WEC instruments. The corruption, by an SEU or bug, of a memory word that contains certain kinds of program variable can be protected against by a defensive style of programming (e.g. always checking variables for valid contents). The operation of this protection may, at worst, cause a hiccup in data output.

DWP has some automatic checks built into its software that monitor performance of WEC instruments interfaced to it. These automatic checks can be disabled from the ground if found necessary to cope with voltage sensor failures for example, that do not generally affect instrument operation. Typically, if an instrument fails a check it is automatically powered off and then powered on again a short time later. This sequence is repeated if necessary a maximum 3 times before DWP decides the instrument has terminally failed and leaves it powered off. The instrument can still be powered back on by a telecommand. In the event of a catastrophic WEC instrument failure causing the operation of the instrument to endanger the operation of the other WEC instruments, a telecommand may be transmitted to inform DWP that the interface or instrument has failed. This telecommand must be sent from the ground. DWP will then ignore all further commands for that instrument without flagging errors in the telemetry.

Faults requiring a restart without loss of mode

Most of the remaining faults caused by corruption of memory by an SEU or software bug fall into this class. If the word holds a transputer instruction in the currently executing command path then behaviour of the software will be affected in some unpredictable way. This is most likely to cause the software to crash due to execution of an illegal transputer instruction or arithmetic overflow. This will cause the watchdog timer to trip a short time later which will reset the DWP instrument, and restart software execution.

In general, a reset caused by a failure within DWP should not cause the mode of an external WEC instrument to change, although some telemetry data loss is allowable. The reason for this is that many commands may have been uploaded to an instrument to place it into a specific mode. In many cases, if DWP were to reset the instrument, this information could not be repeated due to the complications of storing large command sequences for each instrument. These command sequences may also have included code patches for those instruments that are microprocessor based. In the case of one instrument that had a moderately complex interface protocol, the software had to be carefully designed to take account of the difficulty in recovering from errors at any point in the exchange. Other instruments generate data almost independently of DWP input and recovery is accomplished without difficulty.

When DWP software starts execution after a reset (either watchdog or power on) it examines the state of the Watchdog flag. This is set if the reset was caused by a Watchdog time-out. DWP then attempts to restore itself to the state it was in before the reset, without disturbing the state of the connected WEC instruments. This is done by storing vital system parameters such as mode information and recently received commands in an area of memory known as checksummed memory . This is an area of conventional volatile RAM which regularly has a checksum computed from its contents.

After a watchdog reset DWP attempts to restore its old state by using the contents of checksummed memory. Before it can do this, it has to verify that the contents were not disturbed by the fault. It does this by computing the checksum over the checksummed memory, and checking it against the stored checksum. In the event of corruption, DWP accesses a redundant copy of checksum memory that is kept up to date at all times.

The concept of a complete redundant copy of checksum memory is feasible as its size is very small (about 100 words). Furthermore, most words stored in checksummed memory are only updated at a low rate (less than once per second) so the overhead of computing a checksum and maintaining a fully redundant copy is not great.

Faults requiring a complete restart

The only cause of this class of fault is a DWP hardware fault which requires reconfiguration (e.g. a processor failure or latch up). Such a fault will cause DWP to restart (in some cases a power cycling command may be required) in its default mode. All instruments are reset and information about the mode prior to the fault is lost.

Irrecoverable Faults

Irrecoverable faults are caused by major hardware failures (possibly due to radiation damage or impact) and redundancy is often used to reduce their probability by eliminating single points of failure. As was stated in section 2, resources for full redundancy are not available to DWP. However, certain major single-point failures have been identified and redundancy used for them. They are mainly in the interfaces between DWP and the spacecraft systems. Main and redundant command and data interfaces are provided and dual power supplies are used with blocking diodes. The most vulnerable hardware is the instrument bus which is non-redundant. The interfaces to the WEC instruments are not redundant so a failure in one of them would be serious (but not an overall catastrophe). The three processor modules, each with a transputer, program ROM, RAM and associated circuitry, form a fault-tolerant system. Any one processor (at half speed) can run the kernel programme which provides the essential communications and system control. The other "applications" tasks are then run in one or both of the other transputer processor modules.

1.4.5.11 Science Telemetry Description

The WEC Spacecraft Block

The WEC *Spacecraft Block* is the unit of science data acquisition by the spacecraft OBDH. The block size and the number of blocks acquired between OBDH reset pulses are fixed for each OBDH acquisition mode. The size and number of blocks for each mode are shown in the table below.

OBDH mode	**Block size**	**Number of blocks**	**Bit rate**
	(16 bit words)	(per 5.1522s)	(bps)
NM1, NM2, NM3	168	10	5217.17
BM1	228	62	43898.73
BM2	474	62	91263.15
BM3	153	62	29458.36

The DWP *Telemetry Buffer* holds a number of Spacecraft Blocks that are ready for acquisition by the spacecraft OBDH.

WEC Science Packets

DWP controls the interfaces to each of the WEC instruments. Science data is read from an instrument interface until a complete *Science Packet* is assembled. A *Science Packet* contains data from only one instrument.
The first two words of the science packet are the *packet descriptor* and the *time tag*. The packet descriptor for a science packet is the same as that for a *mini-packet* of type *single* as described in the next section. The format of the time tag will be described in section 1.4.5.15.
The size of a science packet is dependent on the source instrument and its mode. Some information on the size of science packets may be found in the WEC Internal EID part 4.
When a *Science Packet* has been assembled it can either be transmitted to the process controlling the assembly of *Spacecraft Blocks* for the *Telemetry Buffer*, or routed to an applications process.

Packaging of Science Packets into Spacecraft Blocks

Science packets from an instrument interface or an applications process are assembled into Spacecraft Blocks and placed in the Telemetry Buffer. To enable every word of a spacecraft block to be used, science packets may be split into several *mini-packets* sized such that a spacecraft block is filled by a whole number of mini-packets. A group of *mini-packets* that make up a *science packet* are placed in a series of consecutive *spacecraft blocks* in the *telemetry buffer*. Each split science packet will consist of one mini-packet of type *first*, followed by zero or more mini-packets of type *middle*, followed by one mini-packet of type *last*.
Streams of mini-packets from different instruments are not interleaved in the spacecraft blocks. Every spacecraft block contains one or more mini-packets. If more than one mini-packet is present in the spacecraft block then the mini-packets must be components of different science packets.
The first word of a spacecraft block is always the first word of a mini-packet. The first word of a mini-packet is always the *mini-packet descriptor* described in the next section.

The Mini-packet Descriptor

The mini-packet descriptor is a 16 bit word with the format shown in the following tables.

Bits	Field description
15..14	Type
13..11	Source instrument
10..9	User bits / sequence count
8..0	Length of remainder of packet

Bit	Type	Bit	Source
15 14		13 12 11	
0 0	Single	0 0 0	EFW
0 1	First	0 0 1	Staff SA
1 0	Last	0 1 0	Staff MWF
1 1	Middle	0 1 1	Whisper
		1 0 0	Wideband
		1 0 1	DWP correlator

When the type is *Single* or *First*, bits 9 and 10 are the user bits (UDEF0 and UDEF1 respectively), and when the type is *Last* or *Middle* they form the mini-packet *sequence count*. This should increment by one (modulo 4) for each component of a science packet.
A *mini-packet descriptor* with the special value 0x3000 (type *single*, source 6, user bits 0, length 0) indicates that the rest of the *spacecraft block* is unused. This condition frequently occurs when WEC instruments are generating telemetry at a lower rate than the current OBDH acquisition mode.
The user defined bits for each source instrument are described in the following sections.

EFW

The user defined bits indicate the EFW mode.

UDEF1	UDEF0	EFW mode

0	0	Normal
0	1	Tape mode 1
1	0	Tape mode 2
1	1	Tape mode 3

STAFF SA

The user defined bits provide information on the mode. Together with the science packet size they allow a complete determination of the analysis mode.

Bit	Description
UDEF1	Set to the LSB of the SA mode word
UDEF0	Set to 1 if STAFF in calibration mode

STAFF MWF

The user defined bits provide information on the mode and data format.

Bit	Description
UDEF1	Set to 0 : Normal Compression Set to 1 : Back up Compression
UDEF0	Set to 1 if STAFF in calibration mode

WHISPER

The user defined bits provide information on the mode and data format.

Bit	Description
UDEF1	Set to 1 if data processed by DWP application
UDEF0	Set to 1 if sounding mode data

WIDEBAND

The user defined bits are a copy of bits 0 and 1 of the Wideband processing word. A non-zero value for either bit indicates that the data is digitally filtered by DWP, but the converse does not necessarily apply (setting *any* bit in the wideband processing word enables digital filtering).

CORRELATOR

Bit	Description
UDEF1	Not Used (undefined)
UDEF0	Not Used (undefined)

Telemetry overflow

If the WEC instruments are consistently generating data at a rate greater than the current OBDH acquisition mode, the DWP *telemetry buffer* becomes full and the *telemetry overflow* condition occurs. In this case *science packets* will be truncated. A truncated science packet will be packaged as one mini-packet of type *first*, followed by zero or more mini-packets of type *middle*, but no final packet of type *last*. They can thus be easily distinguished from normal (non-truncated) science packets. Telemetry overflow is also indicated by an error bit in the housekeeping.
Under gross telemetry overflow condition (such as operating the WEC in burst mode with the OBDH in normal mode) science packets can be lost completely.

1.4.5.12 Decommutation of WEC science telemetry

Decommutation of science telemetry is the process of converting the spacecraft blocks back into science packets. This is a two stage process; first the spacecraft blocks are split up into mini-packets, then the mini-packets are re-assembled into science packets.

Splitting up the spacecraft blocks

The first word of a spacecraft block should be the descriptor of the first mini-packet. This descriptor may be one of three types:

1) An unused block descriptor (0x3000).

2) A valid mini-packet descriptor.

3) An illegal descriptor (ie. neither of the above).

In cases (1) and (3) the rest of the spacecraft block should be discarded.
In case (2) the mini-packet should be passed on for re-assembly. The first word of any remaining space in the block will be another descriptor. The process should be repeated until the end of the block is reached.
Valid mini-packet descriptors must have a legal source instrument field, and a length greater than 0 and less than or equal to the size of the rest of the spacecraft block. As a special case a length of 0 with type *first* is also acceptable (this can occur when there is just one word left at the end of a spacecraft block).

Re-assembly of mini-packets

Re-assembly of mini-packets proceeds according to the following rules.

1) Mini-packets of type *single* should be passed directly to the output as a *science packet*.

2) Mini-packets of type *middle* or *last* received while not in a re-assembly sequence (or which cause premature termination of a re-assembly sequence) are anomalous and should be handled appropriately. The packet could be passed to the output accompanied by an error message, or perhaps just discarded.

3) Mini-packets of type *first* start a re-assembly sequence. The source instrument field and user defined bits for the re-assembled *science packet* are taken from the descriptor of this mini-packet. Zero or more mini-packets of type *middle*, followed by one mini-packet of type *last*, all with matching source instrument fields, and incrementing sequence counts should then be received. These

should be appended to the science packet which should be passed to the output after the *last* packet is received.

4) If, while in a re-assembly sequence, any mini-packet is received which does not fit (ie. wrong type, different source instrument, or out of sequence count) the sequence should be terminated and the partially assembled science packet passed to the output with an error message. The rogue mini-packet should then be processed as in 1, 2, or 3 above.

1.4.5.13 Science Packet Format

The first two words of the science packets are the *packet descriptor* (section 1.4.5.11*)* and the *time tag* (section 1.4.5.14). The following sections briefly describe the contents of the rest of the packet.

EFW

The EFW science packets contain a sub-section of the block received from EFW. The contents of the EFW blocks are described in EFW documentation.
The table below shows the first and last byte of the EFW block forming the sub-section placed in the science packet. In normal mode one second of data is contained in a single block. In the three tape modes each one second of data is split into 10 blocks; the first, middle and last blocks are each handled differently by DWP. The packet length field in the table includes the *time tag* word but not the *packet descriptor*.
Pairs of bytes from the EFW block are packed into 16 bit words in the science packet with the first byte of the pair in the most significant end of the word.

Mode	**Block sequence**	**Block size** (bytes)	**First byte**	**Last byte**	**Packet length** (words)
Normal	N/A	184	4	183	91
Tape 1	1	192	4	191	95
"	2..9	192	2	191	96
"	10	192	2	173	87
Tape 2	1	282	4	281	140
"	2..9	282	2	281	141
"	10	282	2	263	132
Tape 3	1	372	4	371	185
"	2..9	372	2	371	186
"	10	372	2	353	179

STAFF SA

The first three words of the STAFF SA science packets are the packet descriptor, the time tag and the STAFF mode word. The rest of the packet is the data received from STAFF SA, excluding the first two bytes which specify the length of the data (this information can be derived from the length field of the packet descriptor), and the final end of block byte. Pairs of bytes from the STAFF SA block are packed into words in the science packet with the first byte of the pair in the least significant end of the word.

STAFF MWF

The first three words of the STAFF MWF science packets are again the packet descriptor, the time tag and the STAFF mode word. The format of the rest of the block depends on whether the data is compressed. If the data is uncompressed the rest of the block contains waveform data in the order X0, Y0, Z0, X1, Y1, Z1 and so on with each sample in a 16 bits word. The format of the compressed data is described in the WEC Internal EID Part 5.

WHISPER

In Whisper processed mode (ie. not using DWP applications processes) the packet descriptor and the time tag are followed by the words of data read from Whisper. The format of this data is described in the Whisper Internal EID.
In DWP processed mode the format is described in the WEC Internal EID Part 5.

WIDEBAND

The first two words of the Wideband science packets are the packet descriptor and the time tag. The rest of the words are the waveform samples. Pairs of 8 bit samples are packed into words with the first sample of the pair in the most significant end of the word.
In the non-filtered mode (1 out of 3 selection) the packets contain 1090 samples which gives a packet length of 546 words (including time tag, but not packet descriptor).
In the filtered mode (reduction to 1/3 sampling rate) the packets may contain 364 or 360 samples and have lengths of 183 or 181 words.

CORRELATOR

The packet descriptor and time tag are followed by two status words and two auto-correlation functions of 15 words each (packet length 33 words). The format of this data is described in the DWP particle correlator description.

1.4.5.14 Time Tagging of WEC Data

DWP time stamps the WEC data with a time tag relative to the spacecraft on-board time which is approximately as accurate as the timing given by the spacecraft systems, i.e. the limiting accuracy is the 11 microseconds of the spacecraft on-board data handling system and the ground segment.

The reset pulse, master clock, and snapshot offset

The spacecraft OBDH operates on a basic cycle of 5.15222168 seconds which is divided into 84414 slots of 61.04 µs each. At the beginning of the first slot the OBDH issues a *reset pulse*. This coincides with the transmission of the first synchronisation bit of the VC0 transfer frame.
The *reset pulse* is used by WEC to co-ordinate WEC internal timing with the spacecraft *on board time* with the aid of a counter in the housekeeping telemetry (parameter EW5RSCNT). Each HK frame is time stamped by the OBDH with the spacecraft *on board time* of the reset pulse following the acquisition of the HK data from WEC.
Note that the HK frame contains data on WEC operations sampled at the reset pulse before the acquisition of the data. There will therefore be a delay of from one to two reset pulse periods between a change occurring in the WEC operation and the corresponding HK parameter changing.

Note that neither the Satellite Services BV 'Spacecraft Interface Simulator', nor the DWP 'Rest of the World' simulator, correctly implement the time stamping of HK frames. In each case the time is that of the acquisition of the data, not the following reset pulse. Furthermore the Spacecraft Interface Simulator does not implement the fractions of seconds fields of the time stamp.

The DWP uses a 900 Hz *master clock* (marked MC in the figure in section 1.4.5.14) to coordinate the operation of the WEC instruments. The *snapshot offset* is the time between the reset pulse and the next pulse of the master clock. This is recorded in housekeeping parameter EW5SSOFF (in micro-seconds). There are very close to a whole number (4637) of master clock cycles in a reset pulse period so the snapshot offset changes only slowly from one HK frame to the next.

The general process involved in WEC time tagging is shown in Figure 1.4.5.14.1

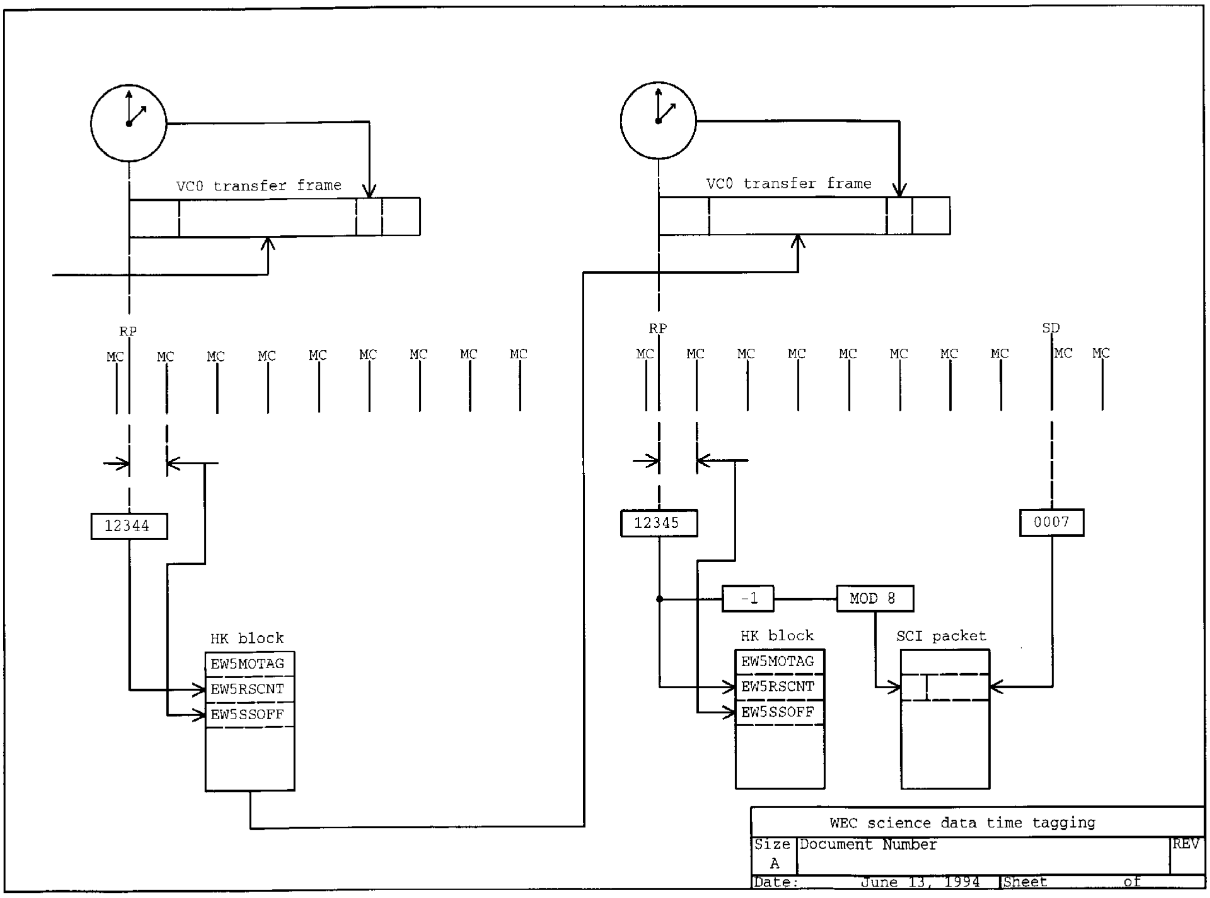


Figure 1.4.5.14.1

Science packet time tagging

The first word of a science packet following the packet descriptor is the *time tag*.

Bits	Description
15..13	Reset pulse count (modulo 8)
12..0	Master clock count

The *reset pulse count* allows the identification of the HK frame acquired just prior to the reset pulse used as the timing reference for this data. This HK frame will be time stamped by the OBDH with the *on board time* of the reset pulse.
The *master clock count* is the number of 900 Hz clock pulses that have occurred between the reset pulse and the timed event.

Timed events

The actual event which is timed by the time tag depends on the WEC instrument concerned.

EFW: The one second timing boundary occurring before the block of EFW data is received by DWP. Note that in burst mode each one second section of data is split into ten science packets each with the same time tag.

STAFF SA: The one second timing boundary coinciding with the transmission of the 'do analysis' command strobe.

STAFF MWF: The time of the first sample of the data block.

Whisper, Wideband: The time at which the data packet was received by DWP.

Correlator: The time of the PEACE flyback following the last block contribuiting to this packet.

1.4.5.15 Discussion of timing accuracy

Timing accuracy is particularly important for EFW and STAFF to allow phase comparison of waveform data recorded on different spacecraft. The time tags specify the time of the first sample in a telemetry packet as the number of cycles of the DWP master clock since the last reset pulse. The precision of this measurement is therefore 1.11 ms. However, since the waveform data is always sampled on the active edge of the 900Hz clock, a much greater accuracy is possible provided the phase of this clock relative to the spacecraft onboard time is known.
To allow the phase of the 900Hz clock to be determined the snapshot offset parameter (EW5SSOFF) is included in the WEC housekeeping which specifies the time interval between the reset pulse and the next active edge of the 900Hz clock. This time is measured by the DWP software (using a transputer timer) to a precision of 1 µs, but the accuracy of each individual measurement is limited by the interrupt latency of the transputer which can be as large as 700 µs.
The parameter EW5SSVAL qualifies the validity of each measurement. The following table shows the range of validity.

EW5SSOFF	EW5SSVAL	Min Actual Value	Max Actual Value
0: 19	0	0	EW5SSOFF+20
20: 1019	0	EW5SSOFF-20	EW5SSOFF+20
1020: 1111	0	EW5SSOFF-20	1111
0: 19	1	0	EW5SSOFF+20
20: 249	1	EW5SSOFF-20	EW5SSOFF+20
250: 1111	1	EW5SSOFF-20	1111

It can be seen that the error is normally in the range of +/-20 microseconds but may be as large as 860 microseconds. Measurements which may be subject to these large errors should be regarded as invalid. To obtain accurate estimates of the clock phase an average should be taken over the last n valid measurements (where n has a value of the order of 10). It is necessary to take proper account of the linear rate of change of phase and the wrap around when it increments above 1111 or below zero. The figure below shows the typical variation of phase with time.

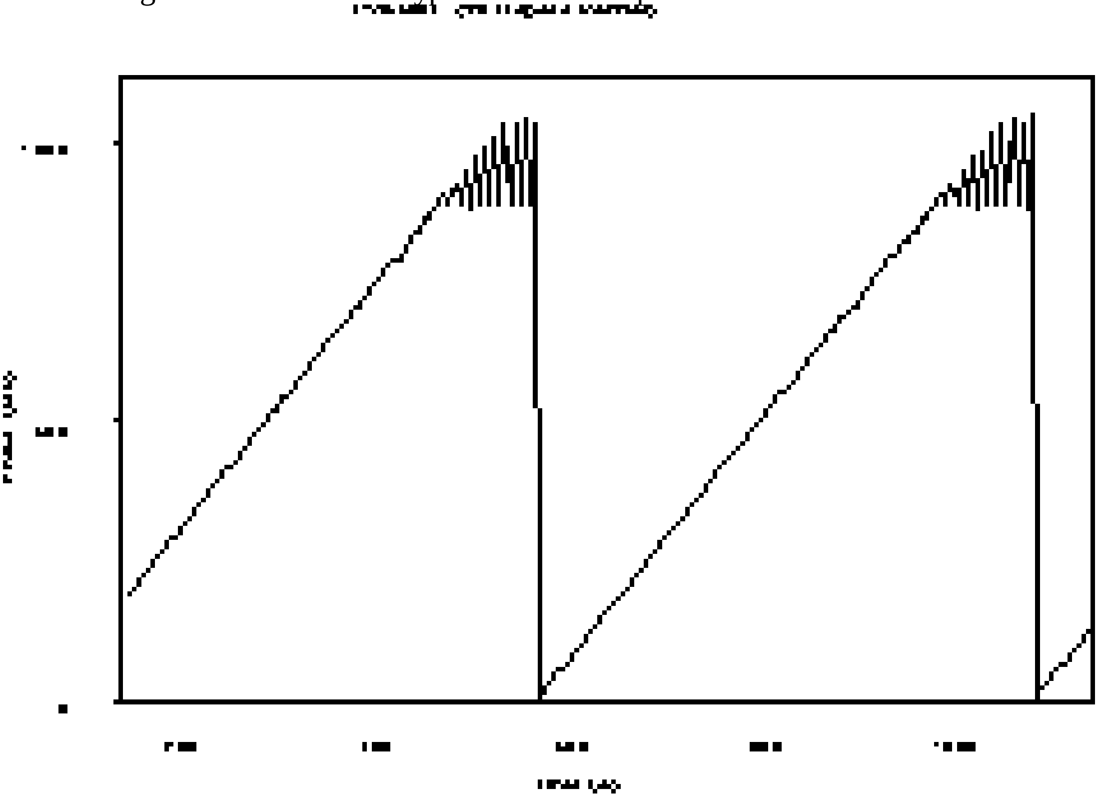


Figure 1.4.5.15.1

1.5 INSTRUMENT PHYSICAL CHARACTERISTICS

1.5.1 Mechanical description (EID-B section 2.1.1)

The Wave Experiment is composed of 11 mechanical elements schematically represented in Figure 1.4.5.15.2 (EID-B Fig 2.1/2), summarised in Table 1.5.1.1 (EID-B Tab 2.1/2) - WEC nomenclature (EID-B tab 2.1/2) and listed below.

The different parts of the WEC are interconnected by a large number of wires. The WEC/harness mass resource estimates are given in section 1.5.4. of EID-B. Refer also to section 3.5 of EID-B for more details.

WEC	ref	experiment	description
WEC	1	EFW	2 pairs of booms, 50 m each
	2		In orthogonal directions
	3	also used by	+
	4	WHISPER/TX	electronic circuits
WEC	5/c	EFW	cables: deploy. units to main elect. box
WEC	5	EFW	main electronic box
WEC	6	STAFF	search coil antennas
WEC	7/c	STAFF	cable : magnetic sensor to preamplifier
WEC	7	STAFF	magnetic preamplifier
WEC	8/1	STAFF	magnetic waveform
WEC	8/2	STAFF	spectrum analyser
WEC	8/c	STAFF	common parts for the stack WEC.8
WEC	9/1	WHISPER	relaxation sounder
WEC	9/2	DWP	digital wave processor
WEC	9/c	WHISPER/DWP	common parts for the stack WEC.9
WEC	10	WBD	wide band data experiment
WEC	11	PWR	WEC power supply
harness		all	WEC interconnections

Table 1.5.1.1 (EID-B Tab 2.1/2) - WEC nomenclature

WEC PACKAGING

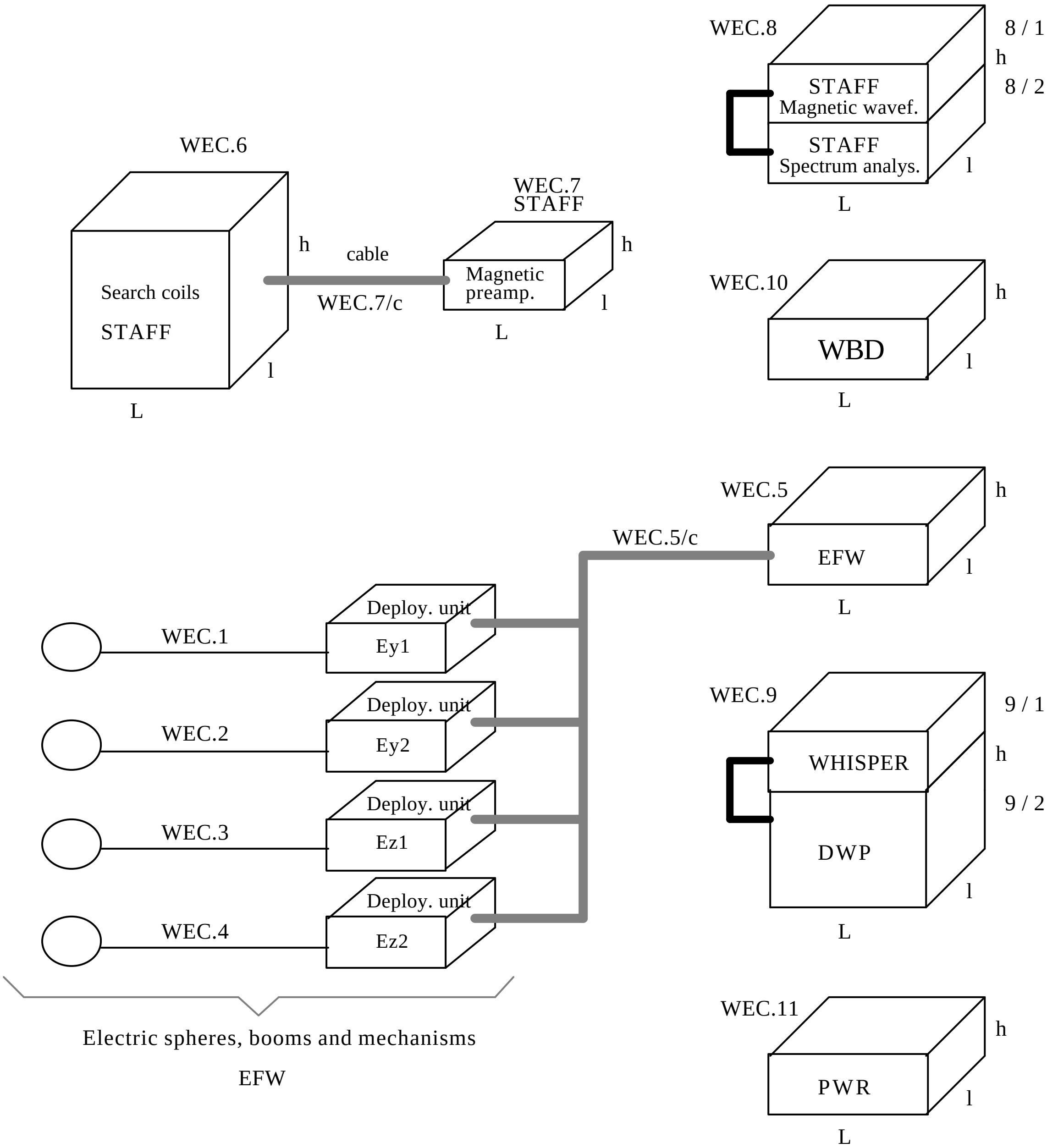


Figure 1.4.5.15.2

1.5.1.1 WEC 1/4

WEC 1 to 4 are the four Radial Wire Booms supplied by the EFW experiment. Each deployment mechanism deploys a 50 meters long wire boom which has a small spherical sensor and hockey puck with amplifier at the end. The shielding of two wires is used as a transmitting wire dipole for WHISPER. According to the current Payload accommodation and in order to minimise the effects of the WHISPER pulse on CIS, PEACE and RAPID, the transmitter will be connected with WEC 3 and WEC 4.

1.5.1.2 WEC 5

WEC 5 is the electronic Aluminium alloy box of EFW and **WEC 5/c** is the cables connecting the deployment units to the main box.

1.5.1.3 WEC 6

WEC 6 is the search coil sensor provided by STAFF and mounted on one deployable rigid boom. The sensor is composed of 3 cylindrical antenna assembled in a glass fibre epoxy box wrapped with thermal blanket. The sensor must be placed at About 2.5 meters from the spacecraft body. This distance between the sensor and the body of the satellite is usually considered as acceptable from the point of view of EMI specifications.

1.5.1.4 WEC 7

WEC 7 is the magnetic preamplifier, an Aluminium alloy box. It is connected to the search coil sensor (WEC 6) with a special cable **WEC 7/c.** The preamplifier is located inside the spacecraft, as close as possible from the root of the boom. The 7 twisted shielded pair used to build the harness is supplied by the experimenter. Since the capacitance of the cable has an important effect on the band pass of the instrument, its length is about 6 meters.

1.5.1.5 WEC 8

WEC 8 is a stack of 2 boxes from STAFF: - the electronic of Magnetic Wave Form (STAFF/mwf - WEC.8/1) and the spectrum analyser (STAFF/spa - WEC.8/2). The 2 boxes are made of Aluminium alloy.

1.5.1.6 WEC 9

WEC 9 is a stack of 2 boxes including WHISPER (WEC.9/1) and DWP (WEC.9/2). The 2 boxes are made of Aluminium alloy.

1.5.1.7 WEC 10

WEC 10 is the unit of WBD experiment. The box is made of aluminium coated with Alodine 1201.

1.5.1.8 WEC 11

WEC 11 is the Power Supply (PWR). The box is made of Aluminium alloy.

1.5.2 Experiment mounting attachments

See EID-B section 2.5.

1.5.3 Mechanism description

See EID-B section 2.1.2

The WEC 1/4 are the only mechanisms of the WEC. Figure 2.1/1.a of EID-B shows the mechanism design.

1.5.4 Structure and mechanism analysis

See EID-B section 2.3.

1.5.5 Experiment physical properties (EID-B section 2.4)

1.5.5.1 Total mass

The total mass for the WEC in launch configuration is 31.200 kg including:

- the internal WEC harness

- 0.31 Kg additional for override facility, in order to allow s/c interventions during boom deployment (in case of failure within the EFW controller) additional control circuits are now implemented within each of the 4 deployment units. (See Note below)

1.5.5.2 Physical properties of the units

The physical characteristics of the WEC are specified in table 2.4/1 of EID-B for the mechanical elements and a summarised description of the internal harness is given in EID-B Sec. 3.5.

In table 2.4/1 of EID-B the weights are given without any margin and are therefore considered by the experimenters as minimum values. Taking into account the current payload accommodation and the corresponding length of the cables, the total mass of the WEC harness is now evaluated to about 2.2 kg (see EID-B Sec. 3.5). The final value can be slightly different depending on the final routing designed by the contractor. The position of the centre of gravity and the moment of inertia are only calculated values and cannot be given with the accuracy requested in EID_A before measurements of the EMs.

1.5.5.3 Perturbations generated by mechanisms movements

During the deployment of the long booms, the variation of the centre of gravity on the spacecraft is null since the booms deploy symmetrically. The variation in the moment of inertia is estimated 3400 kgm^2 for 100 m sphere to sphere. The part A allocation of 2600 kgm^2 might be met by reducing the sphere to sphere distance to 90 m if this is a firm requirement. The installed cable lengths will be updated as the actual cable and sensor properties are evaluated. For balance purposes, deployed wire lengths are microprocessor controlled to a tolerance of 5 cm and spheres balanced to 1 gram. The total linear forces and torques on the spacecraft are balanced by symmetry under equilibrium conditions. Transient forces and torques are dictated by the AOCS and spacecraft dynamics. For analyses, the boom cable may be treated as a distributed mass having virtually no residual stiffness.

1.5.6 Experiment aperture covers (EID-B section 2.7)

1.5.6.1 Type of Aperture Cover

The EFW deployment units (WEC1/4) have flight covers:
The boom mechanisms have gull-wing type doors which are opened prior to deployment.

No covers for any other units.

1.5.6.2 Cover Deployment and Retention Systems

The spring loaded doors are held in place by a wire which is fed through a pair of pyrotechnic cable cutters in the base of the unit. If either cable cutter works, the doors will be released. The cable cutters have been approved in the CRRES project for use on the STS.

1.5.6.3 Purging Interface

N/A