

# EFW Filter Group Delay

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## Document control

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=====  
Revision  Date          Comments  
-----  
A          2001-12-13      Initial revision  
=====
```

## 1 Scope

This summarizes the background for the filter group delay correction in the EFW Isdat server included in WEC-Isdat 2.8.0.

## 2 Background

EFW includes several filters. The L (0 - 10 Hz) and M (0 - 180 Hz) filters are normally used in the standard data in the LX and HX telemetry areas, i.e. for continuous monitoring of probe potentials (LX) and electric fields (HX). Other filters (H and U) are mainly used for EFW internal bursts and are not considered here.

## 3 Group delays from ground tests

Filter characteristics as determined in ground tests are shown in the figures in Appendix A, and summarized in the following e-mail:

```
Frn: "Anders Eriksson" <aie@irfu.se>  
Till: "Per-Arne Lindqvist" <lindqvist@plasma.kth.se>;
```

"Georg Gustafsson" <gg@irfu.se>; "Forrest Mozer" <mozer@ssl.berkeley.edu>;  
"Mats ANDRE" <andre@space.umu.se>; "Bjrn Lybekk" <bjorn.lybekk@fys.uio.no>;  
"Arne Pedersen" <arne.pedersen@fys.uio.no>; "Lennart hln" <ala@irfu.se>;  
<Jackv@cluster1.ssl.berkeley.edu>; "Tobia Carozzi" <tc@irfu.se>  
mne: Group delays from ground tests (VxL)  
Datum: den 11 oktober 2000 17:44

Friends in space,

I have calculated the group delays for the VxL quantities from Lennart's calibration data on the WEC-5 units (no boom electronics connected). The averages in the frequency bands 0-2 Hz, 0-4 Hz, and 4-8 Hz are as follows:

SC	P	Group delay [ms]		
		f<2	f<4	4<f<8
1	1	79.3	79.6	90.1
1	2	79.4	79.8	90.1
1	3	79.3	79.7	90.0
1	4	79.3	79.6	90.0
2	1	71.2	71.6	82.6
2	2	79.3	79.6	89.8
2	3	71.0	71.4	82.6
2	4	79.0	79.3	89.7
3	1	79.9	80.1	90.8
3	2	79.6	79.9	90.4
3	3	79.4	79.8	90.1
3	4	79.4	79.7	90.2
4	1	79.4	79.7	90.2
4	2	79.5	79.8	90.1
4	3	79.3	79.6	90.1
4	4	79.5	79.9	90.3

I do not yet know if the values for P1 and P3 on SC2 are real or artifacts: I will check with Lennart.

The list above compares well to what I found by in-flight comparison in a previous mail today. If you really stretch things, they may marginally agree with the observed 120 plus minus 40 ms sunpulse delay -- comments?

Plots of the amplitude response, phase response, and group delay as functions of frequency are available at <ftp://irfu.se/pub/aie/EFW/gdelay>.

Very best regards,

Anders

The plots mentioned as available on the ftp site are included in Appendix A.

## 4 Group delays determined in space

Assuming that the L and M filters are identical except for a factor 18 in frequency, the group delays may be determined by cross-correlation of simultaneously sampled L and M signals, e.g. V3L and V3M. A first determination using this method in October 2000 (see e-mail in Appendix B) compared V1L-V2L to V12M, without considering the  $3/450$  s = 6.7 ms offset of the V1L and V2L signals in Isdat. This means that the delays derived in Appendix B are exaggerated by 6.7 ms.

Using data from 2001-03-31, when EFW operated in tape mode 2 for four hours and then acquired V3M and V4M together with V12M in HX while keeping the usual LX content (V1L, V2L, V3L, V4L, BP12, BPC), new comparisons have been made. Figures 1 – 4 show examples of the unbiased cross covariances based on two minutes of the L and M signals originating from probes 3 and 4, respectively. The Matlab code for producing these plots is contained in Appendix C. The plots show time delays of 33 and 35 HX samples, and study of a few others show that the mean value is close to 34 HX samples. Assuming that M and L filters are identical but a factor different in frequency, the true time delay in the L filter becomes

$$t_L = \frac{18}{17} \cdot \frac{34}{450} \text{ s} = 80 \text{ ms.}$$

This value is consistent with the ground tests (see Section 3 above) and is taken as the nominal value for the L filters. For the M filters, we thus use

$$t_M = t_L/18 = 4.44 \text{ ms.}$$

## 5 Isdat implementation

The general policy of the EFW Isdat server module have been that data should be tampered with as little as possible, and as closely resemble the ADC output as possible. However, as the STAFF SC data are corrected for the group delay time by their use of a frequency-domain calibration, this means that EFW and STAFF SC data have had different timing philosophies. Implementing the group delays into the EFW server is the first order correction needed to make the data comparable, and it has thus been decided to do so.

The nominal group delays defined in Section 4 have thus been introduced in the delay calculation in the file EfwLow.c in the Isdat server (Appendix D), committed to

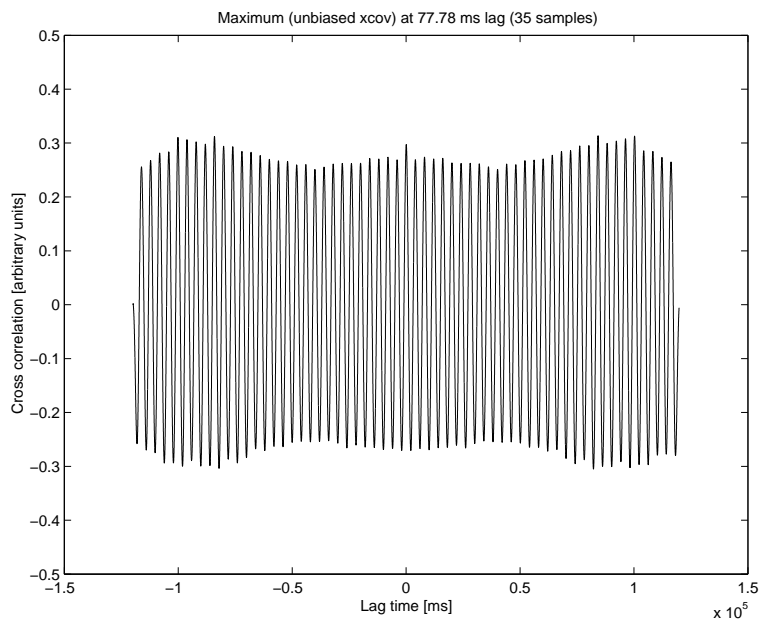


Figure 1: Unbiased cross covariance of V3L and V3M.

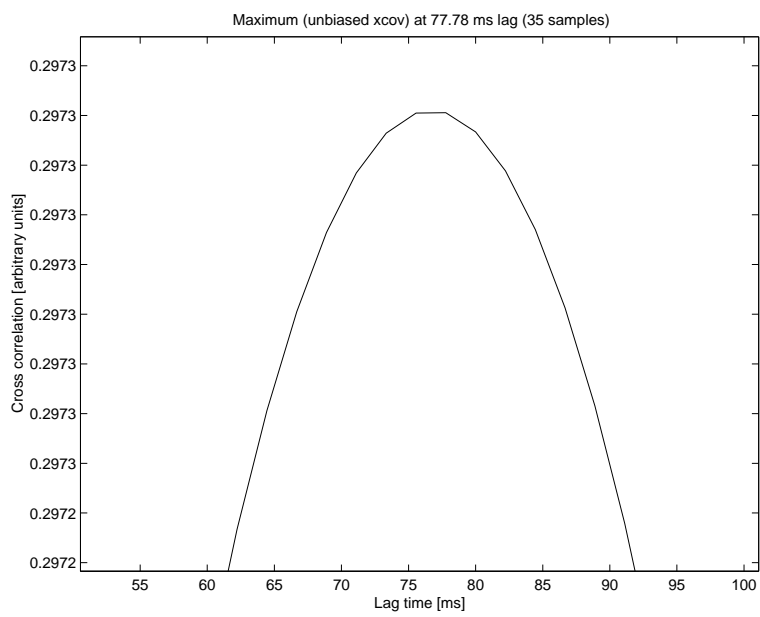


Figure 2: Zooming in on the central peak of Figure 1.

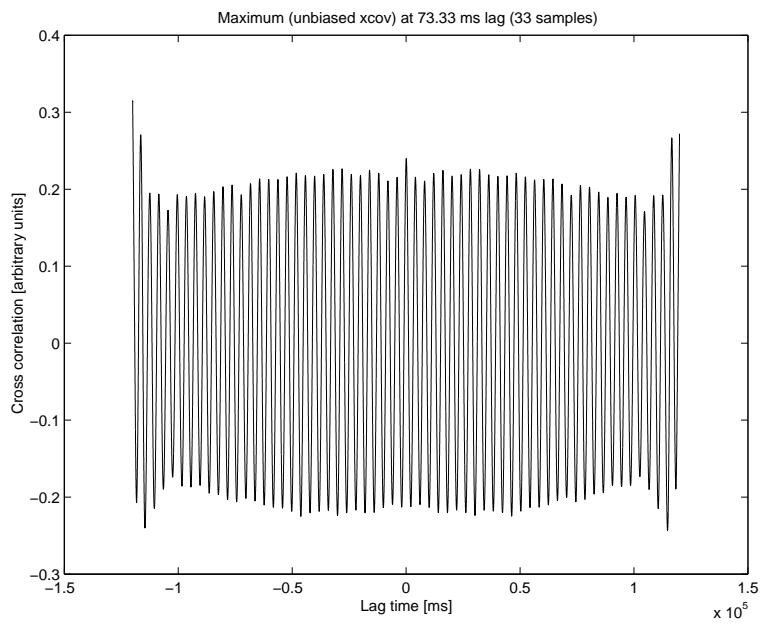


Figure 3: Unbiased cross covariance of V4L and V4M.

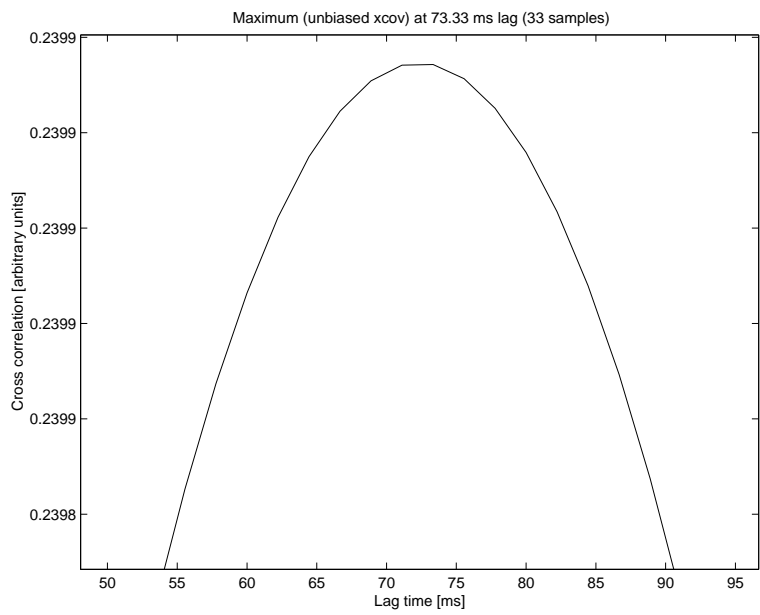


Figure 4: Zooming in on the central peak of Figure 3.

the CVS repository on 2001-12-12. Appendix E contains plots and data files validating the change.

Note that all LX quantities are still treated as sampled simultaneously, at the time of the V3L V4L sampling. This means that the time stamped on V1L and V2L is 6.67 ms too high, while the time value on BPC and BP12 is 6.67 ms too low. The reason for using this timing presumably was to facilitate rough comparisons between the quantities. It may be that this policy should change as well, giving the correct time stamps not only to V3L V4L.

## **Appendix A**

### **Ground test frequency response plots for L filters**

The format of each plot is as follows:

- Top left: Measured amplitude response
- Top right: Measured phase response,  $\phi(f)$
- Low left: Group delay, i.e.  $-\frac{1}{2\pi} \frac{d\phi}{df}$ , calculated from the unwrapped phase.
- Low right: Unwrapped phase (i.e. can take any value)

F9<sub>V</sub>1L<sub>0</sub>

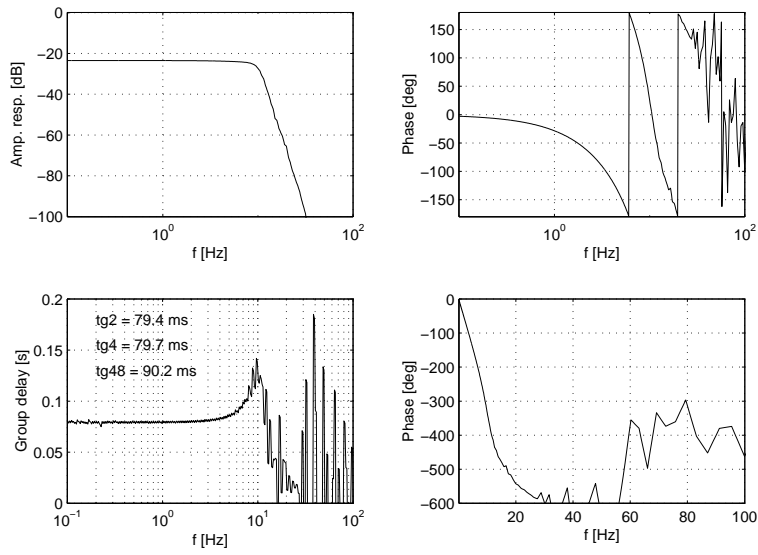


Figure 5: SC1 V1L

F9<sub>V</sub>2L<sub>0</sub>

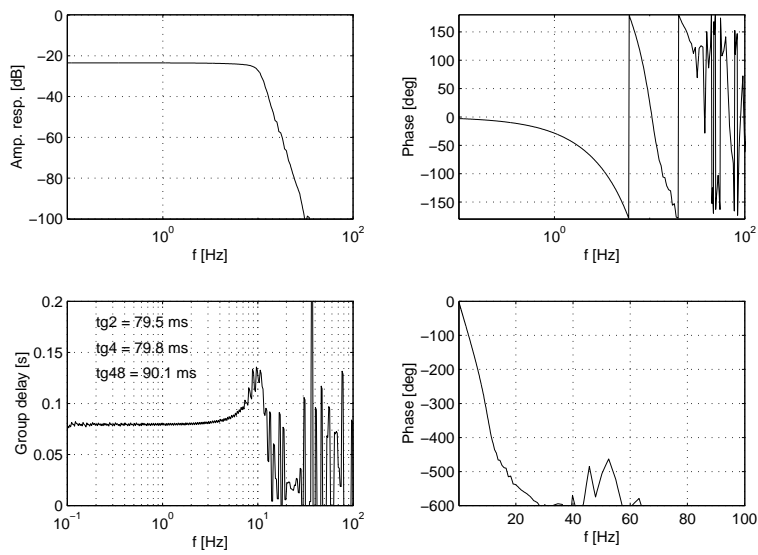


Figure 6: SC1 V2L



F9<sub>V3L</sub>o

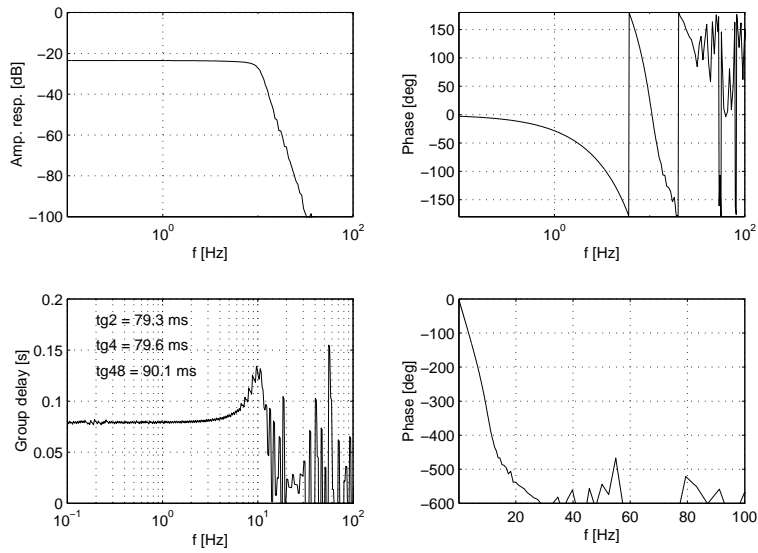


Figure 7: SC1 V3L

F9<sub>V4L</sub>o

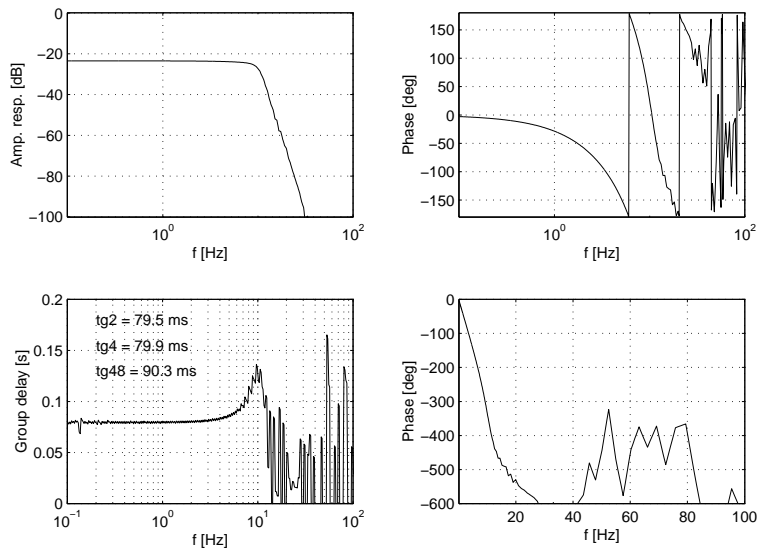


Figure 8: SC1 V4L

F6<sub>V</sub>1L<sub>0</sub>

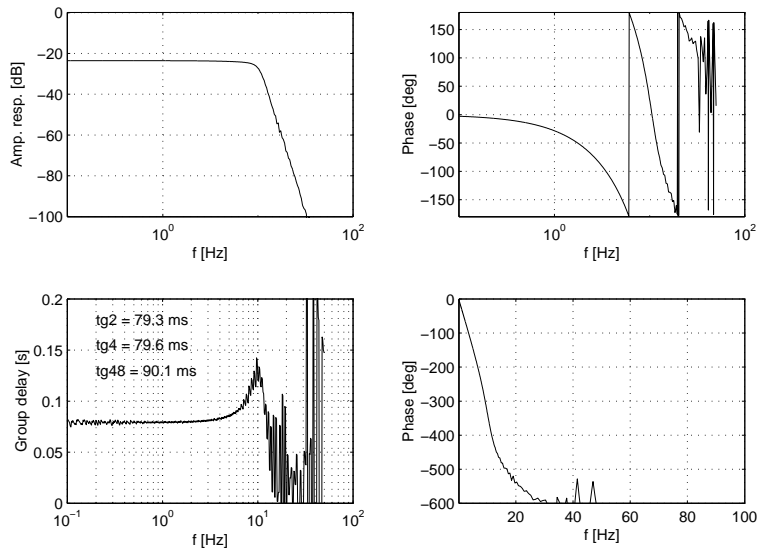


Figure 9: SC2 V1L

F6<sub>V</sub>2L<sub>0</sub>

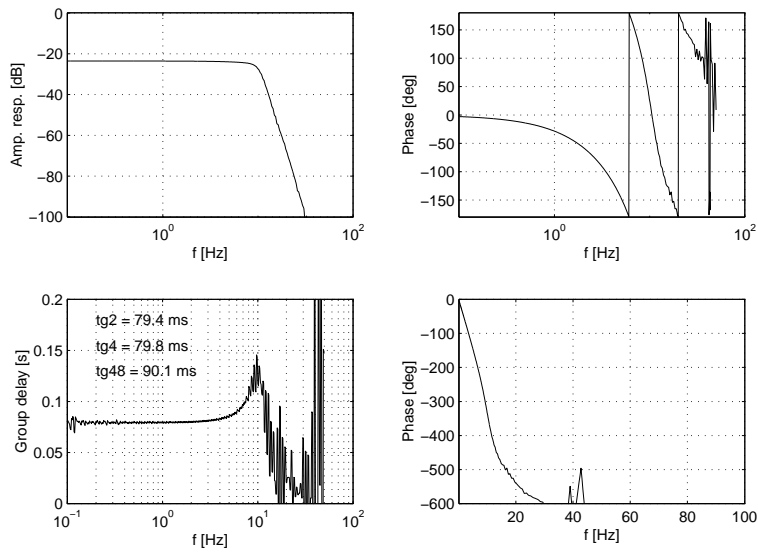


Figure 10: SC2 V2L

F6<sub>V3L</sub>o

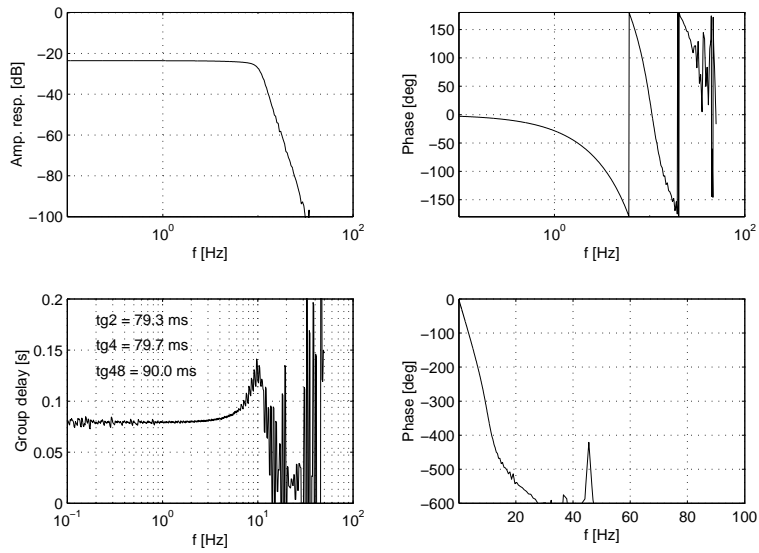


Figure 11: SC2 V3L

F6<sub>V4L</sub>o

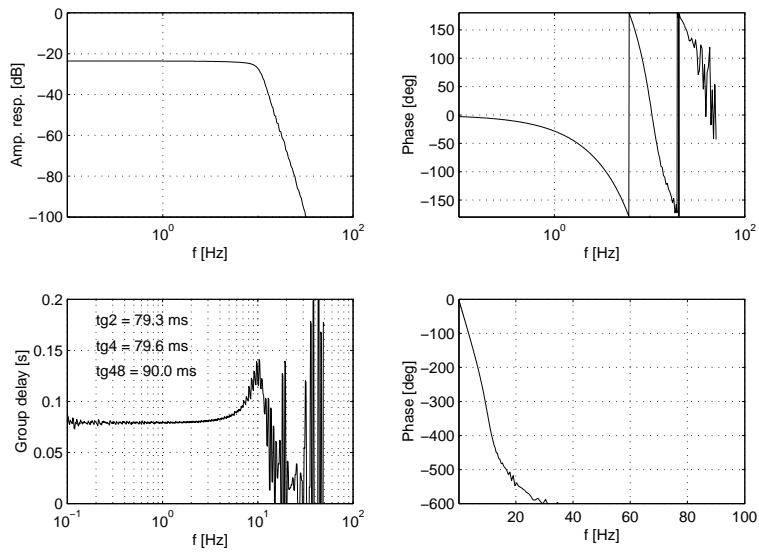


Figure 12: SC2 V4L

F7<sub>v</sub>1L<sub>o</sub>

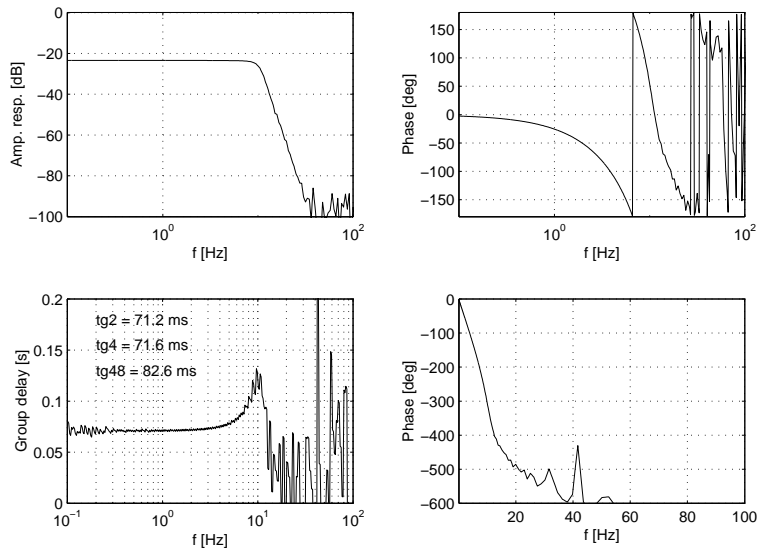


Figure 13: SC3 V1L

F7<sub>v</sub>2L<sub>o</sub>

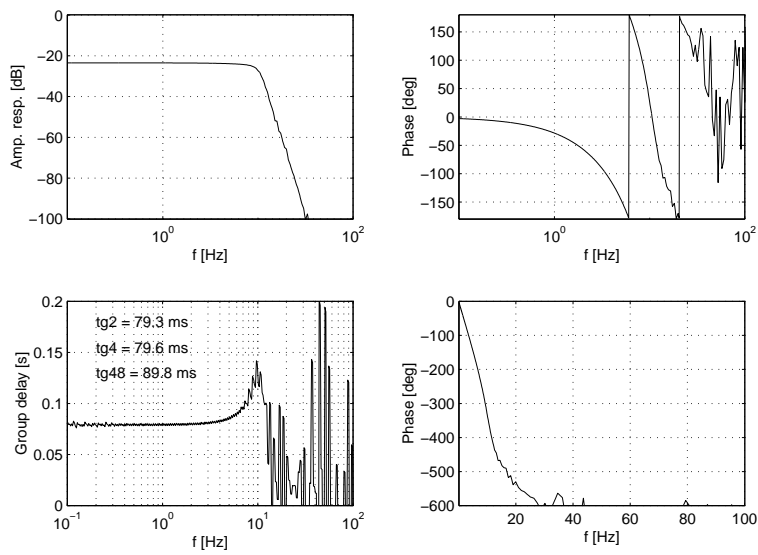


Figure 14: SC3 V2L

F7<sub>V</sub>3L<sub>0</sub>

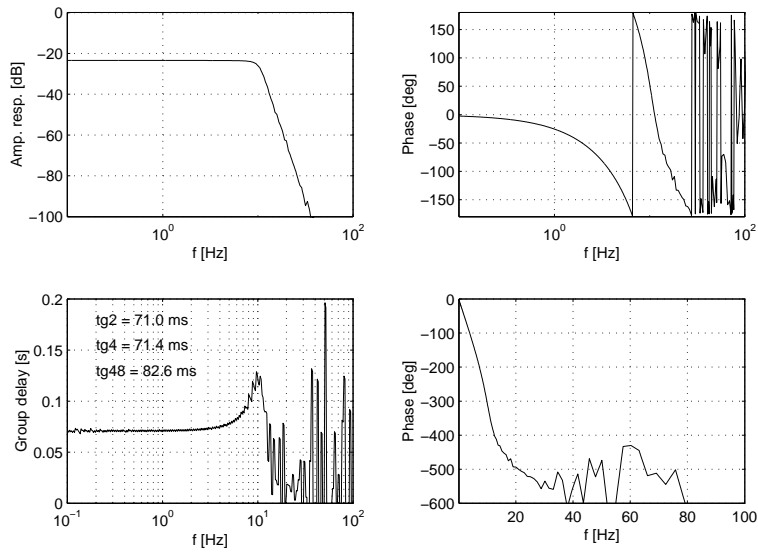


Figure 15: SC3 V3L

F7<sub>V</sub>4L<sub>0</sub>

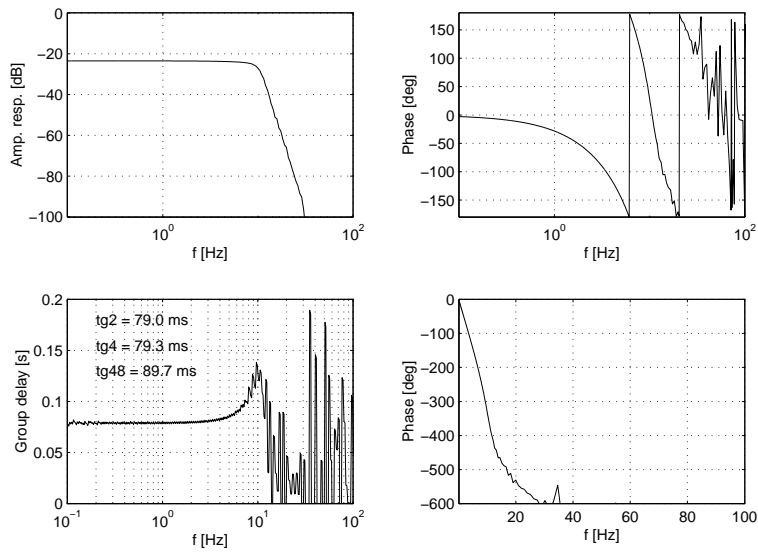


Figure 16: SC3 V4L

F8<sub>V</sub>1L<sub>0</sub>

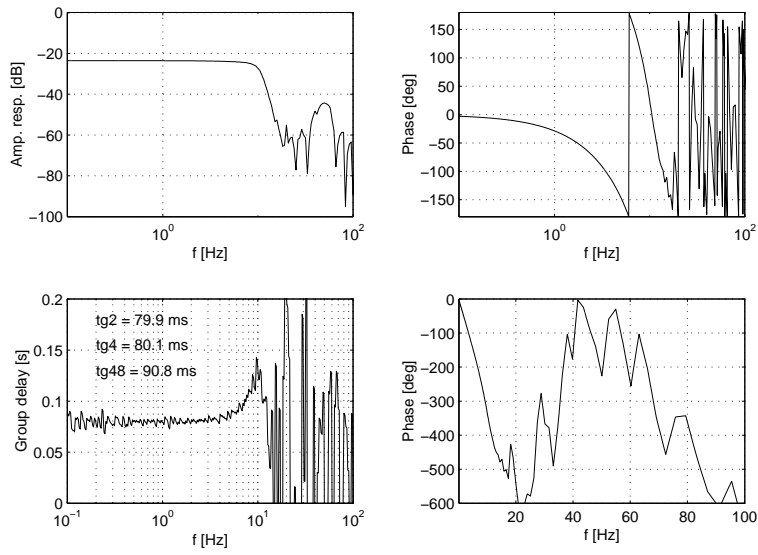


Figure 17: SC4 VIL

F8<sub>V</sub>2L<sub>0</sub>

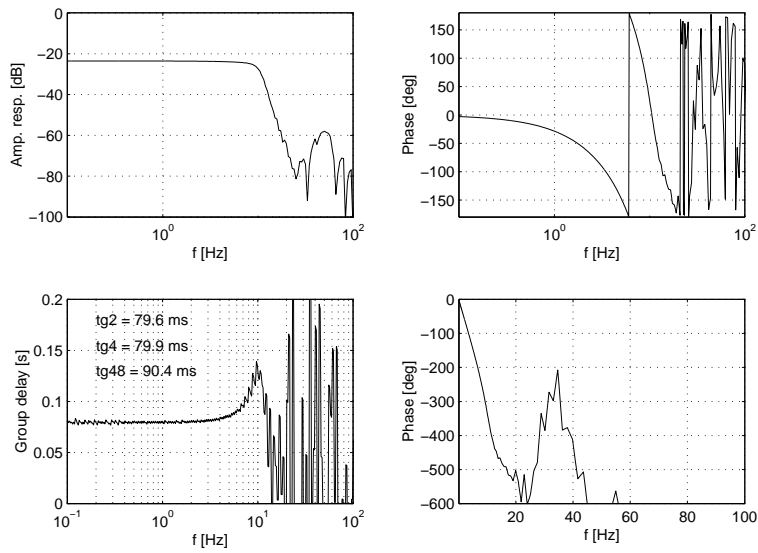


Figure 18: SC4 V2L

F8<sub>V3L</sub>o

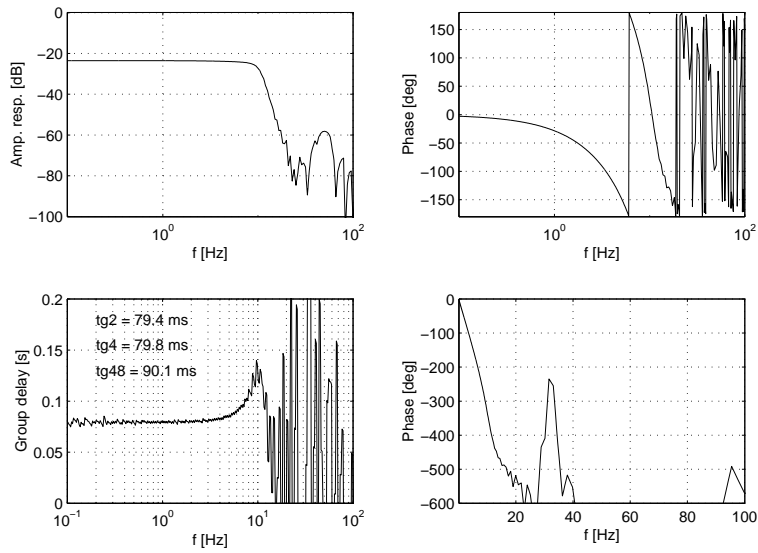


Figure 19: SC4 V3L

F8<sub>V4L</sub>o

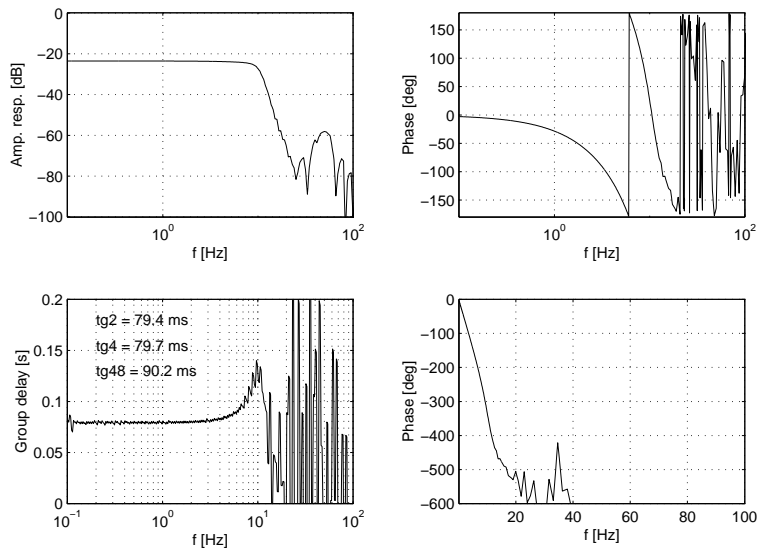


Figure 20: SC4 V4L

## Appendix B

### E-mail on group delay determination in space

Note that this e-mail is erroneous in that it does not consider that the V1L/V2L timing presently used in Isdat is off by 3/450 s (see Section 4).

```
Frn: "Anders Eriksson" <aie@irfu.se>
Till: "Mats Andr" <Mats.Andre@irfu.se>;
<Jackv@cluster1.ssl.berkeley.edu>; "Lennart hln" <ala@irfu.se>;
"Per-Arne Lindqvist" <lindqvist@plasma.kth.se>;
"Forrest Mozer" <mozer@ssl.berkeley.edu>; "Georg Gustafsson" <gg@irfu.se>;
"Arne Pedersen" <arne.pedersen@fys.uio.no>;
"Bjrn Lybekk" <bjorn.lybekk@fys.uio.no>; "Tobia Carozzi" <tc@irfu.se>
mne: Group delay
Datum: den 11 oktober 2000 15:08
```

Friends in space,

I started by looking at already collected useful data from space. Using the BM1 data from Sep 18, one can compare V1L-V2L from Lx with V12M from Hx. The result is that over 30 seconds, V1L-V2L lags V12M by 80 - 84 ms (36-38 samples at 450 Hz). This value should be corrected for the group delay in the 180 Hz filter, which is 1/18 of the 10 Hz delay, so that the resulting value for the 10 Hz delay is 85 - 89 ms.

The procedure for arriving at this was as follows:

- Use interpolation on the Lx data to get it sampled at the same times as the 450 Hz data
- Filter the 450 Hz data at 10 Hz with a zero-shift digital filter
- Remove averages from both signals
- Compute cross correlation
- Find lag for maximum x-corr

Figures can be found at <ftp://irfu.se/pub/aie/EFW>, files ts.ps and xcorr.ps.

I go on with the other approaches to the problem.

Anders



## Appendix C

### Matlab code for cross covariance analysis

The cross covariance is the cross correlation of two signals from which the mean values have been removed. Using an unbiased estimator means that there is a weighting introduced to correct for the fact that there are fewer and fewer points involved when increasing the lag time: this is the reasons for why there are many peaks of similar height in Figures 1 and 3, separated by the spin period. The group delay is found by studying the central peak (Figures 2 and 4).

```
% Matlab routine for comparing V3L and V3M data

% Note that Isdat treats V3L and V4L timing correctly,
% while V1L and V2L are off by 3/450 ms (see file
% EfwLow.c in the Efw server)

load V4L.d;
load V4M.d;

V3L = V4L;
V3M = V4M;

t1 = V3L(:,1);
v1 = V3L(:,2);
tm = V3M(:,1);
vm = V3M(:,2);

% Ensure that there are no M samples outside the interval
% of L samples:
tmin = min(t1);
ind = find(tm <= tmin);
tm(ind) = [];
vm(ind) = [];
tmax = max(t1);
ind = find(tm >= tmax);
tm(ind) = [];
vm(ind) = [];

% Interpolate V3L to V3M timeline (450 S/s):
vc = interp1(t1,v1,tm);

% Find cross-covariance function for vc and vm:
xc = xcov(vc,vm,'unbiased');
xlen = length(xc);
n = (xlen-1)/2;
```

```
lag = (-n:n)'*1000/450; % Lag time [ms]

% Determine lag of maximum:
ind = find(abs(lag)>400);
xc1 = xc;
xc1(ind) = 0;
maxu = find(xc1 == max(xc1));

plot(lag,xc);
xlabel('Lag time [ms]');
ylabel('Cross correlation [arbitrary units]');
titstr = sprintf('Maximum (unbiased xcov) at %.2f ms lag (%.0f samples)',lag(maxu),maxu);
title(titstr);
```

## Appendix D

### EfwLow.c

Omissions are denoted by [...].

```
#include "W.h"
#include "E.h"

/*
 * EfwLowData()
 *
 * Gets one block of Efw waveform data in normal and high bit rate.
 * (Internal burst data and sweep playbacks are handled separately.)
 * The start time of the data is computed and each data point
 * will be time stamped if requested.
 *
 */
int EfwLowData(pOrbit, req, obj, sys, dest, time)
OrbitPtr pOrbit;
DbDataRequest *req;
DbDataObject *obj;
DataInternals *sys;
void *dest;
IsTime *time;
{
    int n;
    int ret;
    int use_hx;
    int ptr;
    double delay;
    IsTime ist;
    IsTime packetTime;
    unsigned char *hkBuf;
    unsigned char *instBuf;
    static int initial_tmode;
    static int any_data;
    static IndexEfwFmt *fmt;
    static Layout *layp;
    void EfwDataCalibrate();

    [...]

    /* Calculate the time of the instrument packet */
    packetTime = WecComputeTime(pOrbit);
    pOrbit->packetTime = packetTime;
}
```

```

/* assume 1.0 sec delay until it's known */
delay = 1.0;
IsSubTimeDouble(&pOrbit->packetTime, delay);

/* WecReadInstrument() increments pOrbit->ptr at the end */
ptr = pOrbit->ptr - 1;
if (ptr < 0) ptr = 0;
fmt = WecGetFormatEntry(pOrbit, ptr);
if (!fmt) {
pOrbit->pending = DbBAD_TIME;
return ERR_ONLY_TIME;
}
layp = EfwGetLayout(pOrbit, req, fmt);
if (!layp) {
pOrbit->pending = DbBAD_CHANNEL;
return ERR_ONLY_TIME;
}

/* recalculate the time of the instrument packet */
pOrbit->packetTime = packetTime;
if (layp->hx) {
/* adjust for HX sampling */
if (pOrbit->efw.tmode) {
delay = 0.1 - 1.0/450.0;
} else {
delay = 1.0 - 1.0/450.0;
}
} else {
/* adjust for LX sampling,
to do it exactly right we need to take into account that
V1V2 is delayed by 26/450, V3V4 by 29/450 and BPCBP12 by 32/450,
to make it simpler we assume 29/450 for all LX quantities */
delay = 1.0 - 1.0/450.0 - 29.0 / 450.0;
}

/* Correct the time for filter group delay (aie@irfu.se Nov 2001) */
if (req->spec.channel == DbCLU_EFW_L) {
/* Group delay taken to be 80 ms for 10 Hz filters */
delay = delay + 0.080;
}
else if (req->spec.channel == DbCLU_EFW_M) {
/* Group delay taken to be 80/18 ms = 4.44 ms for 180 Hz filters */
delay = delay + 0.00444;
}
/* end of aie contribution */

```

```
    IsSubTimeDouble(&pOrbit->packetTime, delay);  
[...]
```

**Appendix E**  
**Validation of Isdat implementation**

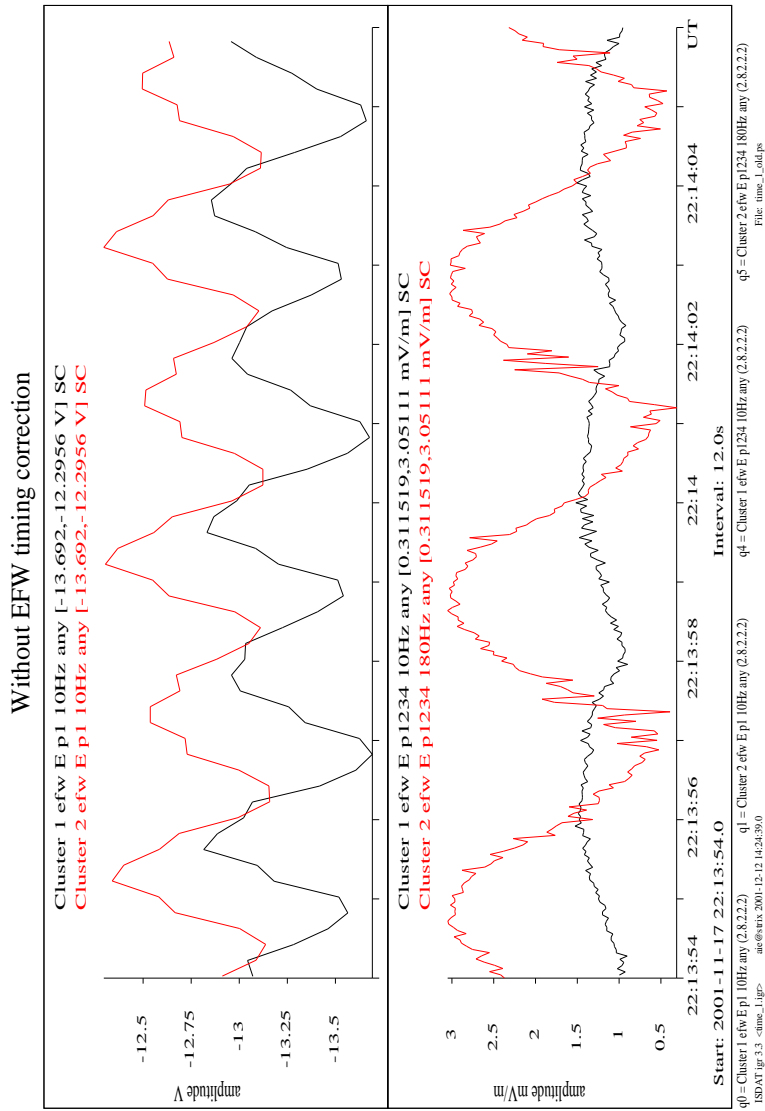


Figure 21: First test interval, no group delay correction.

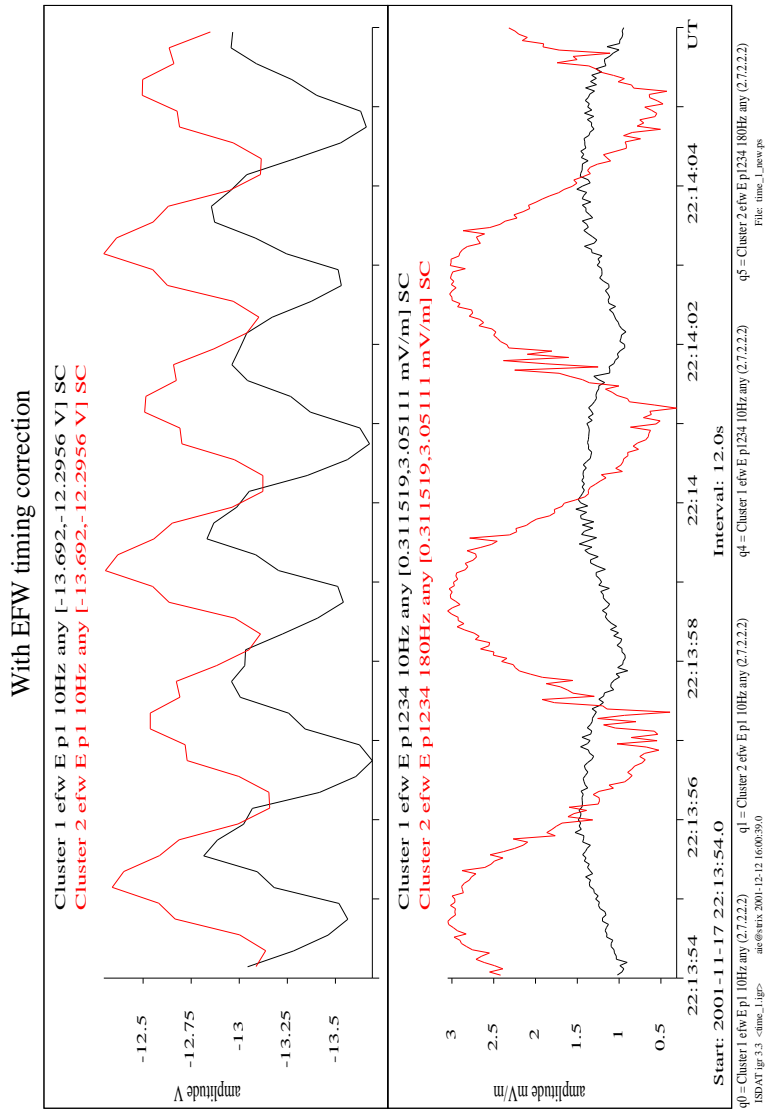


Figure 22: First test interval, with group delay correction.



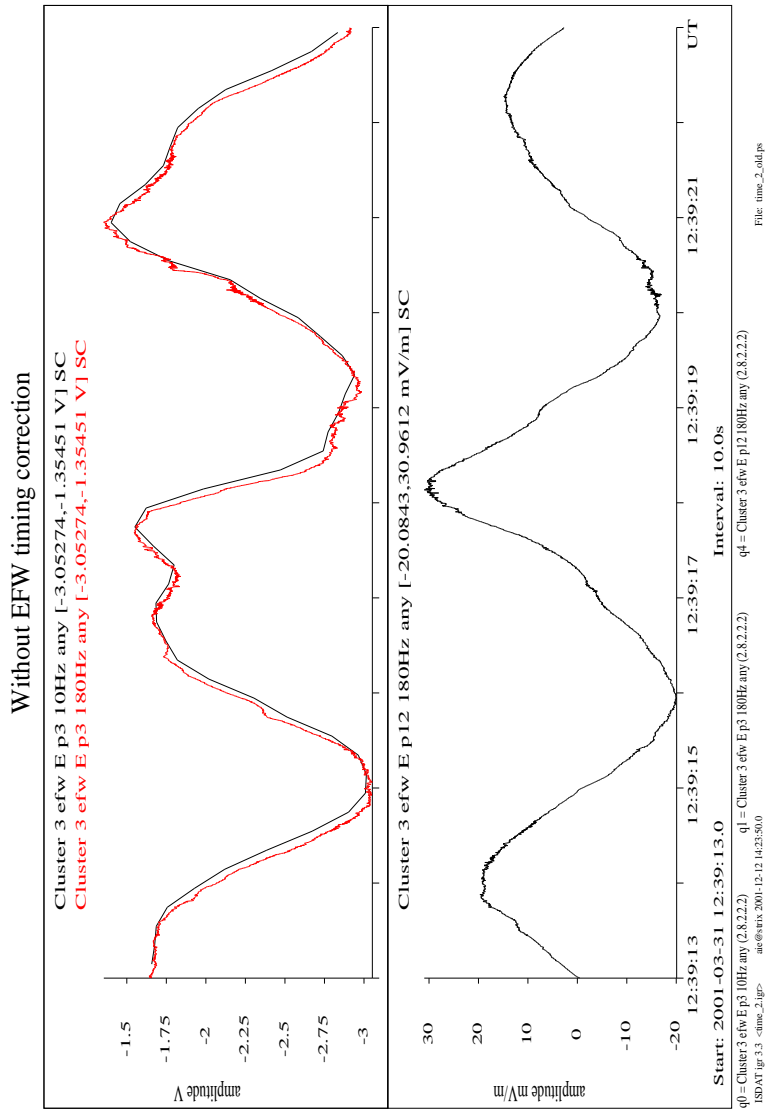


Figure 23: Second test interval, no group delay correction.

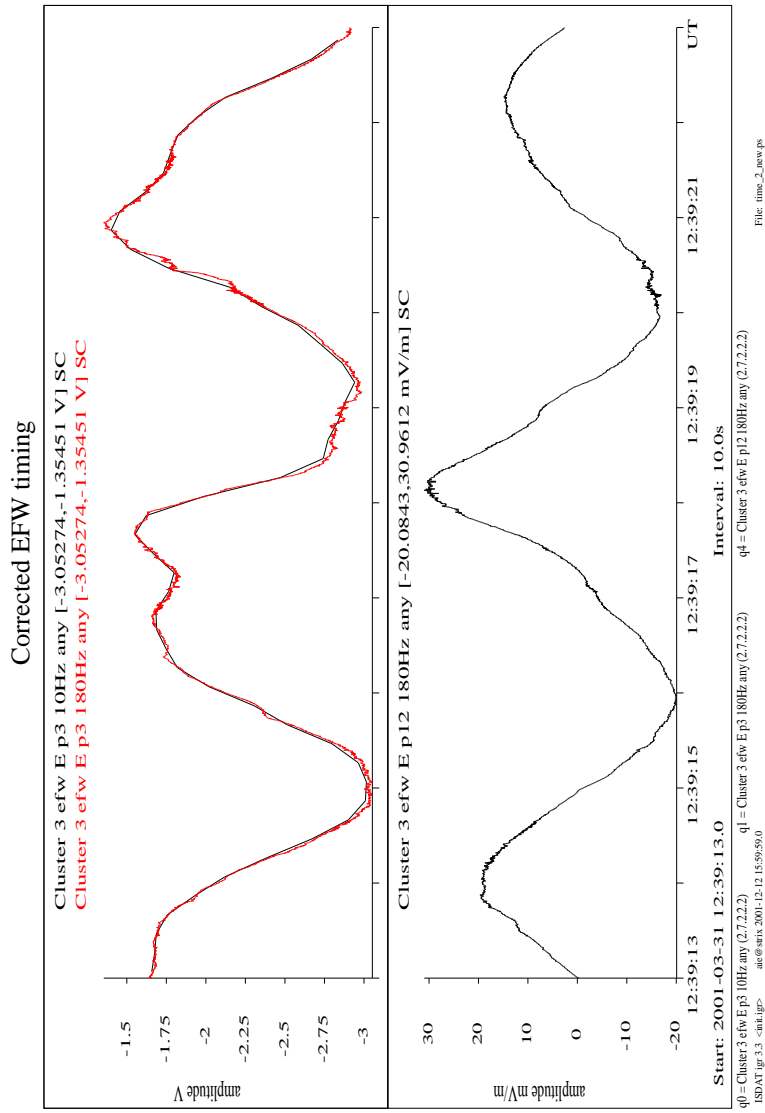


Figure 24: Second test interval, with group delay correction.

## First test interval, uncorrected data, 1 sec

```
# Data from ISDAT igr
#
# Filename:      time_1_new.flat
# Created date:  Wed Dec 12 16:01:14 2001
# Version:      aie@strix 2001-12-12 16:01:14.0
#
#
#
# Time start at: 2001-11-17 22:13:54.0
#
#   Time from start   , Cluster 1 efw E p1 10Hz any SC
#   [s]                [V]
#   0.142812778      -13.04334
#   0.342812778      -13.28187
#   0.542812778      -13.46181
#   0.742812778      -13.56434
#   0.942812777      -13.51831
#
#   Time from start   , Cluster 2 efw E p1 10Hz any SC
#   [s]                [V]
#   0.146062555      -13.08736
#   0.346062555      -13.13736
#   0.546062555      -13.00194
#   0.746062554      -12.66649
#   0.946062555      -12.58107
#
#   Time from start   , Cluster 1 efw E p1234 10Hz any SC
#   [s]                [mV/m]
#   0.038368334      1.020977
#   0.078368334      0.9652172
#   0.118368333      0.9433301
#   0.158368334      0.9908274
#   0.198368334      0.9034953
#   0.238368333      1.033056
#   0.278368334      1.033629
#   0.318368334      1.055883
#   0.358368334      1.061248
#   0.398368333      1.095409
#   0.438368334      1.094337
#   0.478368334      1.07499
#   0.518368333      1.148853
#   0.558368334      1.145806
#   0.598368334      1.166799
```

0.638368333	1.151627
0.678368334	1.127183
0.718368334	1.198606
0.758368333	1.19854
0.798368334	1.157147
0.838368334	1.169763
0.878368333	1.228167
0.918368334	1.246764
0.958368334	1.235733
0.998368333	1.280239

#	Time from start	, Cluster 2	efw	E	p1234	180Hz	any	SC
#	[s]	[mV/m]						
	0.037178111	2.417572						
	0.077178111	2.549442						
	0.117178110	2.390879						
	0.157178111	2.489325						
	0.197178111	2.613529						
	0.237178111	2.711571						
	0.277178110	2.644048						
	0.317178111	2.55168						
	0.357178111	2.754831						
	0.397178110	2.823378						
	0.437178111	2.885927						
	0.477178111	2.903241						
	0.517178110	2.974356						
	0.557178111	2.829762						
	0.597178111	2.933223						
	0.637178110	2.982813						
	0.677178111	3.039574						
	0.717178111	3.048294						
	0.757178110	3.011371						
	0.797178111	2.957516						
	0.837178111	2.965483						
	0.877178110	2.95766						
	0.917178111	3.017627						
	0.957178111	2.964318						
	0.997178110	2.965846						

## First test interval, corrected data, 1 sec

```
# Data from ISDAT igr
#
# Filename:      time_1_old.flat
# Created date:  Wed Dec 12 14:11:13 2001
# Version:      aie@strix 2001-12-12 14:11:13.0
#
#
#
# Time start at: 2001-11-17 22:13:54.0
#
#   Time from start    , Cluster 1 efw E p1 10Hz any SC
#   [s]                [V]
#       0.022812777    -13.07054
#       0.222812778    -13.04334
#       0.422812778    -13.28187
#       0.622812778    -13.46181
#       0.822812778    -13.56434
#
#   Time from start    , Cluster 2 efw E p1 10Hz any SC
#   [s]                [V]
#       0.026062555    -12.91234
#       0.226062555    -13.08736
#       0.426062555    -13.13736
#       0.626062555    -13.00194
#       0.826062554    -12.66649
#
#   Time from start    , Cluster 1 efw E p1234 10Hz any SC
#   [s]                [mV/m]
#       0.038368334    0.9965656
#       0.078368333    0.9268022
#       0.118368334    1.020977
#       0.158368334    0.9652172
#       0.198368333    0.9433301
#       0.238368334    0.9908274
#       0.278368334    0.9034953
#       0.318368333    1.033056
#       0.358368334    1.033629
#       0.398368334    1.055883
#       0.438368334    1.061248
#       0.478368333    1.095409
#       0.518368334    1.094337
#       0.558368334    1.07499
```

0.598368333	1.148853
0.638368334	1.145806
0.678368334	1.166799
0.718368333	1.151627
0.758368334	1.127183
0.798368334	1.198606
0.838368333	1.19854
0.878368334	1.157147
0.918368334	1.169763
0.958368333	1.228167
0.998368334	1.246764

#	Time from start	, Cluster 2 efw E p1234 180Hz any SC
#	[s]	[mV/m]
	0.001618110	2.372681
	0.041618111	2.417572
	0.081618111	2.549442
	0.121618110	2.390879
	0.161618111	2.489325
	0.201618111	2.613529
	0.241618111	2.711571
	0.281618110	2.644048
	0.321618111	2.55168
	0.361618111	2.754831
	0.401618110	2.823378
	0.441618111	2.885927
	0.481618111	2.903241
	0.521618110	2.974356
	0.561618111	2.829762
	0.601618111	2.933223
	0.641618110	2.982813
	0.681618111	3.039574
	0.721618111	3.048294
	0.761618110	3.011371
	0.801618111	2.957516
	0.841618111	2.965483
	0.881618110	2.95766
	0.921618111	3.017627
	0.961618111	2.964318

## Second test interval, uncorrected data

```
# Data from ISDAT igr
#
# Filename:      time_2_old.flat
# Created date:  Wed Dec 12 14:31:04 2001
# Version:      aie@strix 2001-12-12 14:31:04.0
#
#
#
# Time start at: 2001-03-31 12:39:13.0
#
#   Time from start    , Cluster 3 efw E p3 10Hz any SC
#   [s]                [V]
#       0.147437889    -1.657677
#       0.345443667    -1.67616
#       0.545443667    -1.686428
#       0.745443667    -1.75625
#       0.945443666    -1.928751
#
#   Time from start    , Cluster 3 efw E p3 180Hz any SC
#   [s]                [V]
#       0.000771222    -1.65725
#       0.002993444    -1.655176
#       0.005215667    -1.653103
#       0.007437889    -1.655176
#       0.009660111    -1.642735
#       0.011882333    -1.659323
#       0.014104556    -1.642735
#       0.016326778    -1.642735
#       0.018549000    -1.651029
#       0.020771222    -1.640661
#       0.022993444    -1.640661
#       0.025215667    -1.644809
#       0.027437889    -1.648956
#       0.029660111    -1.646882
#       0.031882333    -1.655176
#       0.034104556    -1.661397
#       0.036326778    -1.651029
#       0.038549000    -1.655176
#       0.040771222    -1.659323
#       0.042993444    -1.659323
#       0.045215667    -1.655176
#       0.047437889    -1.661397
#       0.049660111    -1.655176
```

#	Time from start	, Cluster 3 efw E p12 180Hz any SC
#	[s]	[mV/m]
	0.000771222	-0.4605743
	0.002993444	-0.4130016
	0.005215667	-0.2940698
	0.007437889	-0.2464971
	0.009660111	-0.05620632
	0.011882333	-0.05620632
	0.014104556	0.0865118
	0.016326778	0.1816572
	0.018549000	0.2054436
	0.020771222	0.2530163
	0.022993444	0.2530163
	0.025215667	0.371948
	0.027437889	0.4908798
	0.029660111	0.5384525
	0.031882333	0.5146661
	0.034104556	0.5860252
	0.036326778	0.6335979
	0.038549000	0.7287433
	0.040771222	0.7525297
	0.042993444	0.7525297
	0.045215667	0.9428205
	0.047437889	0.9903932
	0.049660111	0.9903932



## Second test interval, corrected data

```
# Data from ISDAT igr
#
# Filename:      time_2_new.flat
# Created date:  Wed Dec 12 16:01:56 2001
# Version:      aie@strix 2001-12-12 16:01:56.0
#
#
#
# Time start at: 2001-03-31 12:39:13.0
#
#   Time from start    , Cluster 3 efw E p3 10Hz any SC
#   [s]                [V]
#       0.067437889    -1.657677
#       0.265443667    -1.67616
#       0.465443667    -1.686428
#       0.665443667    -1.75625
#       0.865443666    -1.928751
#
#   Time from start    , Cluster 3 efw E p3 180Hz any SC
#   [s]                [V]
#       0.000775667    -1.653103
#       0.002997889    -1.655176
#       0.005220111    -1.642735
#       0.007442333    -1.659323
#       0.009664556    -1.642735
#       0.011886778    -1.642735
#       0.014109000    -1.651029
#       0.016331222    -1.640661
#       0.018553444    -1.640661
#       0.020775667    -1.644809
#       0.022997889    -1.648956
#       0.025220111    -1.646882
#       0.027442333    -1.655176
#       0.029664556    -1.661397
#       0.031886778    -1.651029
#       0.034109000    -1.655176
#       0.036331222    -1.659323
#       0.038553444    -1.659323
#       0.040775667    -1.655176
#       0.042997889    -1.661397
#       0.045220111    -1.655176
#       0.047442333    -1.66347
#       0.049664556    -1.661397
```

#	Time from start	, Cluster 3 efw E p12 180Hz any SC
#	[s]	[mV/m]
	0.000775667	-0.2940698
	0.002997889	-0.2464971
	0.005220111	-0.05620632
	0.007442333	-0.05620632
	0.009664556	0.0865118
	0.011886778	0.1816572
	0.014109000	0.2054436
	0.016331222	0.2530163
	0.018553444	0.2530163
	0.020775667	0.371948
	0.022997889	0.4908798
	0.025220111	0.5384525
	0.027442333	0.5146661
	0.029664556	0.5860252
	0.031886778	0.6335979
	0.034109000	0.7287433
	0.036331222	0.7525297
	0.038553444	0.7525297
	0.040775667	0.9428205
	0.042997889	0.9903932
	0.045220111	0.9903932
	0.047442333	1.085539
	0.049664556	1.061752