



Calibration Report of the **WBD** Measurements in the Cluster Active Archive (CAA)

prepared by

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1 Introduction

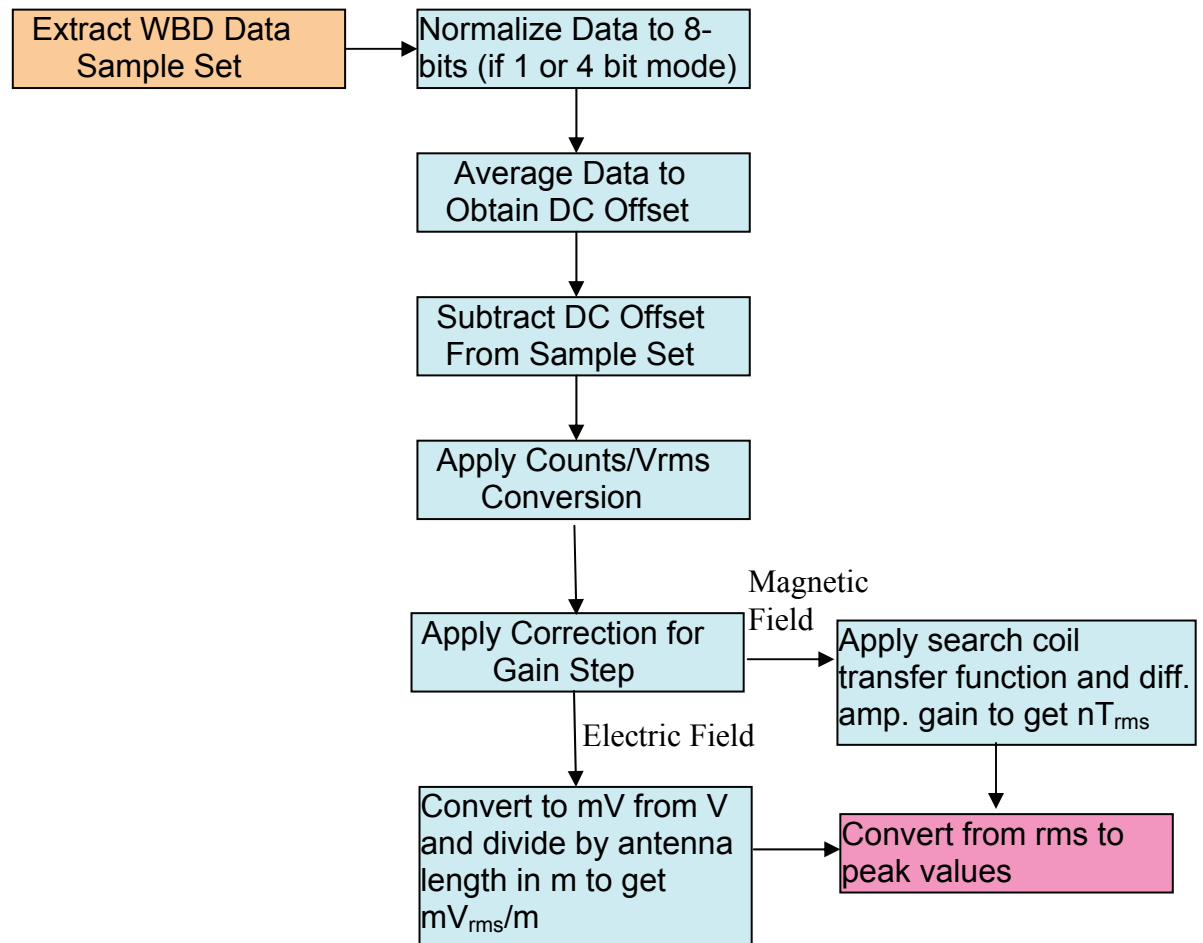
This document describes the procedure for obtaining calibrated data values from the Cluster Wideband Data (WBD) Receiver raw telemetry values. The calibrations supplied here are first order calibrations, which are suitable for most data analysis purposes. The calibration method described below was used when creating the WBD CDF calibrated data files, which are archived at NASA's CDAWeb, and the WBD CEF files, which were created from the CDF files and which are archived at the Cluster Active Archive (CAA). The same calibration method has been used in the example software (CALIBRATE.C) which is available on the WBD website at <http://www-pw.physics.uiowa.edu/cluster/dvd/>. Please note that a more accurate calibration could be achieved by using frequency dependent tables as discussed in Section 4, B(4), but there are no plans to develop these tables at the present time.

2 Instrument Description

The Wideband Data (WBD) Plasma Wave Investigation for CLUSTER provides wideband (bandwidths up to 77 kHz) waveform measurements of plasma waves in the Earth's magnetosphere. A Wideband Receiver system which measures electric and magnetic fields over the frequency range 100 Hz to 577 kHz is provided by the WBD investigation as part of the Wave Experiment Consortium (WEC) instrumentation. The WBD technique involves transmitting band-limited waveform (time series) data, in real time, to a NASA DSN or Czech Republic Panska Ves ground station using a high-rate data link. This is the unique aspect of the WBD instrument since all other Cluster data are obtained and stored onboard for later playback to a receiving antenna on the ground. The primary advantage of the WBD approach is that complete, high-resolution, electric or magnetic field waveforms are available along one axis for detailed time and/or frequency analysis. Infrequently, WBD obtains data through an onboard Burst Mode 2 (BM2) mode which means the data are stored onboard and played back with other Cluster data, but this mode has drawbacks for WBD and the other instruments. For a more complete description of the WBD instrument, the user is referred to the WBD User Guide located at the CAA, and the references included at the end of that document.

3 Measurement Calibration Procedures

The WBD calibration procedure is straightforward. Apart from issues regarding the length of the electric field antenna used in obtaining scientific units of mV/m of the electric field data obtained by WBD, the calibration employed for WBD data does not change over time. Below is a flow diagram showing the steps which are carried out in calibrating the WBD data.



4 Measurement Processing Procedures

A. Calibrated Time Series (Waveforms)

The following equations are used to obtain a calibrated WBD time series, either electric or magnetic field depending on the antenna that has been selected:

$$E_m = \frac{-(\text{Raw Counts} - \text{DCoffset}) * \sqrt{2} * 1000}{\text{counts} / V_{rm} * \text{antenna length} * 10^{G/20}} \quad (1)$$

$$B_n = \frac{(\text{Raw Counts} - \text{DCoffset}) * \sqrt{2} * 2}{\text{counts} / V_{rms} * 10^{G/20}} \quad (2)$$

Below is an explanation of how these equations are used and of the various terms therein:

(1) First a snapshot (one minor frame) consisting of 1090 raw WBD data samples (Raw Counts) is obtained from the WBD Level 1 data files. These data samples can be 8-bits (0-255 raw count), 4-bits (0-15 raw count), or 1-bit in size (0-1 raw count). The following calibrations are specified for 8-bit samples, so the raw counts for the 4-bit samples should be shifted up 4 bits and the 1-bit samples should be shifted up 7 bits to produce 8-bit samples for any data size. There are a number of options for the lower bits after shifting up: zeroes can be left in those bit positions, or the shifted bits can be replicated in the lower bit positions, or random noise could be inserted into those bit positions. Since the values of the lower bits are not known, any of these options are valid.

(2) Because the WBD receiver is an AC-coupled system, the 1090 raw data samples ranging from 0 to 255 represent the values of the AC field fluctuating around the zero AC field of 127.5 (1/2 of 256 for 8-bit mode) if no DC field is present. However, a small residual DC field is often present even though the WBD filters are designed to filter out the DC field. In order to remove the residual DC field from the AC measurements, the 1090 raw data samples are averaged to obtain a "DC offset" which is specific to these 1090 samples and which should be

close to 127.5 for 8-bit mode. This resulting DC offset is then subtracted from the each of the 1090 samples. Removing this DC offset is necessary for the next step in the calibration procedure.

(3) The proper counts-to-Volts-rms factor is now applied to the data. This is the amplitude (in counts) of a sine wave in the middle of the passband which would be measured by the WBD receiver if a 1 Volt-rms signal were injected into the electric or magnetic differential amplifier and the WBD receiver had no gain amplifier turned on. The 1090 samples, which have been adjusted by the DC Offset, are all divided by this factor. Another way this is expressed is the decibels (dB) below a maximum amplitude sine wave, which can range from 0 through 255 for 8-bit data. This is the number of dBs below a sine wave of amplitude 127.5 counts and is referred to as dBmax. This factor depends upon the WBD mode:

<u>Translation Mode</u>	<u>Filter</u>	<u>counts/V-rms</u>	<u>dBmax</u>
Baseband	9.5 kHz	52.5	-7.7
Baseband	19 kHz	51.0	-8.0
Baseband	77 kHz	55.5	-7.2
125 kHz	9.5 kHz	26.5	-13.6
125 kHz	19 kHz	27.0	-13.5
125 kHz	77 kHz	30.0	-12.6
250 kHz	9.5 kHz	27.0	-13.5
250 kHz	19 kHz	27.5	-13.3
250 kHz	77 kHz	30.0	-12.6
500 kHz	9.5 kHz	18.0	-17.0
500 kHz	19 kHz	18.0	-17.0
500 kHz	77 kHz	30.0	-12.6

(4) Next the WBD gain amplifier value must be divided out. The gain can vary from 0 dB through 75 dB in steps of 5 dB. If the gain is G, then the 1090 samples should all be divided by $10^{G/20}$.

NOTE: The next (5th) step in the calibration process is different for the electric field than for the magnetic field.

(5E) To obtain the magnitude of the electric field for the electric antennas (Equation 1), we must now multiply by 1000 (to convert Volts to milliVolts/meter) and divide by the effective antenna length, thus obtaining units of milliVolts-rms per meter. Here the effective antenna lengths are defined as the physical tip-to-tip lengths, or tip to center of spacecraft for those antennas in which one of the EFW probes have failed. The following table lists the antenna lengths that are used when calibrating WBD electric data (note that the date ranges are not necessarily indicative of the actual dates of failure of EFW probes):

Spacecraft	Ez Antenna Length (m)	Ey Antenna Length (m)
1	Feb. 1, 2001 – Apr. 30, 2009: 88 May 1, 2009 – present: 44	Feb. 1, 2001 – Oct. 27, 2009: 88 Oct. 28, 2009 – present: 44
2	Feb. 1, 2001 – April 30, 2009: 88 May 1, 2009 – present: 44	Feb. 1, 2001 – present: 88
3	Feb. 1, 2001 – April 30, 2009: 88 May 1, 2009 – present: 44	Feb. 1, 2001 – present: 88
4	Feb. 1, 2001 – present: 88	Feb. 1, 2001 – present: 88

Please be aware that the effective antenna length may differ from the physical length in some regions of Cluster's orbit (see Beghin et al., 2005).

(5M) To obtain the magnitude of the magnetic field for the magnetic search coil antennas (Equation 2), we now apply the search coil transfer function of 1 Volt = 1 nT by dividing by 1 (in effect multiplying counts/V-rms by 1 to get counts/nT-rms), and also take into account a -6 dB gain factor in the magnetic sensor differential amplifiers by multiplying by 2, thus obtaining units of nT-rms.¹

(6) Finally, we multiply both equations (1) and (2) by the square root of 2 in order to obtain peak field values, as opposed to rms (root mean square) values. The units of the electric field will be mV/m peak and of the magnetic field will be nT peak.

¹ Magnetic calibration is only valid in the range of 70 Hz to 4 kHz.

At this point, we have a calibrated time series (for those who wish to obtain a calibrated spectrogram, see Section 2B below). The greatest error associated with the calibrated values of the WBD data resides in the gain term in the denominator of Equations (1) and (2) because the uncertainty in this term can be 1 gain step, or 5 dB (see WBD Caveats document for more detail on this possible error). Thus, the user should assume that the calibrated WBD electric and magnetic field values have an error bar of +/- two times the calibrated value. In reality the error in these measurements is probably much lower than this, but we provide the worst case as a guideline. In addition, the accuracy of the time tags (Epoch variable) associated with those field values is stated to be 50 μ s. This again is the worst case, since the WBD team has two different methods of obtaining the time tags, either through the ground receive times supplied by the ground station, or through the onboard time counter that accompanies every WBD frame to the ground. The WBD team supplies the time tag with the best accuracy for each track based on a number of different factors. Refer to the WBD Caveats document for more information on time tags.

B. Calibrated Spectrogram Using an FFT

The preferred method for obtaining a calibrated spectrogram from a calibrated time series is to use a Fast Fourier Transform (FFT). When an FFT is being used, it is very important to first check the normalization of a given FFT implementation: Apply the FFT (using a simple rectangular window) to a sine wave of amplitude A ; square the real and imaginary parts of each FFT coefficient; add each resulting pair; sum over all coefficients; then take the square root of the sum. Divide the rms amplitude of the input wave ($A/\sqrt{2}$) by the above square root of the sum to obtain the FFT normalization factor. Note that the normalization factors may be different for different FFT implementations, but if the FFT is equivalent to the discrete Fourier transform in the form $F_u = 1/N \sum f_x \exp(i2\pi ux/N)$, the FFT normalization factor is equal to $\sqrt{2}$.

To obtain a calibrated spectrogram of the WBD data using an FFT, below is a suggested series of steps that should be undertaken:

- (1) Complete steps A(1) through A(5) to obtain the calibrated time series of the rms electric field or of the magnetic field if the raw, uncalibrated waveform data are being used. If the

WBD calibrated time series data are obtained from the CDAWeb CDF or CAA CEF data files, proceed directly to Step 2.

(2) First reverse step A(6) to go back to the rms values. Apply a Hann window to a calibrated sequence of N continuous samples. Some **caution** should be used with regard to selecting these N samples if the data period being analyzed is from a noncontinuous mode (refer to the WBD User Guide) as it may be undesirable to apply an FFT across data points separated by a gap in time. For a Hann window the coherent gain is 0.5 (Harris, 1978). Therefore the N samples must be multiplied by 2 if the Hann window is used. The coefficients for a Hann window are

$$H_i = 0.5 [1 - \cos(2\pi i / N)] \text{ for } i = 0 \dots N-1.$$

(3) An FFT should be performed on the N samples, ensuring that the FFT output is properly normalized (multiplied by the FFT normalization factor - refer to the first paragraph of this section B). The phase information from the FFT is not useful, so the magnitudes can now be calculated by squaring the real and imaginary parts, summing them, and taking the square root.

(4) Now the frequency-dependent adjustments can be made if frequency dependent calibration tables are available. The calibration table provided for the time series in Step A(3) above gives frequency-independent calibration factors. However, the WBD amplitude response is not necessarily constant across any of the WBD passbands, so frequency-dependent calibration adjustments may be helpful for some applications of WBD data. There are no plans to develop frequency dependent calibration tables at this time. The errors associated with using the frequency-independent calibration tables are small and exist primarily on the edges of the passbands. Frequency-dependent calibration adjustments will probably be of minimal benefit to most users of WBD data.

(5) At this point we have meaningful geophysical units: At each FFT frequency we have for the electric antennas the electric field in mV-rms/m, and for the magnetic sensors we have the magnetic field in nT-rms.

(6) Finally, to obtain spectral density, one must square the values obtained from Steps B(3) through B(5) and divide by the bandwidth, which depends upon the type of window function used before performing the FFT. If no window function is used, then the equivalent noise bandwidth is the FFT bin width, which is the sampling frequency, f_s , divided by the number of samples, N , sent into the FFT (f_s/N). Note that the sampling frequency can take on three different values depending on the WBD filter mode (Bandwidth). Refer to Table 2.4 in the WBD User Guide for these sampling frequencies. If the Hann window suggested above is used, then the equivalent noise bandwidth is 1.5 times the FFT bin width (Harris, 1978). This operation applies for both electric field and magnetic field spectral density, obtaining units of $mV_{rms}^2/m^2/Hz$ or nT_{rms}^2/Hz , respectively. **CAVEAT: The magnetic calibrations are only valid in the range of 70 Hz to 4 kHz. The WBD receiver obtains frequency components in the passband of 70 Hz to 9.5 kHz, the filter mode that should be used when obtaining magnetic data with the search coil. However, the STAFF search coil provides calibrated data only up to its roll-off at 4 kHz. Frequency components above 4 kHz may be observed in the spectrum of WBD data, but the obtained spectral density of those frequencies is invalid.**

(7) If the translation mode of the data is non-zero, then the value of that translation needs to be added to the FFT frequency that corresponds to each FFT amplitude calculated in the above steps. This shift accounts for the downconversion process that was used when acquiring such data. See the WBD User Guide, Section 2, for more information on this downconversion.

C. Special Processing Procedures

There are no special measurement processing procedures for WBD. However, some users of WBD data may be interested in the raw data values (values of 0 to 255) originally measured on the spacecraft and telemetered to the ground for initial processing by the WBD team. The WBD team has developed a routine for reversing the calibration procedure in order to obtain these raw data values. A description of the routine and a sample IDL program to carry out this reverse calibration is supplied in Appendix A.

5 Results of Calibration Activities

The results of the WBD calibration activities are the production of WBD CDF files, containing calibrated waveform (time series) data, and calibrated spectrograms of all WBD data intervals. The user is referred to the WBD User Guide archived at the CAA for a description of these calibrated data products. The CDF files that are produced are converted to CEF format at the CAA and made available for download to CAA users. The user is strongly recommended to consult the WBD User Guide, WBD Interpretation Issues, and WBD Caveats documents in order to help them analyze the WBD data and to avoid misinterpretation or misuse of the data. All of these documents are available through the CAA.

6 Results of Cross-Calibration Activities

WBD has analyzed the cutoff frequency of the L-X mode waves sometimes observed in the magnetotail where the plasma density is low, i.e., the plasma frequency lies well below 10 kHz. This cutoff frequency gives a good measure of the local plasma density for comparison with the density values obtained by PEACE. When the cutoff frequency is above 2 kHz, it can also be compared to the cutoff frequency observed in the WHISPER spectrum. Cluster traverses the magnetotail roughly in the months of June through October each year. Thus, the WBD team's analysis of the L-X mode cutoff frequency is confined to those months each year. The comparison of the densities obtained by WBD when compared to those obtained by PEACE is sometimes quite good. The user is referred to the cross calibration section of the CAA website for more information.

Early in the mission, WBD data spectral densities were compared to those of WHISPER and STAFF in the overlapping frequency ranges resulting in some needed corrections to some of the STAFF calibrations. In addition, the electric field amplitudes in the time domain were compared between EFW and WBD, resulting in a sign correction for the WBD data, and in a time shift for the time tagging of the EFW data.

7 Summary

The WBD time series data have been fully calibrated using the procedures described in this document. This calibration procedure and the calibration factors do not change over time with one exception. Due to failures of some of the EFW probes contained in the electric field antennas used by WBD to make its electric field measurements, the actual full tip to tip length of these antennas cannot be used, but is instead modified to half the length using the spacecraft center as one of the tips (see the table in Section 4). Calibrated time series data have been archived at the CAA along with pre-generated calibrated spectrograms of the WBD data. An estimate of the errors associated with the WBD calibrated electric and magnetic field values and the accuracy of the time tags (Epoch variables) attached to those field variables has been provided at the end of Section 4(A) above.

8 References

- F. J. Harris, On the Use of Windows for Harmonic Analysis with the Discrete Fourier Transform, *Proceedings of the IEEE* 66 (1), 51-83, 1978.
- C. Beghin, P. M. E. Decreau, J. Pickett, D. Sundkvist, and B. Lefebvre, **Modeling of Cluster's Electric Antennas in Space: Application to Plasma Diagnostics**, *Radio Science*, 40, RS6008, doi:10.1029/2005RS003264, Nov. 24, 2005.



APPENDIX A

For anyone who wishes to work with the WBD data in its raw, uncalibrated state, i.e., with the raw data values 0 to 255 (raw counts in equations 1 and 2) as measured onboard, the following routines, written in IDL, should suffice for the purposes of reverse calibration. First, the user will need to read the WBD data from the CEF files. The generic CEF reader can be downloaded from the CAA along with the WBD data for the interval of interest.

=====

ROUTINE FOR READING CEF FILE:

```

;Attempt to read a Cluster WBD waveform CEF file downloaded
;from the CAA using the caa_cef_read.pro routine downloaded from the CAA.
;
;Pointers are used in this routine, but it returns a structure called wbd
;to the main program.
;
;EXAMPLE:
;Path to the CEF file and the CEF filename
;file_path='/home/kms/caa_data/cef_files/C3_CP_WBD_WAVEFORM/'
;filename='C3_CP_WBD_WAVEFORM_20020217_091600_20020217_091700_V101216.cef'
;time_range='2002-02-17T09:16:00/2002-02-17T09:17:00'
;
;file_path='/home/kms/caa_data/cef_files/C4_CP_WBD_WAVEFORM/'
;filename='C4_CP_WBD_WAVEFORM_20020121_015400_20020121_015500_V110125.cef'
;time_range='2002-01-21T01:54:00/2002-01-21T01:55:00'
;
;IDL>caa_cef_wbd_waveform_read,filename,file_path,time_range,wbd
;
;IDL> help,wbd,/struct
;** Structure WBD_DATA, 13 tags, length=92208200, data length=92208200:
; TJULDAY          DOUBLE      Array[1, 1646575]
; BANDWIDTH        FLOAT       Array[1, 1646575]
; TRANSLATION      FLOAT       Array[1, 1646575]
; RESOLUTION       LONG        Array[1, 1646575]
; ANTENNA          LONG        Array[1, 1646575]
; GAIN             LONG        Array[1, 1646575]
; ANT_BANGLE       FLOAT       Array[1, 1646575]
; ANT_XGSE_ANGLE   FLOAT       Array[1, 1646575]
; ANT_YZGSE_ANGLE  FLOAT       Array[1, 1646575]
; DC_OFFSET        FLOAT       Array[1, 1646575]
; E_WAVEFORM       FLOAT       Array[1, 1646575]
; B_WAVEFORM       FLOAT       Array[1, 1646575]
; QUALITY          LONG        Array[1, 1646575]

```

PRO caa_cef_wbd_waveform_read,filename,file_path,time_range,wbd

;Compile the caa_cef_read.pro set of routines. At the IDL command line,
;I would just type '.compile caa_cef_read' but inside a procedure I need
;to use IDL's resolve_routine procedure to do this. Trying to compile
;the routines as if they were a batch file using '@caa_cef_read' only
;works inside a main program.



```
resolve_routine,'cef_read',/compile_full_file,/is_function
status=routine_info()

print,status
;$MAIN$ CAANOTIFY CAA_CEF_FGM_5VPS_READ CEFREADDATA EXAMPLE1 EXAMPLE2 FILTERNAMES

;Call the routine to read the CEF file
result=cef_read(file_path+filename,trange=time_range,/julday)

;help,result
;RESULT          POINTER    = Array[7]

;Loop to read in the names of the variables in this file. Note that we need
;to put a * at the beginning of the variable result because it is a pointer.
for i=0, n_elements(result)-1 do print, i, ': ', (*result(i)).VARNAME
;This gives the result
;INFO: Reading data records, please wait...
;% Compiled module: JULDAY.
;INFO: Finished reading
/home/kms/caa_data/cef_files/C4_CP_WBD_WAVEFORM/C4_CP_WBD_WAVEFORM__20020121_015400_20020121
_015500_V110125.cef
;      0: time_tags_C4_CP_WBD_WAVEFORM
;      1: Bandwidth_C4_CP_WBD_WAVEFORM
;      2: Translation_C4_CP_WBD_WAVEFORM
;      3: Resolution_C4_CP_WBD_WAVEFORM
;      4: Antenna_C4_CP_WBD_WAVEFORM
;      5: Gain_C4_CP_WBD_WAVEFORM
;      6: Ant_B_Field_Angle_C4_CP_WBD_WAVEFORM
;      7: Ant_Xgse_Angle_C4_CP_WBD_WAVEFORM
;      8: Ant_YZgse_Plane_Angle_C4_CP_WBD_WAVEFORM
;      9: DC_Offset_C4_CP_WBD_WAVEFORM
;     10: E_C4_CP_WBD_WAVEFORM
;     11: B_C4_CP_WBD_WAVEFORM
;     12: Quality_C4_CP_WBD_WAVEFORM

;Print out a few of the time tags
nparam=0
;print,(*result(0)).data(0:3)
;IDL prints out (note this was done without the /julday keyword)
;2002-01-21T01:54:00.021808104Z
;2002-01-21T01:54:00.021812659Z
;2002-01-21T01:54:00.021817214Z
;2002-01-21T01:54:00.021821769Z
;With the /julday keyword, we get the Julian days instead.

;help,(*result(0)),/struct
;** Structure <1290d284>, 67 tags, length=19761376, data length=19761369, refs=1:
;  ERROR          INT          0
;  NGLOBAL        INT          42
;  NPARAM         INT          1
;  NREC           LONG         1646575
;  EOR            BYTE         36
;  FILE_NAME      STRING
'C4_CP_WBD_WAVEFORM__20020121_015400_20020121_015500_V110125.cef'
;
;
;... and so on.
```



```

STOP

;Julian day
tjulday=(*result(0)).data

;Bandwidth and other parameters
bandwidth=(*result(1)).data
translation=(*result(2)).data
resolution=(*result(3)).data
antenna=(*result(4)).data
gain=(*result(5)).data
ant_bangle=(*result(6)).data
ant_xgse_angle=(*result(7)).data
ant_yzgse_angle=(*result(8)).data
dc_offset=(*result(9)).data

;Finally we get to the waveforms.
e_waveform=(*result(10)).data
b_waveform=(*result(11)).data

;Data quality flag
quality=(*result(12)).data

wbd={WBD_Data,tjulday:tjulday,bandwidth:bandwidth,translation:translation,$
      resolution:resolution,antenna:antenna,gain:gain,ant_bangle:ant_bangle,$
      ant_xgse_angle:ant_xgse_angle,ant_yzgse_angle:ant_yzgse_angle,$
      dc_offset:dc_offset,e_waveform:e_waveform,b_waveform:b_waveform,$
      quality:quality}

END

```

=====

ROUTINE FOR REVERSING THE WBD CALIBRATION TO RAW VALUES:

```

;+
;
; NAME: CLUSTER_WBD_REVERSE_CAL_CDAWEB
;
; PURPOSE:
;
; This routine will perform the reverse calibration on WBD electric and magnetic
; field waveform data, converting them from floating point values in mV/m or nT
; into integer or byte values from 0 to 255 counts. Currently, this routine only
; works for 8-bit digital resolution data.
;
; CATEGORY: Cluster WBD CDF Files
;
; CALLING SEQUENCE:
;
; CLUSTER_WBD_REVERSE_CAL_CDAWEB, Wbd_elec, Wbd_mag, Antenna, Bandwidth,
Translation, $
; Resolution, Gain, Dc_offset, Data_quality, $
; Wbd_elec_cnts, Wbd_mag_cnts, Inverse_ecal,
Inverse_bcal, Cal_fac
;
; INPUTS:

```



```
;  
;  
; Wbd_elec: The calibrated WBD electric field array from the CDF file.  
;  
; Wbd_mag: The calibrated WBD magnetic field array from the CDF file.  
;  
; Antenna: An array indicating a value for which antenna was used.  
; Possible values for antenna in the CDF files, 0=Ez, 1=Bx,  
; 2=By, 3=Ey.  
;  
; Bandwidth: The bandwidth values from the CDF files.  
; Possible values of Bandwith in the CDF files are: 9, 19, 77  
;  
; Translation:  
; The translation values (base frequency) from the CDF files.  
; Possible values are: 0, 125, 250, and 500 kHz.  
;  
; Resolution: The digital resolution values from the CDF files. Needed to  
; check to make sure that we have 8 bit data (see RESTRICTIONS  
; below).  
;  
; Gain: The value in dB of the gain from the CDF file.  
;  
; Dc_offset: The DC offset value from the CDF file.  
;  
; Data_quality: The data quality flag (0 or 1) from the CDF file.  
;  
; OUTPUTS:  
;  
; Wbd_elec_cnts: An array containing the reverse-calibrated WBD electric field  
; in counts (0 to 255).  
;  
; Wbd_mag_cnts: An array containing the reverse-calibrated WBD magnetic field  
; in counts (0 to 255).  
;  
; Inverse_ecal: The value by which Wbd_elec was multiplied to obtain the reverse  
; calibrated values  
;  
; Inverse_bcal: The value by which Wbd_elec was multiplied to obtain the reverse  
; calibrated values  
;  
; Cal_fac: An array giving the factor that values in raw counts (minus the  
; zero offset) should be multiplied by to get the calibrated value.  
;  
; RESTRICTIONS:  
;  
; This procedure does not work with 1-bit or 4-bit data. The input arrays must  
; be time series arrays loaded from the CDF file. This routine will not accept  
; 2-d arrays with each waveform stored according to frames, as in the WBD Level 1  
files.  
;  
; MODIFICATION HISTORY:  
;  
; Written by: Kristine Sigsbee March 16, 2009  
;  
; Last Modified: March 17, 2009  
; Added check of digital resolution.  
; Added check of difference from integer values of the data arrays  
; after the reverse calibration factor is applied. This has only been
```




```
; checked using a 77 kHz electric field only file. Need to check a
; file in another mode with magnetic field.
;
;-

PRO CLUSTER_WBD_REVERSE_CAL_CDAWEB, Wbd_elec, Wbd_mag, Antenna, Bandwidth, Translation, $
Resolution, Gain, Dc_offset, Data_quality, $
Wbd_elec_cnts, Wbd_mag_cnts, Inverse_ecal, Inverse_bcal,
Cal_fac

;Some helpful information about the WBD receiver modes and sampling rates.
; MODE BANDWIDTH SAMPLE RATE BITS/SAMPLE DUTY CYCLE SAMPLE TIME (1090)
; 0 10Hz-9,5kHz 27.4kHz 8 100% .0397186279 sec
; 1 10Hz-9,5kHz 27.4kHz 8 100% .0397186279 sec
; 2 50Hz-19kHz 54.9kHz 4 100% .0397186279 sec
; 3 50Hz-19kHz 54.9kHz 8 50% .01985931395 sec
; 4 1kHz-77kHz 219.5kHz 8 12.5% .00496482848 sec
; 5 1kHz-77kHz 219.5kHz 1 100% .0397186279 sec
; 6 1kHz-77kHz 219.5kHz 4 25% .00992965697 sec
; 7 1kHz-77kHz 219.5kHz 8 12.5% .00496482848 sec
; sample rates are 219.54434 Khz 54.88585 Khz 27.44304 Khz
;
;Set up the matrix of calibration values (number of counts 0-255 per
;Volt RMS).
;
; Bandwidth
; B 9 kHz 19 kHz 77 kHz (For Modes 5,6,7?)
; a 0 kHz 52.5 51.0 55.5 55.5
; s 125 kHz 26.5 27.0 30.0 30.0
; e 250 kHz 27.0 27.5 30.0 30.0
; f 500 kHz 18.0 18.0 30.0 30.0
;

;Valid for modes 1-7
counts_per_voltrms = [[52.5, 51.0, 55.5, 55.5], $
[26.5, 27.0, 30.0, 30.0], $
[27.0, 27.5, 30.0, 30.0], $
[18.0, 18.0, 30.0, 30.0]]

;To index the matrix of counts_per_voltrms values we need the frequency translation
;and bandwidth from the WBD CDF file. Convert to integers because sometimes using
;byte arrays causes problems!
bandwidth=floor(bandwidth)
translation=floor(translation)
resolution=floor(resolution)
antenna=floor(antenna)

;We need to set up an array of indices for the bandwidths and translations.
;The lines of code below will tell us where we have different bandwidths and
;translations. Note that this does not use the last column of the counts_per_voltrms
;matrix at all! Hopefully this is okay, as the last two columns are identical.
;To separate out modes 5,6, and 7, we will need to look at the resolution too.
;I still need to check that this works 19 and 77 kHz modes with non-zero translations.
;I also do not check for points where the bandwidth and translation are fill values.

npts=n_elements(bandwidth)
bandindex=intarr(npts)
tranindex=intarr(npts)
```



```
col0=where(bandwidth eq 9,ccnt0)
if ccnt0 gt 0 then begin
    bandindex(col0)=0
endif

col1=where(bandwidth eq 19,ccnt1)
if ccnt1 gt 0 then begin
    bandindex(col1)=1
endif

col2=where(bandwidth eq 77,ccnt2)
if ccnt2 gt 0 then begin
    bandindex(col2)=2
endif

row0=where(translation eq 0,rcnt0)
if rcnt0 gt 0 then begin
    tranindex(row0)=0
endif

row1=where(translation eq 125,rcnt1)
if rcnt1 gt 0 then begin
    tranindex(row1)=1
endif

row2=where(translation eq 250,rcnt2)
if rcnt2 gt 0 then begin
    tranindex(row2)=2
endif

row3=where(translation eq 500,rcnt3)
if rcnt3 gt 0 then begin
    tranindex(row3)=3
endif

mycounts_per_voltrms=counts_per_voltrms(bandindex,tranindex)

;STOP

;Now let's perform the reverse of the calibration on this waveform. First we need
;find out where we have electric field data or magnetic field data. Both types may
;be found in the same file. When valid data points are not available, the quantities
;WBD_Elec and WBD_Mag are fill values (-1.00000e31).
fille=where(wbd_elec eq -1.00000e31,fillc)
fillb=where(wbd_mag eq -1.00000e31,fillbc)

valide=where(wbd_elec ne -1.00000e31 and resolution eq 8,validc)
validb=where(wbd_mag ne -1.00000e31 and resolution eq 8,validbc)

;A quick check of the file that we can do here is to see if the places where
;we have valide and validb agree with the places where we are using the E or B
;antennas. In the CDF files, 0=Ez, 1=Bx, 2=By, 3=Ey.
eantindex=where(antenna eq 0 or antenna eq 3,eantc)
bantindex=where(antenna eq 1 or antenna eq 2,bantc)

;We should have eantc=validc and bantc=validbc
if eantc eq validc then begin
    print,'Check: numbers of valid WBD_Elec and Antenna=0 or 3 points agree!'
```



```
endif else begin
    print,'Check Failed: numbers of valid WBD_Elec and Antenna=0 or 3 points DO NOT agree!'
endelse

if bantcnt eq validbcnt then begin
    print,'Check: numbers of valid WBD_Mag and Antenna=1 or 2 points agree!'
endif else begin
    print,'Check Failed: numbers of valid WBD_Elec and Antenna=1 or 2 points DO NOT agree!'
endelse

gain=floor(gain)
wbd_elec_cnts=wbd_elec
wbd_elec_float=wbd_elec
wbd_mag_cnts=wbd_mag
wbd_mag_float=wbd_mag
inverse_ecal=fltarr(npts)
inverse_ecal(*)=-1.00000e31
inverse_bcal=fltarr(npts)
inverse_bcal(*)=-1.00000e31
cal_fac=fltarr(npts)
cal_fac(*)=-1.00000e31

if validecnt gt 0 then begin

    print,'Performing reverse calibration on WBD Electric Field...'

    ;Get the reverse calibration factor.

inverse_ecal(valide)=(88.0*mycounts_per_voltrms(valide)*(10.0^(gain(valide)/20.0)))/(sqrt(2.0)*1000.0)
    wbd_elec_float(valide)=(inverse_ecal(valide)*wbd_elec(valide))+dc_offset(valide)
    wbd_elec_cnts(valide)=round((inverse_ecal(valide)*wbd_elec(valide))+dc_offset(valide))

cal_fac(valide)=(sqrt(2.0)*1000.0)/(88.0*mycounts_per_voltrms(valide)*(10.0^(gain(valide)/20.0)))

endif else begin

    print,'All WBD Electric Field values are fill.'
    wbd_elec_cnts(*)=-1.00000e31

endelse

if validbcnt gt 0 then begin

    print,'Performing reverse calibration on WBD Magnetic Field...'

inverse_bcal(validb)=(mycounts_per_voltrms(validb)*(10.0^(gain(validb)/20.0)))/(2.0*sqrt(2.0))
    wbd_mag_float(validb)=(inverse_bcal(validb)*wbd_mag(validb))+dc_offset(validb)
    wbd_mag_cnts(validb)=round((inverse_bcal(validb)*wbd_mag(validb))+dc_offset(validb))
    cal_fac(validb)=(2.0*sqrt(2.0))/(mycounts_per_voltrms(validb)*(10.0^(gain(validb)/20.0)))

endif else begin

    print,'All WBD Magnetic Field values are fill.'
    wbd_mag_cnts(*)=-1.00000e31
```



```
endelse

;Here are some example diagnostic checks!!!!
;
;Check to see if we have done a decent job of reverse calibrating by comparing
;the CDF data quality flag with the locations of clipped (0 or 255 counts) data.
;If everything worked okay, we should have clipcnt1=clipcnt2+clipcnt3
clipped1=where(data_quality eq 1,clipcnt1)
clipped2=where(wbd_elec_cnts eq 0 or wbd_elec_cnts eq 255,clipcnt2)
clipped3=where(wbd_mag_cnts eq 0 or wbd_mag_cnts eq 255,clipcnt3)

;Check to see how close the values were to integers before we rounded them.
;For the test case, there were 16443740 data points and only 293708 (or 1.79%)
;had non-integer results (nonzero reverse_cal_diff) after the reverse
;calibration factor was applied. The maximum difference was 3.05176e-05,
;the minimum difference was -2.28882e-05, and the average difference was -8.69528e-08.
;Since these are extremely small, we can conclude that the reverse calibration works
;quite well!

if validecnt gt 0 then begin
  reverse_cal_diff1=wbd_elec_float-wbd_elec_cnts
  nonzero_diff1=where(reverse_cal_diff1 ne 0,diffcnt1)
  maxdiff1=max(reverse_cal_diff1,maxdiffind1)
  mindiff1=min(reverse_cal_diff1,mindiffind1)
  avgdiff1=total(reverse_cal_diff1)/float(n_elements(reverse_cal_diff1))
endif

if validbcnt gt 0 then begin
  reverse_cal_diff2=wbd_mag_float-wbd_mag_cnts
  nonzero_diff2=where(reverse_cal_diff2 ne 0,diffcnt2)
  maxdiff2=max(reverse_cal_diff2,maxdiffind2)
  mindiff2=min(reverse_cal_diff2,mindiffind2)
  avgdiff2=total(reverse_cal_diff2)/float(n_elements(reverse_cal_diff2))
endif

STOP

END
```

=====