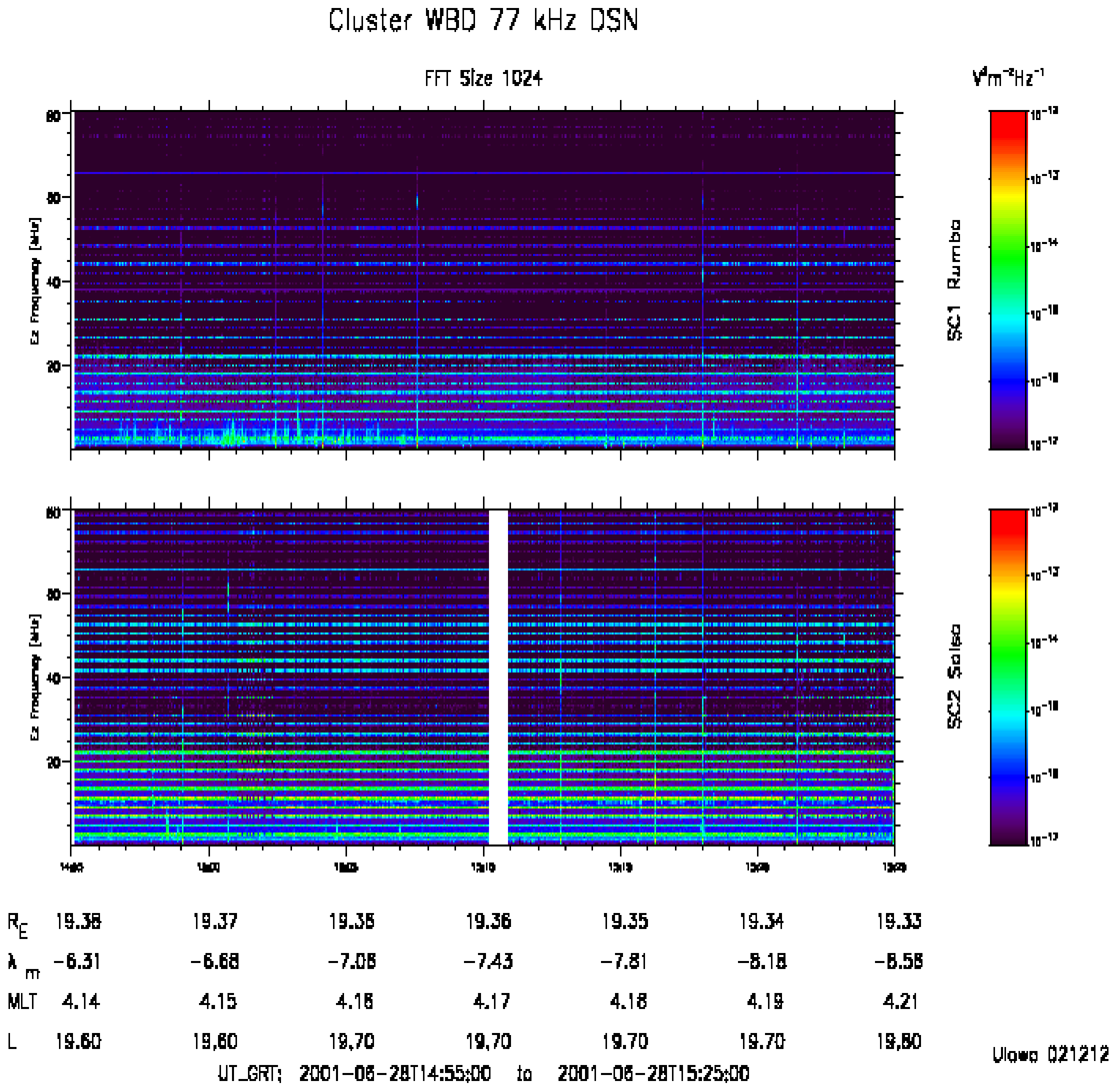
CLUSTER WBD INTERPRETATION ISSUES

In certain regions of the orbit and during certain planned operations, interference from other instruments and/or spacecraft systems affects the WBD measurements. At these times one must use caution so as not to misinterpret the WBD data. In addition certain design features of the WBD hardware and software and of the electric antenna that is used by WBD make the WBD instrument 1) vulnerable to nonlinear effects in the form of harmonic generation under certain environmental conditions and 2) susceptible to distorting waveforms when measuring specific types of waves, most notably solitary waves. In these cases, extreme caution must be used when analyzing the data. The remainder of this page will be devoted to a description of the various known interferences and instrumental effects with examples of how they are manifested in the WBD data. If you need further information on these issues, please contact Jolene Pickett, project manager, at: *pickett@uiowa.edu*.

Electron Drift Instrument (EDI)

The purpose of the Electron Drift Instrument (EDI) is to measure the strength of electric and magnetic fields in the vicinity of the Cluster spacecraft. This is done by firing two weak beams of electrons into the space around each spacecraft and receiving them on the other side of the spacecraft from which each was fired. Figures 1 and 2 below show how active operation of EDI affects WBD measurements. Both of these calibrated spectrograms reveal EDI's operation as horizontal lines of interference. On this date EDI was running in high current mode, making it easily detectable by the electric antennas. Figure 1 shows what EDI's interference looks like on a half hour time scale. When viewed on a smaller time scale, it becomes apparent that the signals produced by EDI pulsate in intensity as is clearly shown in Figure 2. This periodicity in the intensity is due to the Windshield-Wiper (WW) Mode EDI was running this day. In the WW-mode EDI sweeps its two weak beams of electrons rapidly back and forth through a range of angles; hence the name 'windshield-wiper'. Over time the paths the two beams of electrons take around the spacecraft change due to the different angles they are swept through upon leaving the spacecraft by EDI's two electron guns. This propagation in the paths that the electron beams take is detected by the electric antennas as varying intensities in the electric field. Interference from EDI on spacecraft 4 will never be seen because this instrument was never operational, and spacecraft 2 produces unusually intense interference due to a malfunction.

Figures 1 and 2 also show a more constant line of intensity at roughly 65.65 kHz. This is the fundamental mode created by the interference associated with the electrical circuits of the spacecrafts' batteries.



Cluster WBD 77 kHz DSN
FFT Size 1024
Ez Frequency [kHz]
SC1 Rumba
SC2 Salsa
RE 19.38 19.37 19.36 19.36 19.35 19.34 19.33
λm -6.31 -6.68 -7.06 -7.43 -7.81 -8.18 -8.56
MLT 4.14 4.15 4.16 4.17 4.18 4.19 4.21
L 19.60 19.60 19.70 19.70 19.70 19.70 19.80
UT_GRT: 2001-06-28T14:55:00 to 2001-06-28T15:25:00
UIowa 021212

Figure 1

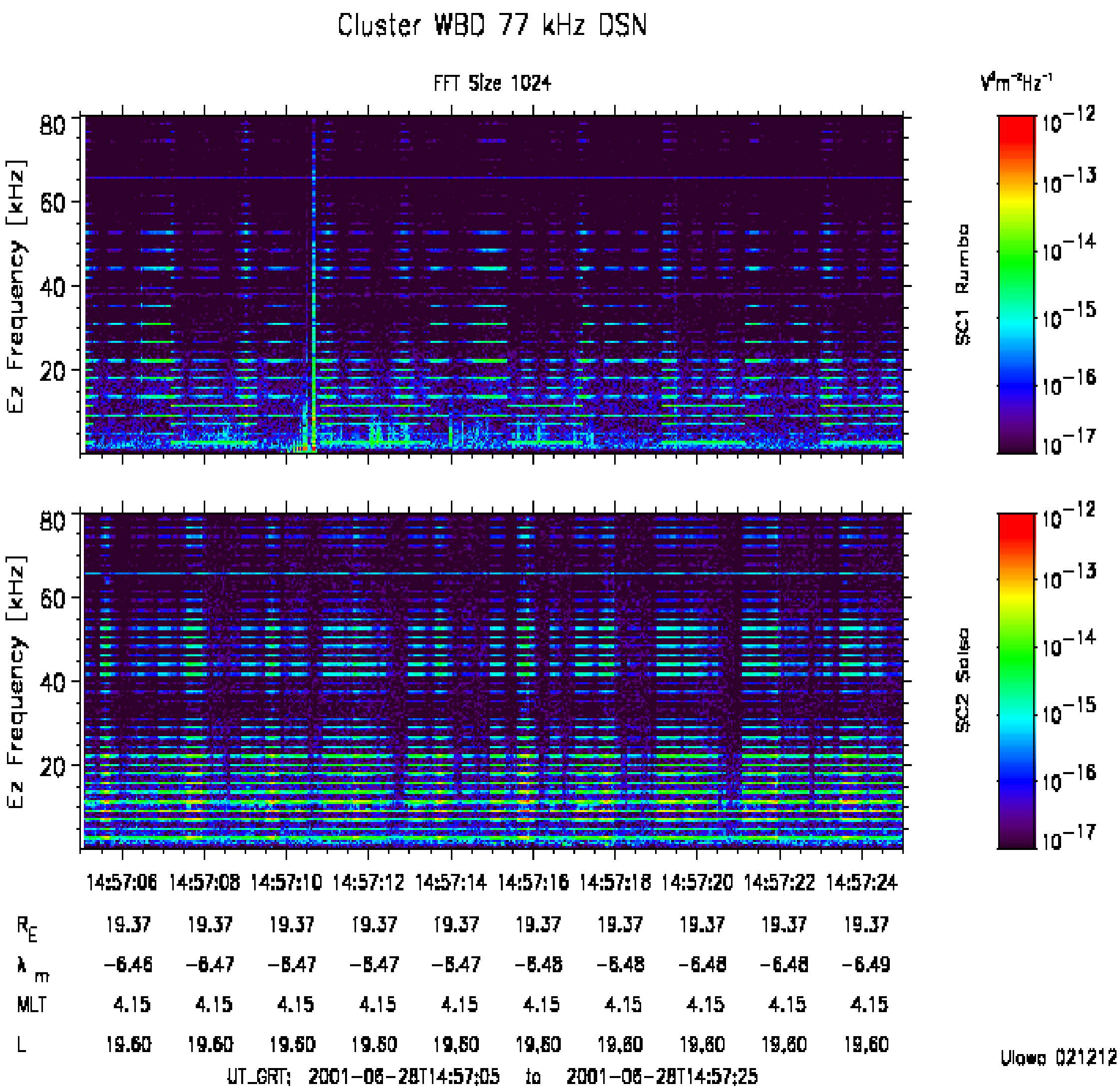


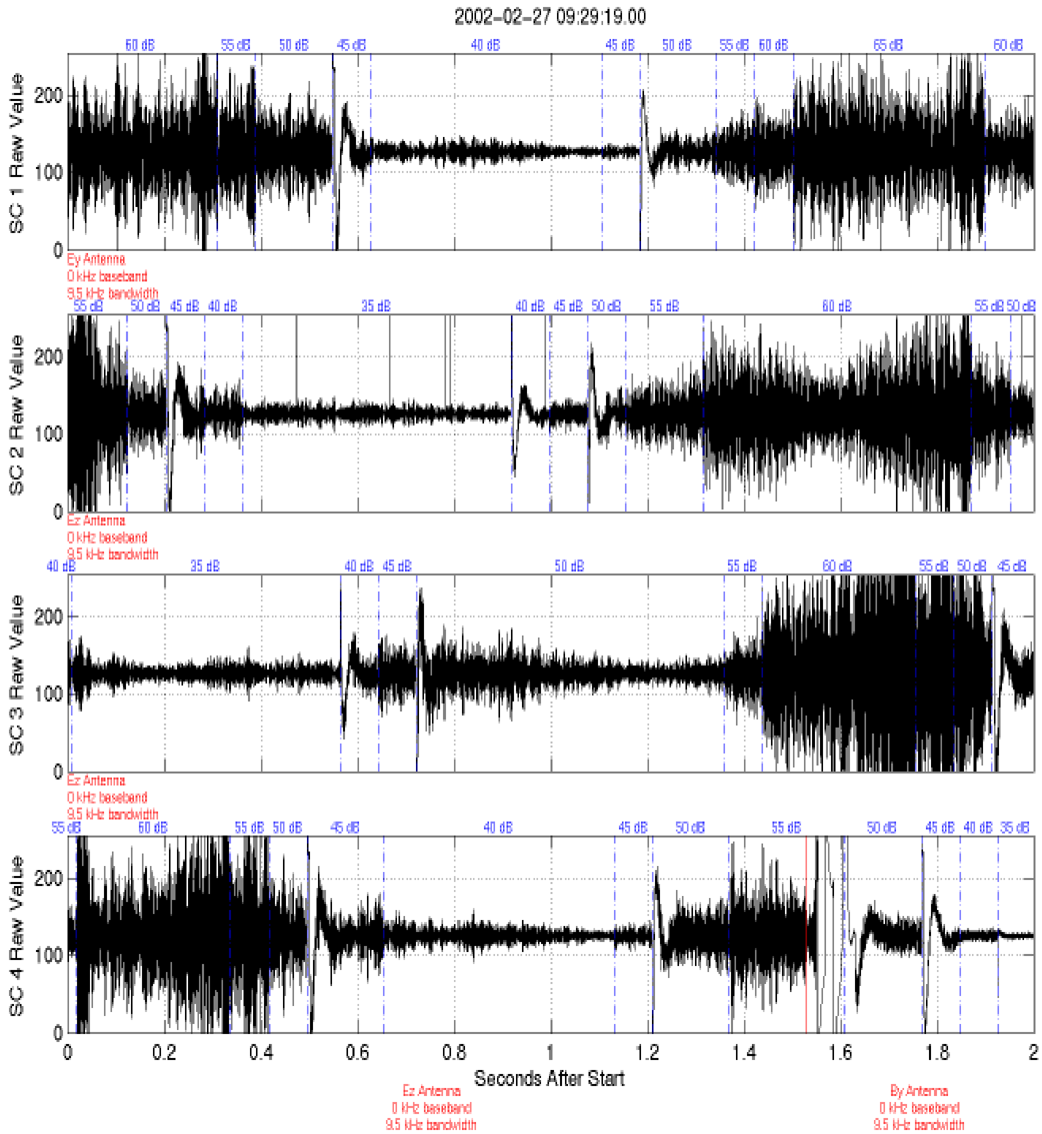
Figure 2

Receiver Gain Effects for Wide Band Data Instrument (WBD)

In November of 2002 it was discovered that automatic gain changes in the WBD receiver were causing impulses to be seen in electric and magnetic field data. Figure 3 shows what these impulses look like in a line plot of the raw count data versus time and Figure 4 is a calibrated spectrogram for the same time period. Examination of Figure 3 shows that there are two kinds of impulses. The first of these two (eg., at ~ 0.55 seconds after start in panel 1 of Figure 3) causes the data to spike and clip in the positive direction (a raw count of 255). The other impulse (eg., at ~ 1.18 seconds after start in panel 1 of Figure) is a reflection of the first about the horizontal axis.

Thus this one clips in the negative direction (a raw count of 0). Only specific changes in the receiver's gain causes these two impulses. The positively clipped impulse is only seen when the gain is changed from 35 dB to 40 dB and 50 dB to 45 dB. The negatively clipped impulse is seen at a gain change from 45 dB to 50 dB. These are the only times such impulses are seen, and, when such gain changes are made, these impulses will always be present in the data. The time it takes these impulses to damp out is roughly one tenth of a second.

Correlations between Figures 3 and 4 are easily seen thus identifying the impulses in a spectrogram. The line plot for spacecraft 1 reveals a positively clipped impulse occurring at approximately 9:29:19.55 and a negatively clipped impulse developing just before 9:29:20.20. Inspection of Figure 4 for spacecraft 1 at these same times shows a disturbance in the spectrogram being one pixel wide that covers the entire bandwidth. The disturbances appear as thin columns that start out red (greatest intensity) at the base frequency and span the visible spectrum to green towards the upper bound of the bandwidth. Similar correlations amongst Figure 3 and Figure 4 can be made for spacecrafts 2, 3 and 4.



2002-02-27 09:29:19.00
60 dB
55 dB
50 dB
45 dB
40 dB
45 dB
50 dB
55 dB
60 dB
65 dB
60 dB
SC 1 Raw Value
Ey Antenna
0 kHz baseband
9.5 kHz bandwidth
SC 2 Raw Value
Ez Antenna
0 kHz baseband
9.5 kHz bandwidth
SC 3 Raw Value
Ez Antenna
0 kHz baseband
9.5 kHz bandwidth
SC 4 Raw Value
Seconds After Start
Ez Antenna
0 kHz baseband
9.5 kHz bandwidth
By Antenna
0 kHz baseband
9.5 kHz bandwidth

Figure 3

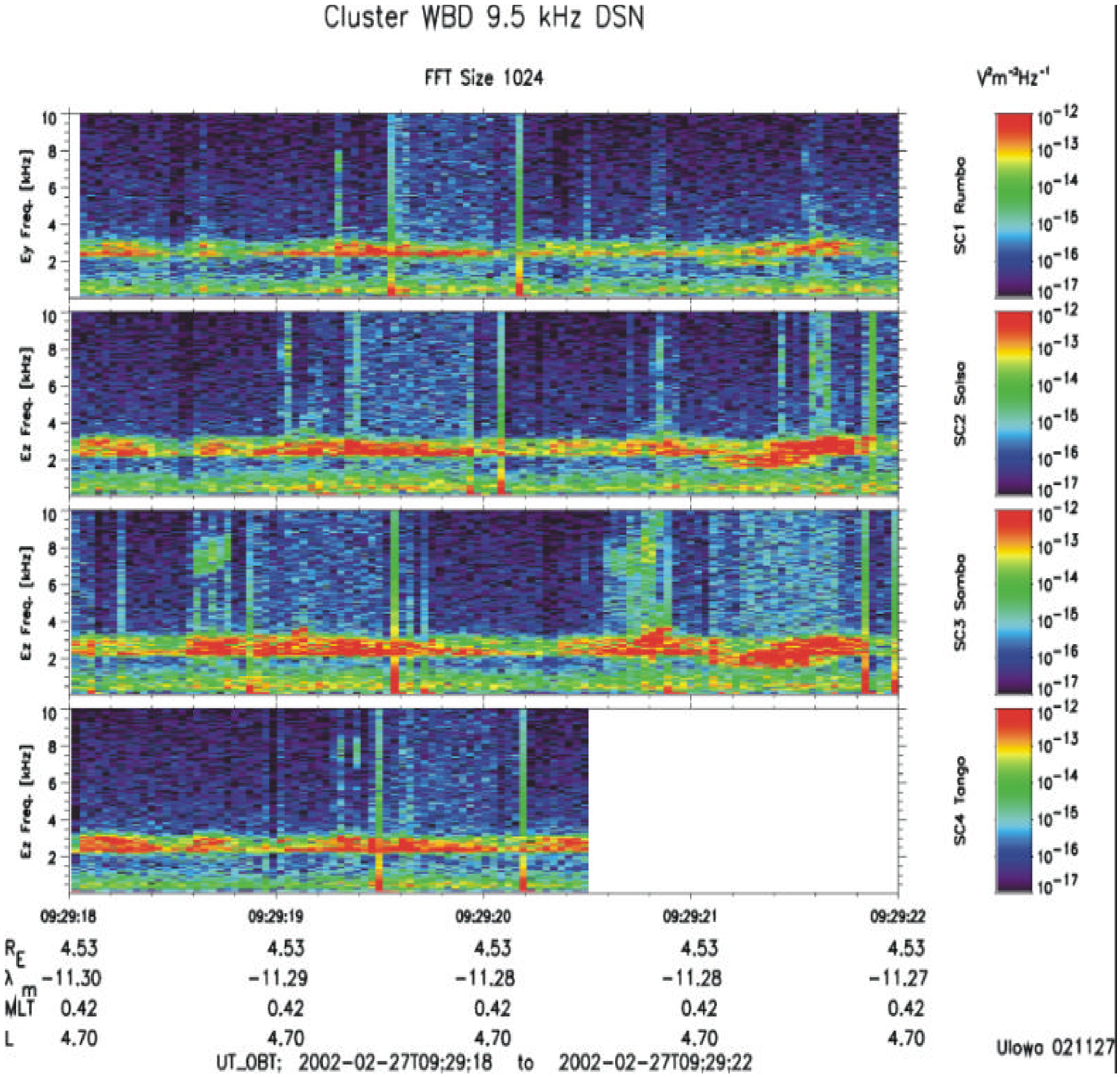


Figure 4

The reason that data appear to be missing for spacecraft 4 in Figure 4 is because a change from an electric antenna to a magnetic search coil was made at approximately 9:29:20.5. This can be seen in Figure 3 where sensor information is given in red. Figure 3 also shows clipped data following this switch for a duration of approximately a tenth of a second. The clipped data over this tenth of a second are not associated with changes in the receiver's gain even though the waveform somewhat resembles the impulses previously discussed.

Spacecraft Battery Interference

Power for the four cluster spacecraft during eclipses and periods of peak power demand is supplied in part by five sliver/cadmium batteries onboard each of the four spacecraft. It has been determined that the electrical circuits connected to these batteries create an interference in the data whose fundamental mode is approximately 65.75 kHz. Figure 5 shows this first harmonic created by the batteries onboard spacecraft 3 and 4 as a narrow horizontal line (constant frequency) residing around 65.75 kHz. Other modes in the harmonic series for this interference are readily seen in data taken from other days. For example, when WBD was set to an input frequency range of 9.5 kHz with a frequency conversion of 125 kHz on June 18, 2002, the second harmonic created by the batteries onboard spacecraft 1 was seen at a frequency of roughly 131.5 kHz in the calibrated spectrogram for this spacecraft (see Figure 6).

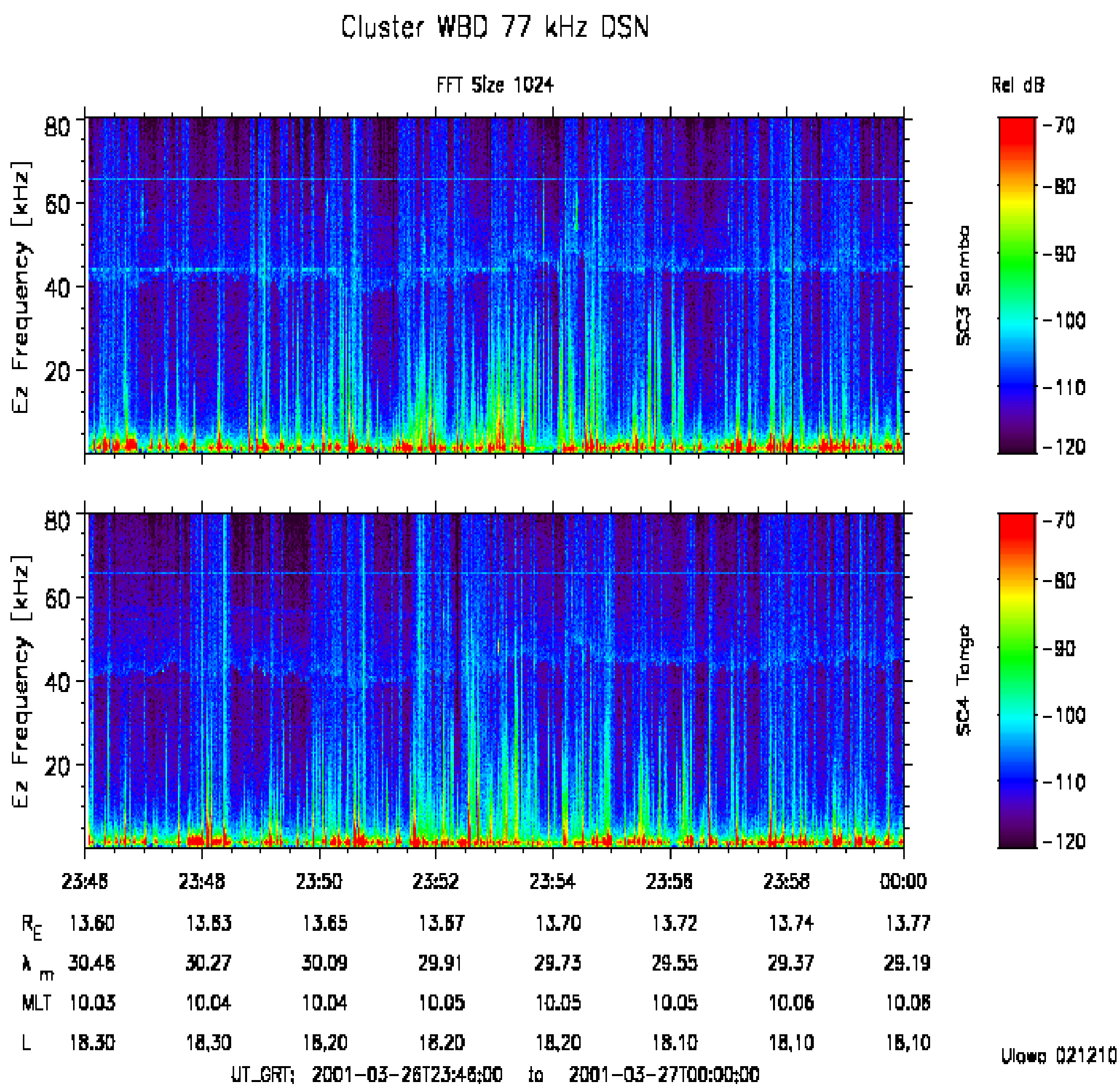


Figure 5

Spacecraft Power Bus Interference

A line of greater intensity at approximately 130.6 kHz has been repeatedly seen in the WBD data. It has been determined that this is the fundamental mode of oscillation created by the spacecraft power bus on all four cluster spacecraft. Figure 6 shows this first harmonic created by the spacecraft power bus in a calibrated spectrogram of the data collected when the wide-band receiver had an input frequency range of 9.5 kHz with a frequency conversion of 125 kHz. As expected, this fundamental mode of 130.6 kHz is the first of a harmonic series for this oscillation created by the spacecraft power bus. When the wide-band receiver has been set with an input frequency range of 19 kHz and a frequency conversion of 250 kHz, the second harmonic created by the power bus is seen at a frequency of roughly 261.2 kHz. An example of this can be seen in the data for August 7, 2002 (not shown here). Likewise, the fourth harmonic of 522.4 kHz can be seen when the wide-band receiver is set to an input frequency range of 77 kHz with a frequency conversion of 500 kHz. An example of this can be seen in the data for May 25, 2001 (not shown here).

It is worth noting that the intensity of the interference is less on spacecraft 2 and 4 than it is on spacecraft 1 and 3. More effort was put into rejecting this interference on these two spacecraft prior to launch, with time constraints preventing the same effort for the other two spacecraft.

In Figure 6 a fainter line at roughly 131.5 kHz can be seen for spacecraft 1. This is the second harmonic of the fundamental mode created by the interference associated with the electrical circuits of the spacecraft's batteries as described in the previous section.

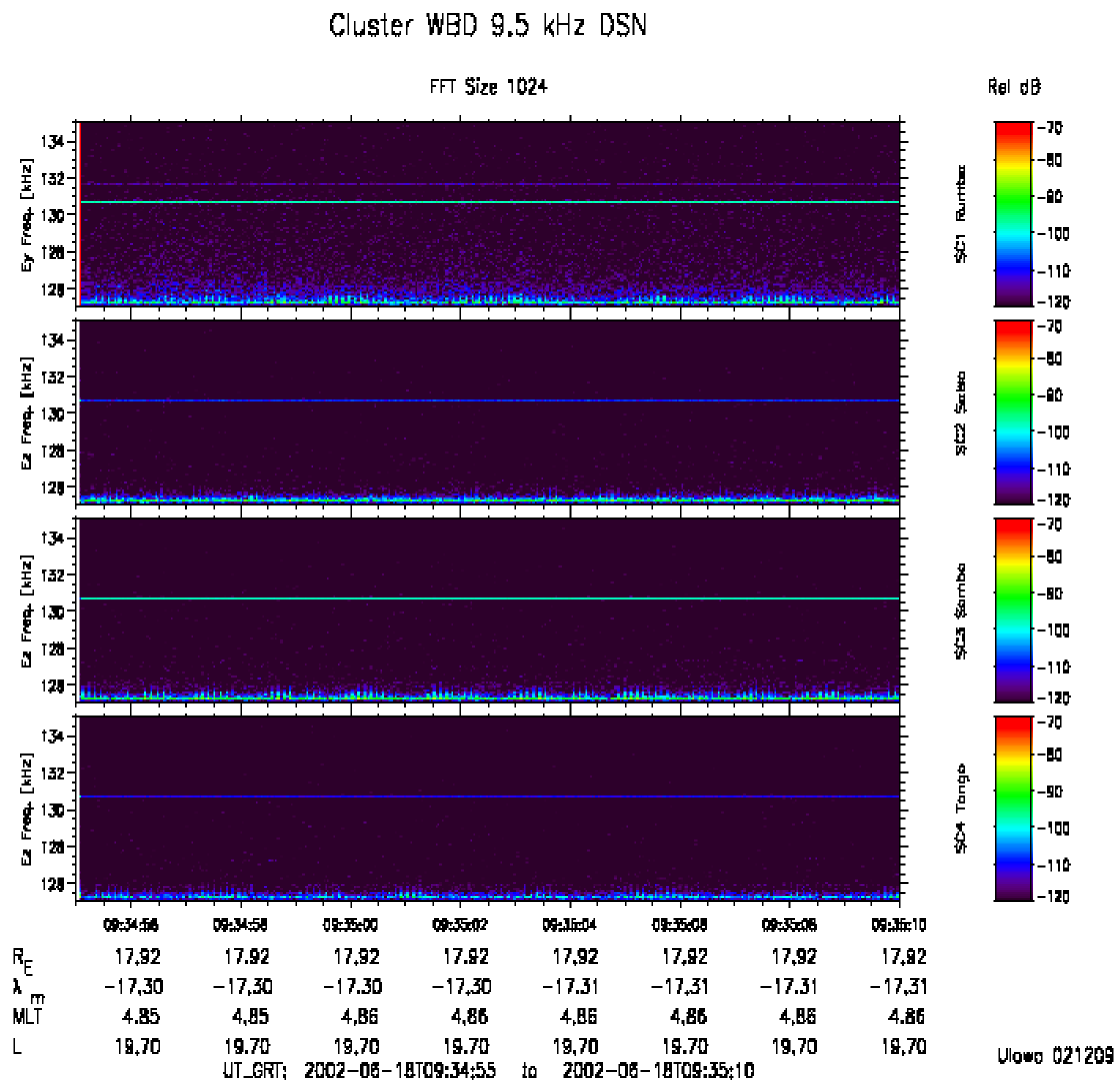


Figure 6

WHISPER Sounder Instrument Interference

WBD data clearly show when active sounding of WHISPER is taking place as seen in Figures 7 and 8 below. Figure 7 reveals that the sounding looks like consecutive impulses in a line plot of the raw count data versus time. It is plainly seen in Figure 7 that active sounding begins at approximately 10:33:36.73 for spacecraft 1, 10:33:37.53 for spacecraft 2, 10:33:37.25 for spacecraft 3, and 10:33:36.88 for spacecraft 4. Figure 8 has a smaller time domain to provide a closer look at the pulses transmitted by the WHISPER sounder. The pulses seem to occur every 26.6 milliseconds, which is one of the step duration settings for the WHISPER sounder. The step duration can also be set at 13.3, 40, 66.6, 106.6, 125, and 250 milliseconds. In all cases, the pulse emitted by the sounder has a time duration of 0.5 to 1 milliseconds.

Figure 9 shows that the sounding appears as a column of greater intensity spanning the entire bandwidth in a calibrated spectrogram. This figure also shows that the sounding lasts for three seconds on all four spacecraft. The sounding appears to have the greatest intensity for spacecraft 1. The reason for this is because the transmitter for WHISPER is connected to the shields of the Ey antenna, which happens to be the antenna used by spacecraft 1 in Figure 9. Because one of the two probes of the Ez antenna on each of spacecraft 1 and 3 failed, all WBD operations on spacecraft 1 starting January 10, 2002 and on spacecraft 3 starting August 6, 2002 were carried out using the Ey antenna. Thus, the active Whisper soundings that are always run using the Ey antenna of all spacecraft will almost always appear more intense in the WBD data on spacecraft 1 and 3.

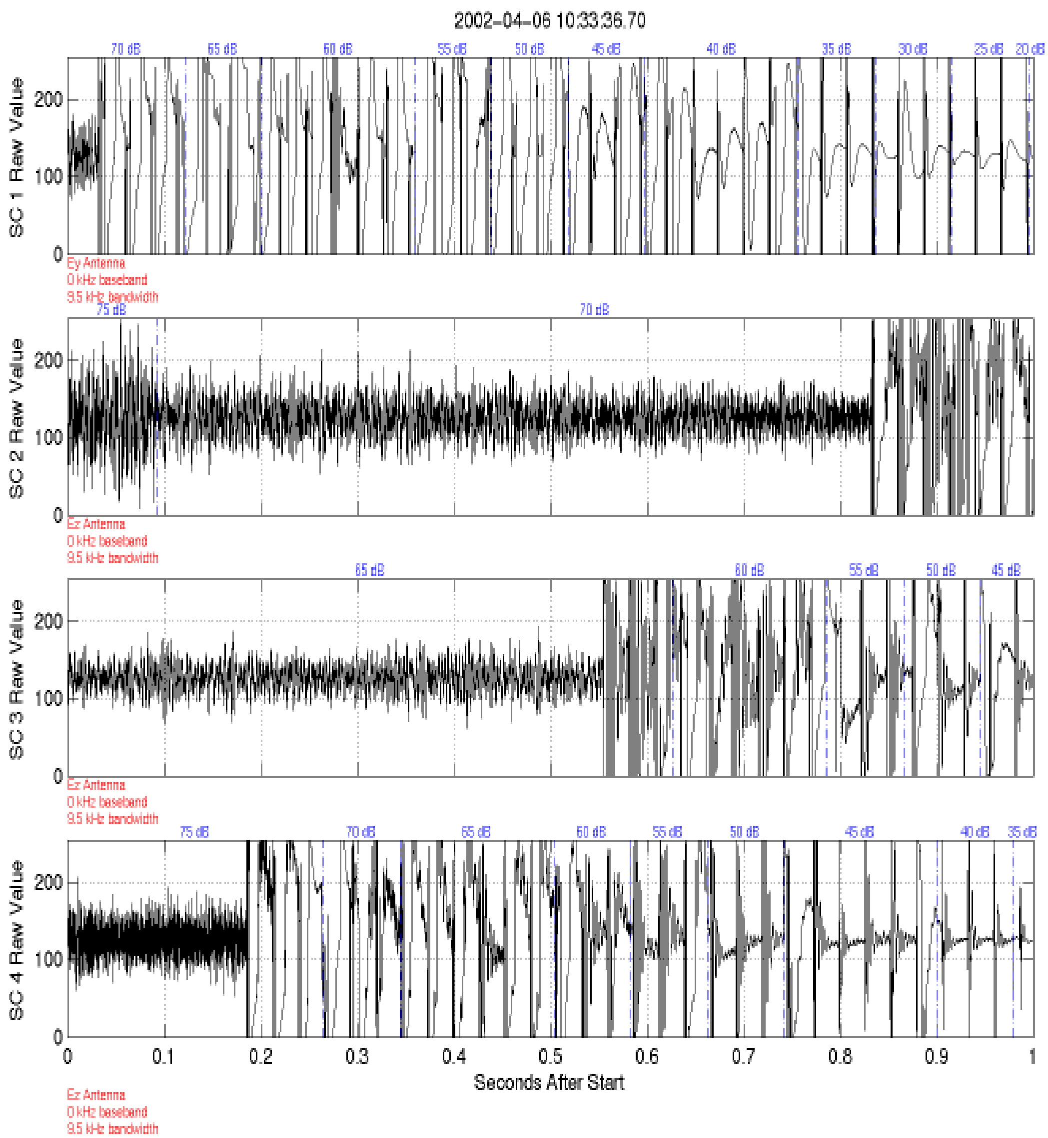


Figure 7

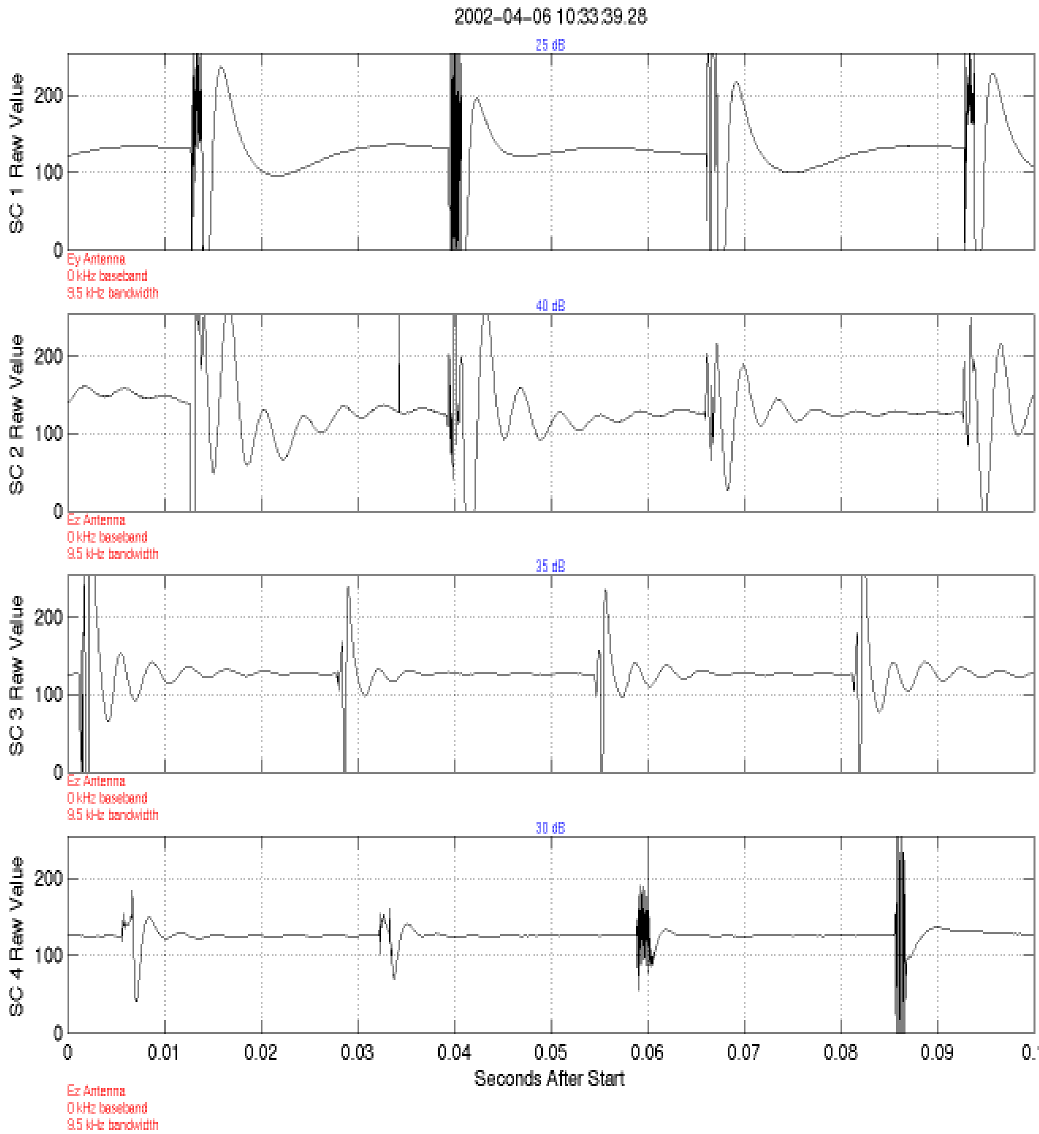


Figure 8

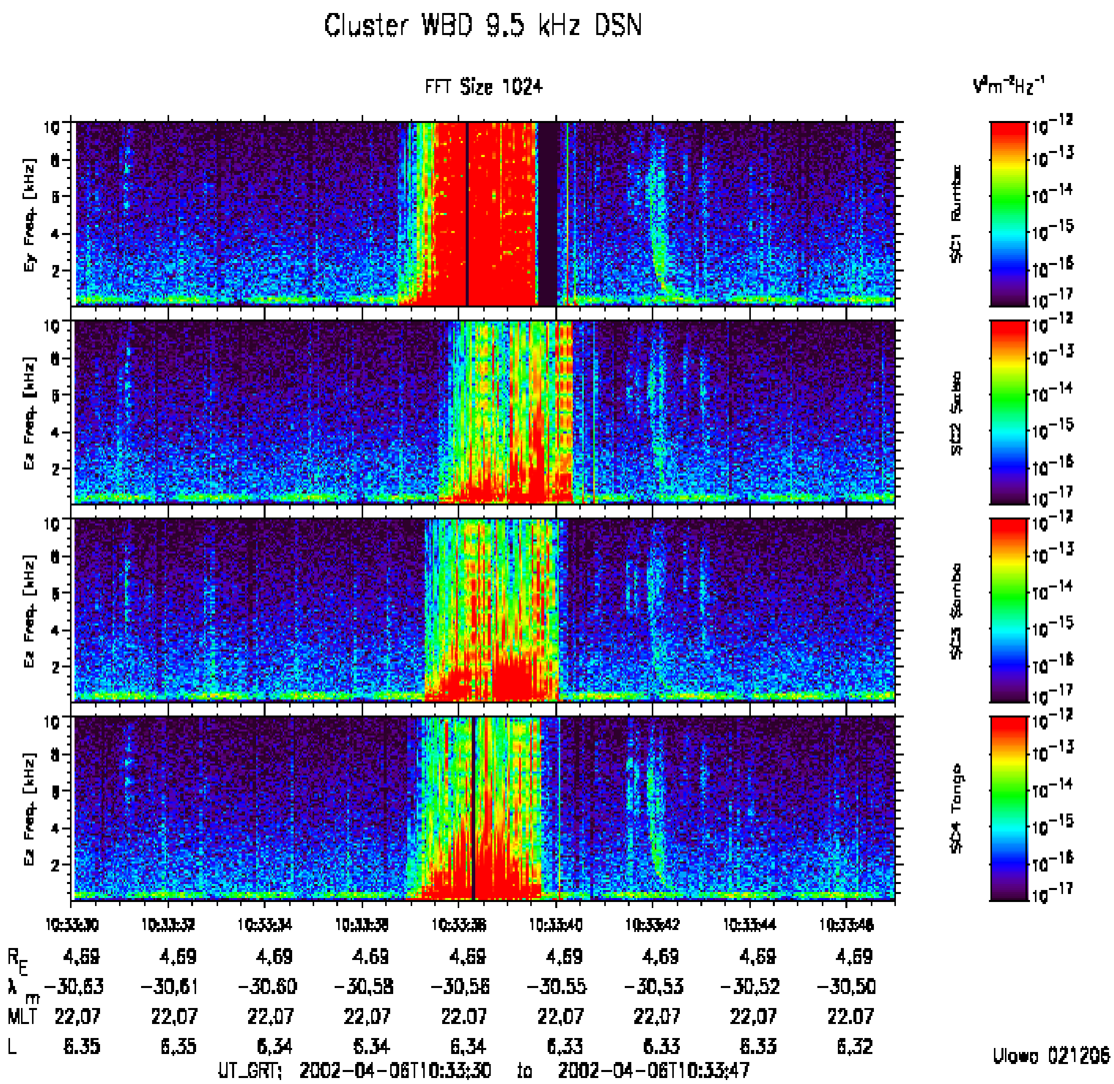


Figure 9

900 Hz Clock Effects for the Digital Wave Processor (DWP)

The DWP 900 Hz clock on all four Cluster spacecraft provides onboard timing allowing for correlation studies between the four spacecraft. Figure 10 shows two interference lines in the magnetic field data for all four Cluster spacecraft. The first resides at a frequency of 900 Hz, which is the fundamental mode produced by the onboard clock. The second interference line is the second harmonic which has a value of 1.8 kHz. This interference produced by the clock is only seen in the magnetic field data.

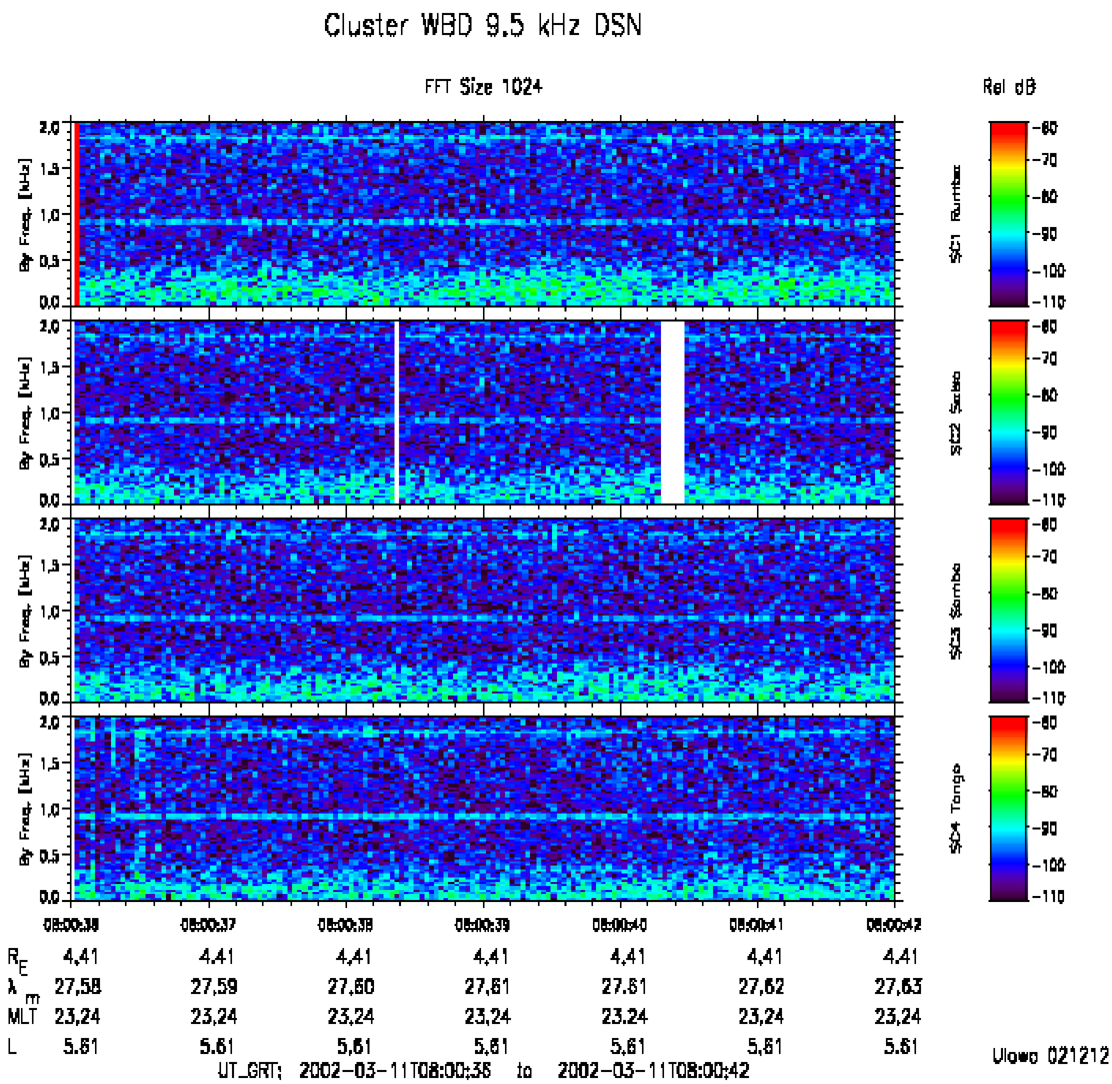


Figure 10

Unknown Periodic Interference Patterns

Figure 11 below shows periodic electrical interference patterns picked up by all four Cluster spacecraft on April 6, 2002. All four spacecraft were in the nightside magnetosphere at the time these data were collected. These interference patterns appear to have a periodicity on the order of two seconds, which is roughly half a spin period for the spacecraft. The cause of these interference patterns are still unknown, but the following is a list of things we either know or suspect concerning them: 1) these are not natural plasma emissions, 2) the interference may be effects that are coupling through the plasma from another spacecraft system or instrument in certain characteristic plasma regions, 3) this is probably not interference from another instrument or spacecraft system that is being picked up through the onboard electrical circuits, 4) the interference is not caused by oscillations or other undesirable effects of the antenna booms, guards, stubs, etc.

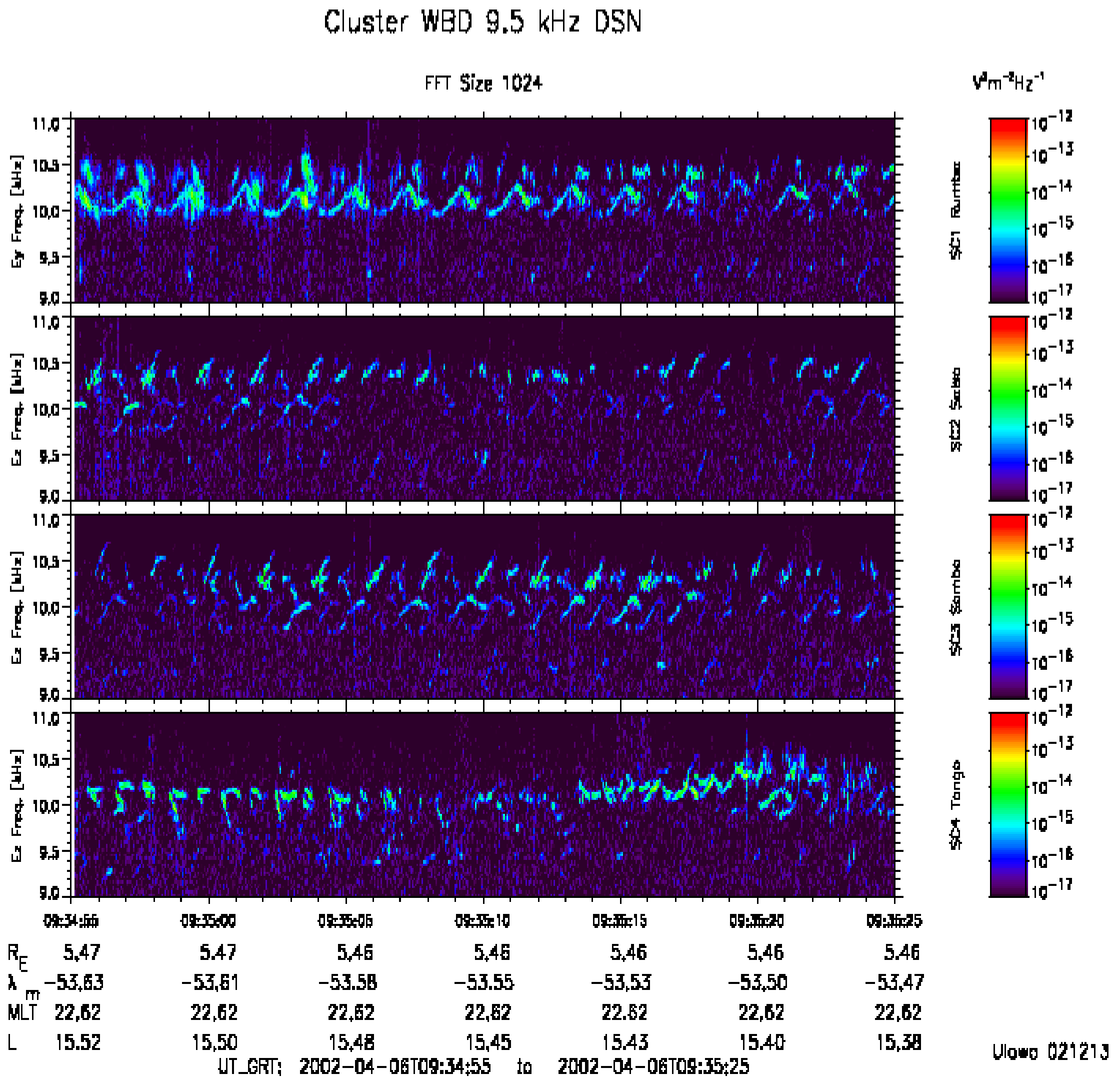


Figure 11

INSTRUMENTAL EFFECTS: WAVEFORM DISTORTION

The digital filters used within the WBD instrument for its three bandwidth modes (9.5, 19 and 77 kHz) and the 300 Hz boom buffer amplifier mounted within the electric antenna that WBD uses have specific response characteristics that are optimized for the detection of multi-cycle, sinusoidal type waveforms. Thus, when impulse-type waves, such as solitary waves, are detected by the WBD/electric field antenna system, some of the actual input waveforms get distorted at the output after processing through these various filters. The point (in terms of solitary wave or pulse time duration) at which the waveforms are distorted is driven by the characteristic response time of the filters, 1/(2*pi*f), where f is the RC time constant. A number of bench tests using the WBD flight spare instrument were carried out at Iowa to verify this turning point experimentally. The results of those tests can be found in the BSc thesis "WBD Response to Bipolar and Tripolar Pulses: Bench Tests vs. in Flight Observations", by J. M. Swanner, J. S. Pickett, J. R. Phillips, and D. L. Kirchner (see http://www-pw.physics.uiowa.edu/cluster/pulse_tests.pdf). For these tests, some solitary waves in the form of bipolar and tripolar pulses were input using a signal generator and the output examined in terms of shape and pulse duration. The referenced document provides some guidelines for each WBD filter mode for the maximum time duration that can be trusted for pulses that are observed with a bipolar or tripolar shape. Any pulses of this type that are observed in the data to have time durations longer than the suggested guidelines should not be used for analysis purposes other than if the researcher clearly states that these pulses, although considered to be solitary waves, cannot be characterized in terms of specific shape, time duration or amplitude. Solitary waves detected with the electric antennas are one of the types of waveforms that are manifested as broadband electrostatic noise in spectrograms created using a Fast Fourier Transform routine.

INSTRUMENTAL EFFECTS: HARMONIC GENERATION

In many regions of space, plasma physics theory predicts the observation of waves at harmonics of natural frequencies. Some measurements of harmonics may indeed be related to natural phenomena. However, it is a well-known fact that plasma wave receivers, and amplifiers in general, can artificially introduce signals into wave data that appear to be waves at harmonics of fundamental natural frequencies.

One source of artificial harmonics in WBD power spectra is the clipping of waveforms when they exceed the amplitude range of the instrument. In the automatic gain control (AGC) mode, the WBD Plasma Wave Receiver gain state is adjusted to keep the average measured signal within the range of the digitizer. The rate at which the gain state is updated can be as fast as once every 0.1 s. However, wave amplitudes can change much more rapidly than the fastest gain update rate. This can result in occasional clipping of the waveform peaks when the wave amplitudes exceed the range of the current gain setting. The power spectra of clipped waveforms generally exhibit significant power at odd harmonics of the plasma frequency, while the even harmonics feature relatively low power. These harmonics are a purely instrumental effect [see Walker, S. N., M. A. Balikhin, I. Bates, and R. Huff, An investigation into instrumental nonlinear effects, Adv. Space Res., 30 (12), 2815-2820, 2002]. An example of a spectrogram with clipped waveforms is shown in Figure 12.

A second source of artificial harmonics are the amplifiers used in the plasma wave receiver. Harmonic generation is a problem for most amplifiers, including those used in the WBD instrument. Although the WBD design attempts to suppress instrumental harmonics, they are often present at intensity levels about 40 dB below the peak in the power spectra at the fundamental tone. In addition, harmonic generation appears to be more prevalent when the wider 77 kHz bandwidth mode is used, as opposed to the narrower 9.5 kHz and 19 kHz bandwidth modes. In order to better understand when and in what modes these harmonics are most likely to occur, a comprehensive set of WBD bench tests were carried out to enable us to characterize which of the harmonics observed in the data are natural and which are instrument generated. A report on the results of these tests will be available soon. Until then, researchers using WBD data need to be extremely cautious about their interpretation of any harmonics observed in the WBD data and should contact the WBD PI for further information.

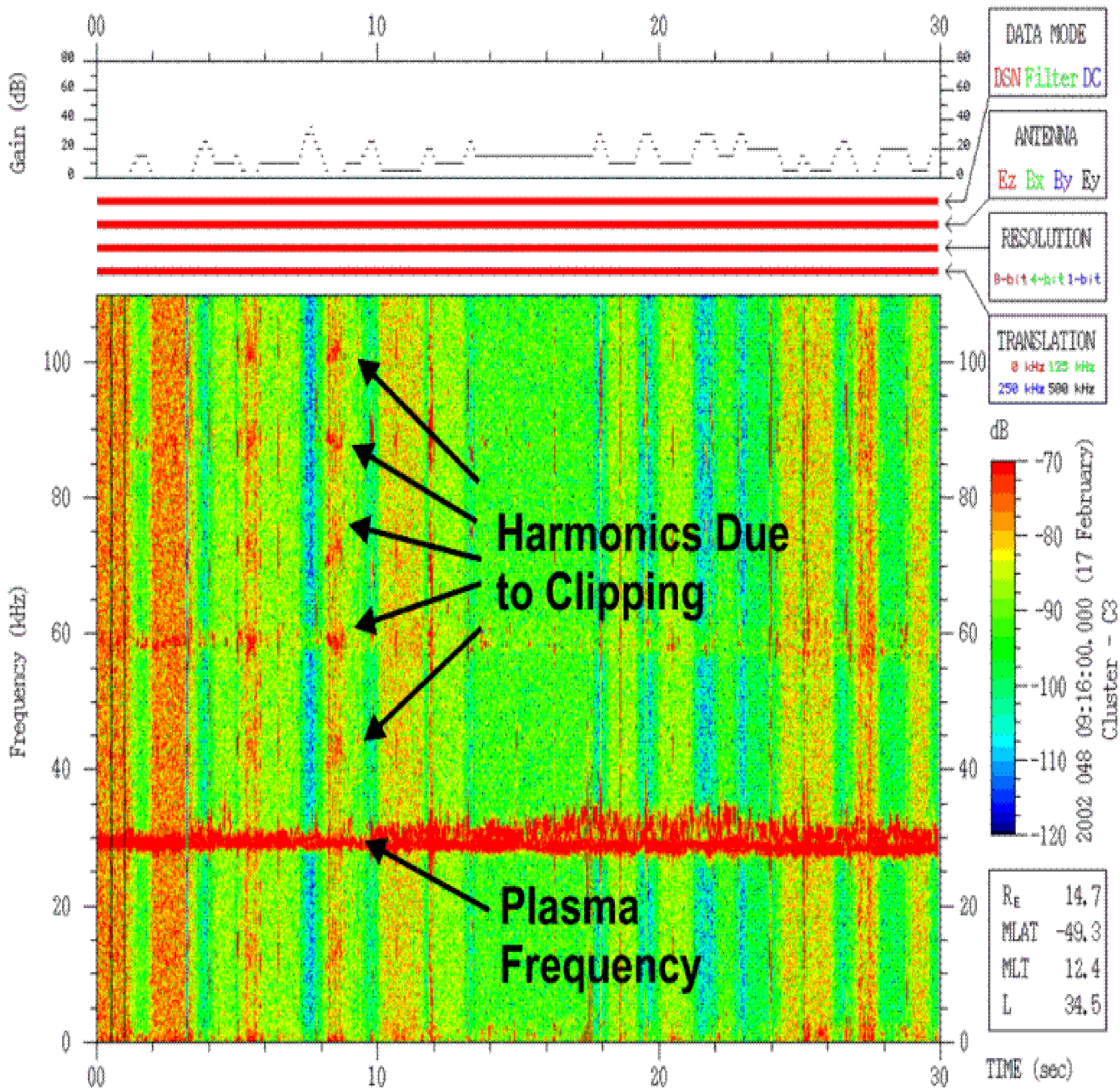


Figure 12

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