Power System Studies

Comparison Testing of
Environmental Potentials EP2000
Cutler Hammer CVL80
Psytronics 480 V3

Report Update with dV/dt Review

for

Environmental Potentials

Carson City, Nevada

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by:

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1.0 Executive Summary

1.1 Introduction and Scope

This report documents independent and objective comparative testing between three 480V Delta configured Transient Voltage Surge Suppression (TVSS)/Surge Protective Devices (SPD) provided by Environmental Potentials (EP). The three delta connected units provided by EP include:

- Environmental Potentials EP2000 Waveform Correction Absorber - 480 V Delta
- Cutler Hammer CVL80 Surge Protective Device - 480 V Delta
- Psytronics 480 V Surge Protective Device - 480 V Delta

The goal of this test was to determine how the devices compare when subjected to ANSI Standard surge waveforms defined in IEEE C62.45, and when subjected to high frequency noise. ANSI Standard tests give an excellent benchmark for comparison, where let through voltages for each device can be compared. The noise tests were used to compare the frequency response of any additional filtering circuits used in each device. Such filters can offer additional absorption of high frequency transients, and other waveform anomalies.

1.2 Results

Testing performed in this effort reveals the following:

1. The EP2000 offers the lowest let through voltage for A1 and B3 Ring Waves (maximum of 84 V and 488 V respectively). These tests are used to simulate transients created by internal switching operations within a building or facility.

2. The Cutler Hammer unit offered modest absorption of the A1 Ring Wave (maximum of 420 V).

3. The Psytronics unit responded with exaggerated waveform swinging, and greater negative peak voltages when exposed to the A1 Ring Wave.

4. The Cutler Hammer and Psytronics units responded with exaggerated waveform swinging, and greater negative peak voltages when exposed to the B3 Ring Wave.

5. All three devices have similar response and let through voltages for the B1 Combination Wave. The B1 and B3 combination waves are used to simulate an incoming lightning induced transient through a branch circuit or at a distribution panel.

6. The EP2000 and Cutler Hammer units have similar response and let through voltages for the B3 Combination Wave.

7. The Psytronics unit failed on the first application of the B3 Combination Wave test, making it unable to complete this test.

8. The EP2000 offers significant high frequency filtering between 1 kHz and 90 kHz, with a corner frequency (resonant peak) around 24 kHz. At 70 kHz noise levels are 19 dB lower generating a nearly 10X reduction.

9. The Cutler Hammer and Psytronics units offer no filtering between 1 kHz and 90 kHz.

10. The Cutler Hammer unit has a resonant peak around 48 kHz.

11. The EP2000 (due to its filtering capability) significantly reduces the maximum dV/dt of both the B1 and B3 Combo Waves. The Cutler Hammer unit had modest reductions, and the Psytronics unit offered little to no reduction of dV/dt.

2.0 Introduction

This report documents independent and objective comparative testing between 3, 480V Delta configured Transient Voltage Surge Suppression (TVSS)/Surge Protective Devices (SPD) provided by Environmental Potentials (EP). The three delta connected units provided by EP included:

- Environmental Potentials EP2000 Waveform Correction Absorber - 480 V Delta
- Cutler Hammer CVL80 Surge Protective Device - 480 V Delta
- Psytronics 480 V Surge Protective Device - 480 V Delta

The goal of this test was to determine how the devices compare when subjected to the tests and test waveforms discussed below.

2.1 Testing Scope

Industry recognized Institute of Electronic and Electrical Engineers (IEEE) standard C62.41 waveforms were utilized for the surge tests and IEEE C62.45 and UL 1449 test standards and guidelines were used to help ensure the accuracy of the test results. Please refer to Section 2.2 of this report for details on the test equipment utilized and the equipment setup for the tests. Noise tests were performed utilizing an industry standard technique of applying uniform random noise to determine frequency response of a circuit. By calculating the spectrum of the noise before and after a device is tested frequency response can be determined. The additional notes here discuss details for each test specification.

- IEEE C62.41, Category A1 (low system exposure) .5uS*100 kHz, 2kV, 70 amp ring wave. Testing was performed with the initial pulse in the positive direction and testing was performed with the unit under test powered at 420V RMS. Testing was performed at 90, 180 and 270 degrees to help establish suppressor and filter performance at the positive peak, the zero crossing and the negative peak of the waveform. This test represents a disturbance waveform that is representative of those that are generated internal by facility loads and switching. Note: only category A1-A3 and category B1-B3 exposure locations are utilized for the .5uS*100 kHz ring wave.

- IEEE C62.41, Category B3 (high system exposure) .5uS*100 kHz, 6kV, 500 amp ring wave Testing was performed with the initial pulse in the positive direction and testing was performed with the unit under test powered at 420V RMS. Testing was performed at 90, 180 and 270 degrees to help establish suppressor and filter performance at the positive peak, the zero crossing and the negative peak of the waveform. This test is similar to the above waveform, only higher voltage and current values are utilized to represent disturbances with higher energy contents.

- IEEE C62.41, Category B1 (low system exposure) 1.5/50uS & 8/20uS, 2kV, 1kA amp combination wave (pulse in positive direction) Testing was performed with the pulse in the positive direction and testing was performed with the unit under test powered at 428V

RMS. This test represents a disturbance waveform that is representative of those that are generated externally to a facility, such as lightning. Note: the combination wave is represented by three facility location categories, A, B and C, with Category A representing a representative surge waveform for outlets and long branch circuits, Category B representing feeders, short branch circuits and distribution panel devices and Category C representing outside, service entrance and service drop locations.

- IEEE C62.41, Category B3 (high system exposure) 1.5/50uS & 8/20uS, 6kV, 3kA combination wave (pulse in positive direction) Testing was performed with the pulse in the positive direction and testing was performed with the unit under test powered at 428V RMS. This test represents a disturbance waveform that is representative of those that are generated externally to a facility, such as lightning.

- Random Noise Testing. A noise generator and a high power amplifier were used to generate random noise. This random noise was used to test the SPD's ability to provide noise attenuation through the internal filter circuits. The noise generated by the noise generator was used to represent noise reflected into the facility power distribution system by facility loads such as AC adjustable frequency drives, DC drives, rectifiers, electronic ballast, switching power supplies, arcing contactors, etc.

2.2 Test Equipment

Test equipment utilized in the surge tests consisted of:

- Schaffner NSG 650 Surge Generator - Supplied all test waveforms.
- Schaffner CDN 110 Coupler Circuit - Coupled test waveforms into 480 V single phase circuit.
- 480 V Three Phase Variac - Supplied fundamental voltage waveform.
- Tektronix TDS 460A Digital Oscilloscope - Used to measure and capture all waveforms.
- Tektronix P6009 100X Probes - Allowed high frequency capture of high voltage waveforms directly into oscilloscope.

Test equipment utilized in the noise tests consisted of:

- Wavetek 395 Function Generator
- Khron-Hite 750 High Voltage Amplifier
- ESA EasyPower Measure Digitizing System
- Two Foot Banana Cables

2.3 Surge Test Procedure

For each device, 12" leads were bundled tightly and connected to the output of the surge generator coupler circuit. Only one phase-to-phase connection of each device was tested. The fundamental voltage was set at 428 V (the limit of Coupler Circuit). Each device was exposed to five of each of the impulse waveforms discussed in Section 2.2 at three different phase locations on the fundamental wave, while results were recorded on the oscilloscope.

2.4 Noise Application Test Procedure

For each device a 6" length of wire was used in addition to the 12" of device wire to connect each device to the output of the high voltage amplifier. Only phase-to-phase connections of each device were tested. The amplifier input was driven by the main output of the Wavetek 395 waveform generator. A signal + noise waveform was selected that generated 1 kHz to 90 kHz uniform random noise superimposed on a 60 Hz waveform. The noise peak to waveform peak ratio was 40% to 60%.

Due to the differing filter nature of the devices and low current capability of the amplifier, levels of the waveform differ slightly from device to device. The technique used was to increase the amplifier signal level until the amplifier noted an overload condition. The gain was then backed off slightly so that no current limiting circuit was invoked in the amplifier. The noise level was recorded. The device under test was then disconnected, and the noise level was measured open circuit, which represents the level of noise without any device filtering it.

3.0 Test Results

3.1 Introduction

The tests performed are summarized using tabulated values of Let Through voltage for the ANSI waveform tests, and plots of captured waveforms. After each table and figure are pertinent comments.

We would note that the Psytronics unit failed on the ANSI B3 Combination Wave test (supposed to be a non-destructive test), and thus we have no Let Through voltages for the Psytronics unit for that test. According to the test engineer, when the first 90 degree B3 Combination Wave was applied to the brand new Psytronics unit "A loud snap was heard from inside the Psytronic enclosure. Following the test it was noted that the two outside phase lamps were on. The unit was opened and the two outside fuses tested open."

3.2 Tables of Let Through Voltage with Comments

Table 1. A1 Ring Wave Let Through Results in Volts.

	Cutler Hammer			EP2000			Psytronics		
Phase	**Baseline**	**Peak**	**Let Through**	**Baseline**	**Peak**	**Let Through**	**Baseline**	**Peak**	**Let Through**
90 degrees	590	996	406	604	668	64	580	1304	724
	576	996	420	592	668	76	580	1328	748
	580	984	404	580	632	52	568	1320	752
	588	980	392	604	656	52	576	1328	752
	580	984	404	604	668	64	576	1328	752
180 degrees	32	432	400	28	76	48	0	1272	1272
	44	444	400	4	64	60	-56	1272	1328
	-44	344	388	28	112	84	-48	1272	1320
	56	444	388	-56	4	60	16	1272	1256
	44	432	388	-4	76	80	-56	1272	1328
270 degrees	-632	-212	420	-628	-544	84	-648	1184	1832
	-620	-212	408	-628	-544	84	-648	1168	1816
	-596	-204	392	-628	-560	68	-632	1168	1800
	-620	-212	408	-628	-544	84	-632	1160	1792
	-620	-212	408	-620	-544	76	-632	1168	1800

In Table 1, we see that the EP2000 has the least let through voltage of the three devices under test, and the Psytronics has the greatest. The filtering action of the EP2000 shows its additional benefit here. Let through voltage is determined by subtracting the Baseline Voltage from the Peak Voltage.

Table 2. B3 Ring Wave Let Through Results in Volts.

	Cutler Hammer			EP2000			Psytronics		
Phase	**Baseline**	**Peak**	**Let Through**	**Baseline**	**Peak**	**Let Through**	**Baseline**	**Peak**	**Let Through**
90 degrees	520	1540	1020	576	1040	464	560	1680	1120
	540	1580	1040	576	1032	456	560	1680	1120
	540	1580	1040	552	1016	464	560	1680	1120
	520	1580	1060	536	1008	472	560	1680	1120
	540	1580	1040	576	1032	456	560	1680	1120
180 degrees	-280	1420	1700	-128	344	472	-300	1620	1920
	-280	1420	1700	-120	344	464	-340	1600	1940
	-360	1400	1760	-192	296	488	-180	1600	1780
	-260	1440	1700	-200	272	472	-280	1620	1900
	-260	1420	1680	-160	320	480	-280	1640	1920
270 degrees	-540	1360	1900	-584	-102	482	-600	1600	2200
	-580	1360	1940	-576	-96	480	-600	1600	2200
	-560	1360	1920	-584	-96	488	-560	1600	2160
	-560	1360	1920	-584	-104	480	-540	1600	2140
	-580	1360	1940	-576	-104	472	-540	1600	2140

In Table 2, we see that with a more severe magnitude of ring wave that again the EP2000 allows the least amount of let through, and the Psytronics the greatest at 270 degrees on the fundamental wave. Again, the filtering action of the EP2000 shows its additional benefit here. Let through voltage is determined by subtracting the Baseline Voltage from the Peak Voltage.

Table 3. B1 Combination Wave Let Through Results in Volts.

	Cutler Hammer			EP2000			Psytronics		
Phase	**Baseline**	**Peak**	**Let Through**	**Baseline**	**Peak**	**Let Through**	**Baseline**	**Peak**	**Let Through**
90 degrees	568	1544	1544	580	1496	1496	576	1552	1552
	568	1536	1536	592	1496	1496	584	1552	1552
	576	1544	1544	592	1508	1508	560	1552	1552
	560	1552	1552	580	1508	1508	552	1552	1552
	560	1552	1552	592	1508	1508	560	1552	1552
180 degrees	-24	1496	1496	-92	1400	1400	-24	1448	1448
	-48	1480	1480	-92	1412	1412	56	1456	1456
	-128	1480	1480	-136	1400	1400	-40	1448	1448
	-64	1480	1480	-92	1412	1412	-40	1456	1456
	-144	1480	1480	-124	1388	1388	48	1472	1472
270 degrees	-600	1408	1408	-624	1264	1264	-632	1280	1280
	-600	1400	1400	-584	1264	1264	-624	1280	1280
	-600	1408	1408	-608	1272	1272	-632	1280	1280
	-600	1408	1408	-584	1272	1272	-624	1280	1280
	-600	1408	1408	-600	1272	1272	-632	1280	1280

In Table 3, we see each device responding about the same to the B1 Combination wave. The EP2000 does show the lowest let through voltage in terms of maximum for any condition (i.e. 1508V vs. 1552 for the Cutler Hammer unit and 1552 for the Psytronic unit). Absorbing this high energy waveform shows limiting action through surge suppression rather than filtering. Each unit appears to be performing such limiting action.

Table 4. B3 Combination Wave Let Though Results in Volts.

	Cutler Hammer			EP2000			Psytronics		
Phase	**Baseline**	**Peak**	**Let Through**	**Baseline**	**Peak**	**Let Through**	**Baseline**	**Peak**	**Let Through**
90 degrees	552	1784	1784	552	1928	1928	-	-	-
	536	1792	1792	528	1920	1920	-	-	-
	552	1792	1792	528	1920	1920	-	-	-
	536	1784	1784	528	1920	1920	-	-	-
	536	1792	1792	520	1920	1920	-	-	-
180 degrees	-264	1720	1720	-184	1880	1880	-	-	-
	-168	1736	1736	-240	1880	1880	-	-	-
	-104	1744	1744	-232	1880	1880	-	-	-
	-248	1736	1736	-248	1872	1872	-	-	-
	-264	1736	1736	-232	1880	1880	-	-	-
270 degrees	-568	1696	1696	-512	1848	1848	-	-	-
	-568	1688	1688	-608	1832	1832	-	-	-
	-552	1696	1696	-568	1848	1848	-	-	-
	-568	1696	1696	-576	1848	1848	-	-	-
	-568	1696	1696	-520	1848	1848	-	-	-

In Table 4, we see the Cutler Hammer and EP2000 responding about the same. The Psytronics unit failed under this test upon the first application of the 90 degree waveform. The Cutler Hammer unit does show the lower let through voltage in terms of maximum for any condition (i.e. 1792V vs. 1928V for the EP2000). Absorbing this high energy waveform shows limiting action through surge suppression rather than filtering. The two surviving units appear to be performing such limiting action.

3.3 Tables of dV/dt for Combo Waves with Comments

Table 5. B1 Combination Wave dV/dt.

(Volts per uSec)

Phase	Wave Alone dV/dt	Cutler Hammer dV/dt	EP2000 dV/dt	Psytronics dV/dt
90 degrees	3451	666	249	2955
180 degrees	3451	785	275	3985
270 degrees	3451	842	288	4698

In Tables 5 and 6, we have presented the measured let through dV/dt for each device tested, as well as the combination waves alone. These values were determined by extracting waveform slope from Figures 9 through 16. In those figures we can clearly see that the EP2000 has the greatest decrease in slope (less vertical). This translates into a lower dV/dt.

Semiconductors (IGBTs, Thyristors, etc.) are sensitive not only to peak voltage (Let Through results in Tables 1 through 4), but also to the rate of change of voltage. The EP2000 is showing the lowest dV/dt of the devices tested, reducing dV/dt by a factor of 12 times for the B1 Combo

Wave, and 16 times for the B3 Combo Wave. The Cutler Hammer unit has decreased dV/dt 4 times for the B1 Combo Wave, and 6 times for the B3 Combo Wave. The Psytronics unit is barely reducing dV/dt, and is in some way increasing voltage slope for the 180 and 270 degrees B1 Combo Wave test. The method at work to do this has not been determined, since the epoxy encapsulated units did not allow for investigation of the internal components. The tests have simply recorded the actual response of the voltage with the unit connected. Also, Psytronics test results are not available for the 180 and 270 degrees tests of the B3 Combo Wave since the unit failed on the 90 degree test.

Table 6. B3 Combination Wave dV/dt.

(Volts per uSec)

Phase	Wave Alone dV/dt	Cutler Hammer dV/dt	EP2000 dV/dt	Psytronics dV/dt
90 degrees	10883	1229	482	6764
180 degrees	10883	1465	641	NA
270 degrees	10883	1668	668	NA

3.4 Captured Surge Waveforms with Comments

3.4.1 Base A1 Ring Wave

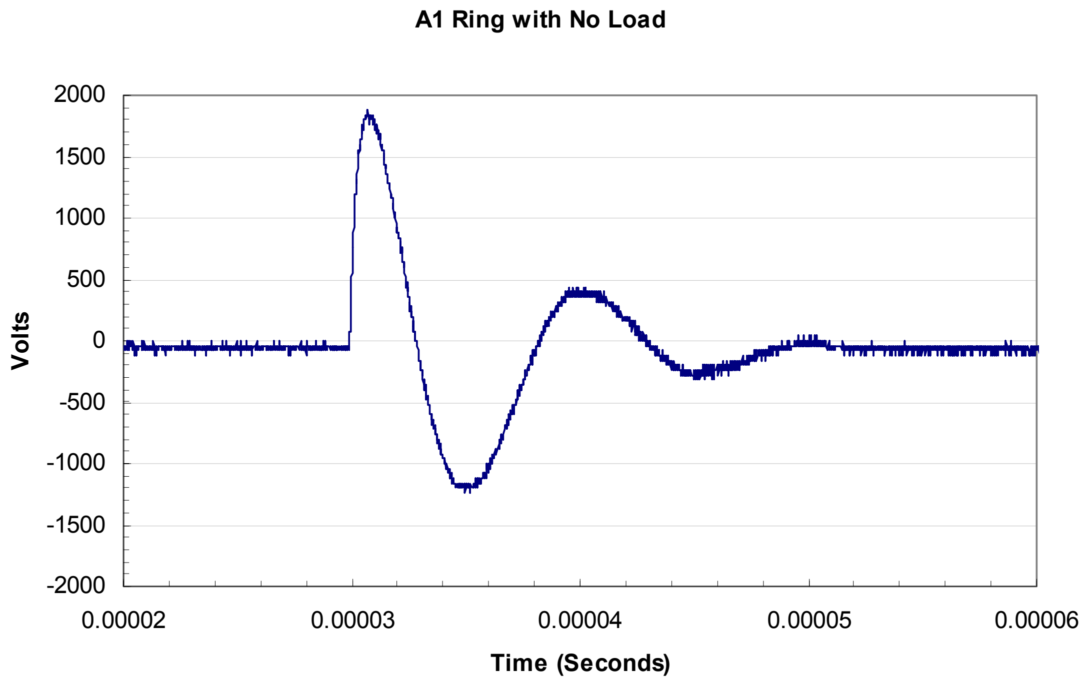

Figure 1. Base A1 Ring Wave with no Devices Connected.

This waveform shows the A1 Ring Wave from IEEE C62.41, Category A1 (low system exposure). That wave has a .5uS voltage rise time with 100 kHz ring, a 2kV peak voltage under open circuit, and supplying 70 A under short circuit conditions. We see that the wave did not peak at exactly 2kV, but appears close enough for comparison efforts. This open circuit test was run several times to verify repeatability of the same peak voltage and ring.

3.4.2 A1 Ring Wave Applied at Peak of Fundamental Wave

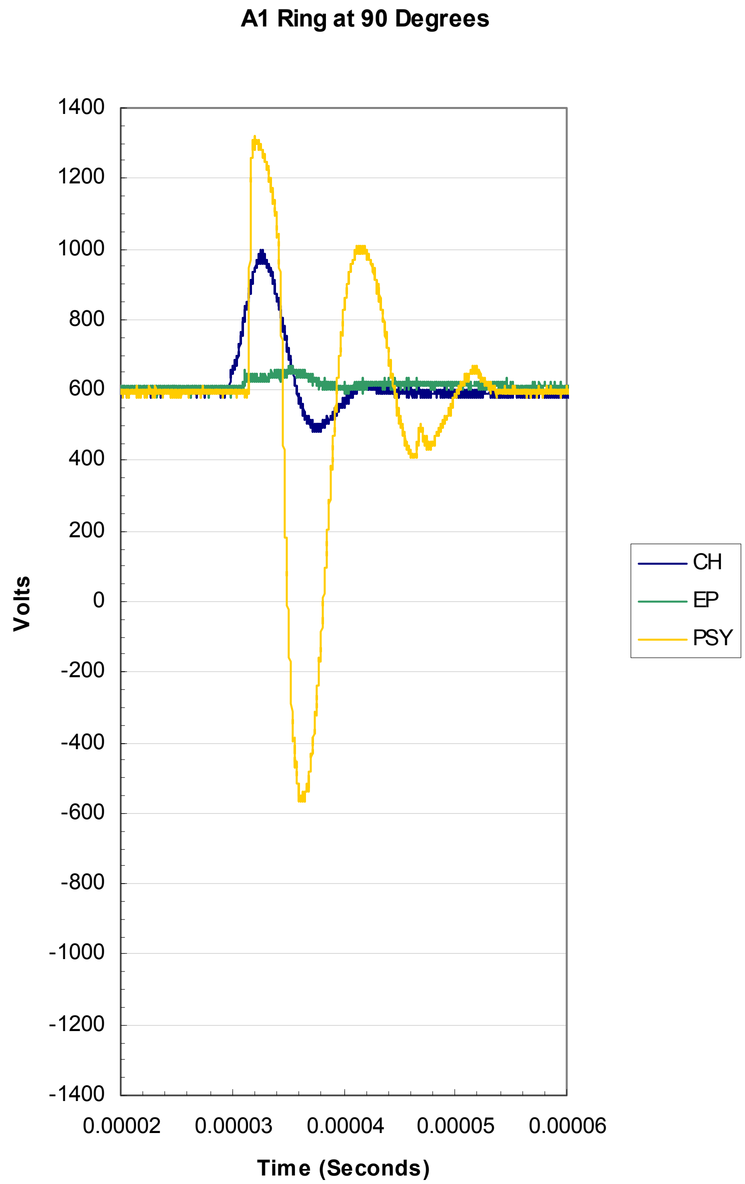

Figure 2. A1 Ring Wave Applied at Peak of Fundamental (90°).

Application of the A1 Ring Wave at the peak of the fundamental voltage wave shows the EP2000 supplying the greatest absorption (green curve). The Cutler Hammer unit (blue curve) also shows significant absorption while the Psytronics unit (yellow curve) shows a wildly swinging negative voltage peak. Note that the negative peak was not used in the tables for calculating let through voltage, only positive was used. We expected the positive peak to be greater than the negative due to the nature of the applied impulse (see Figure 1). Using the negative peak for let through voltage (which is a correct application) yields an even greater value.

3.4.3 A1 Ring Wave Applied at Zero Cross of Fundamental Wave

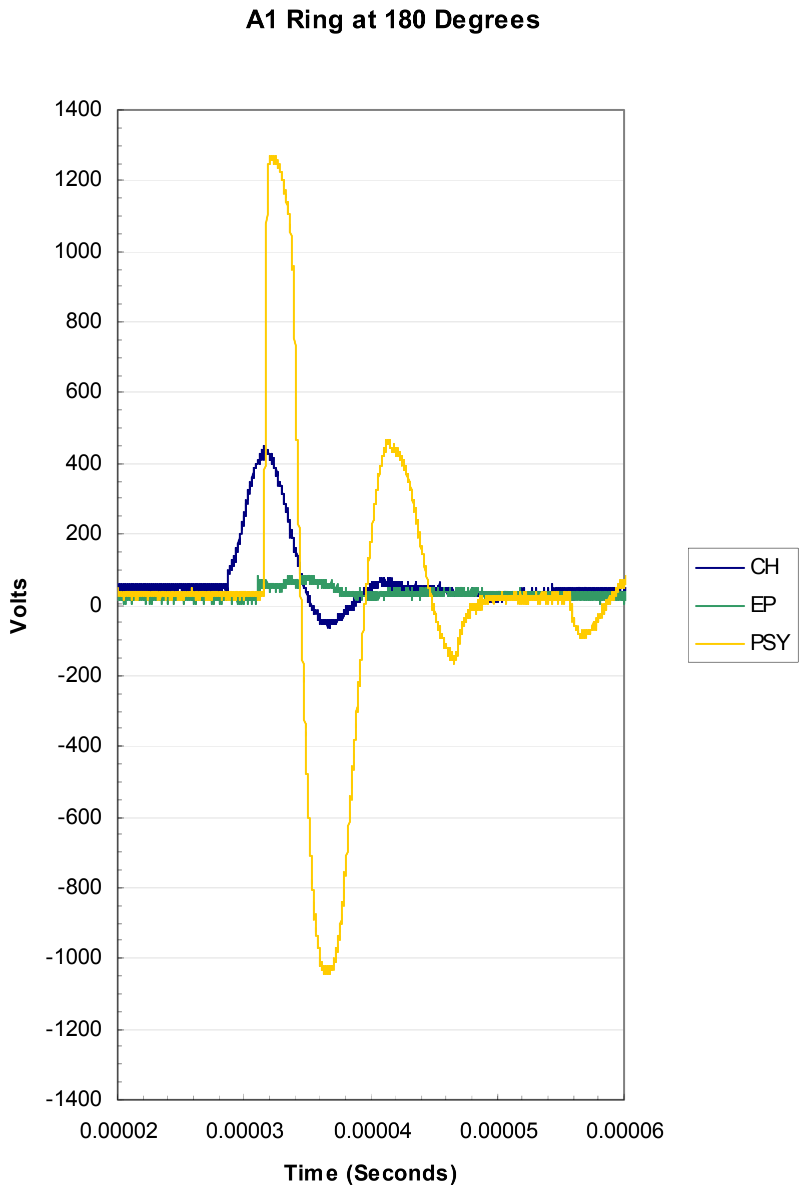

Figure 3. A1 Ring Wave Applied at Zero Cross of Fundamental (180°).

Application of the A1 Ring Wave at the zero cross of the fundamental voltage wave shows the EP2000 supplying the greatest absorption (green curve). The Cutler Hammer unit (blue curve) also shows significant absorption while the Psytronics unit (yellow curve) shows a wildly swinging negative voltage peak. Note that the negative peak was not used in the tables for calculating let through voltage, only positive was used. We expected the positive peak to be greater than the negative due to the nature of the applied impulse (see previous figure). Using the negative peak for let through voltage (which is a correct application) yields an even greater value.

3.4.4 A1 Ring Wave Applied at Negative Peak of Fundamental Wave

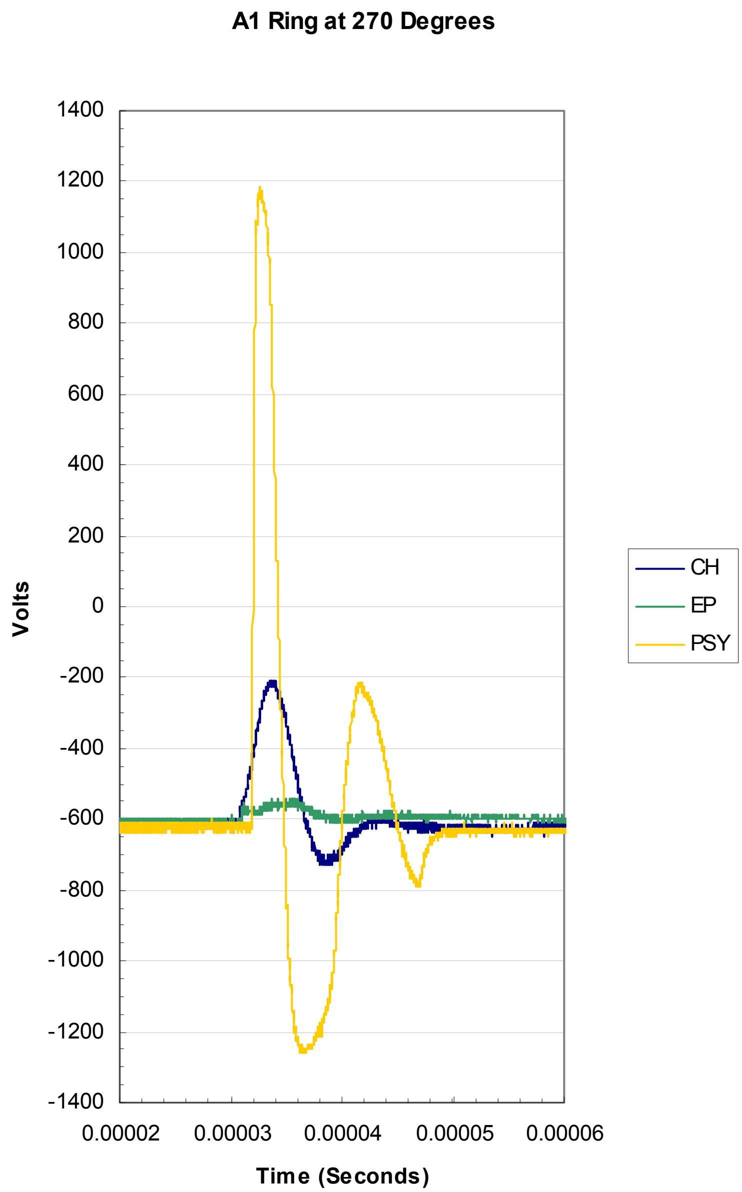

Figure 4. A1 Ring Wave Applied at Negative Peak of Fundamental (270°).

As in Figures 3 and 4, application of the A1 Ring Wave at the negative peak of the fundamental voltage wave shows the EP2000 supplying the greatest absorption. The Cutler Hammer unit also shows significant absorption while the Psytronics unit now shows a very high positive peak voltage and still appears to be swinging excessively.

3.4.5 Base B3 Ring Wave

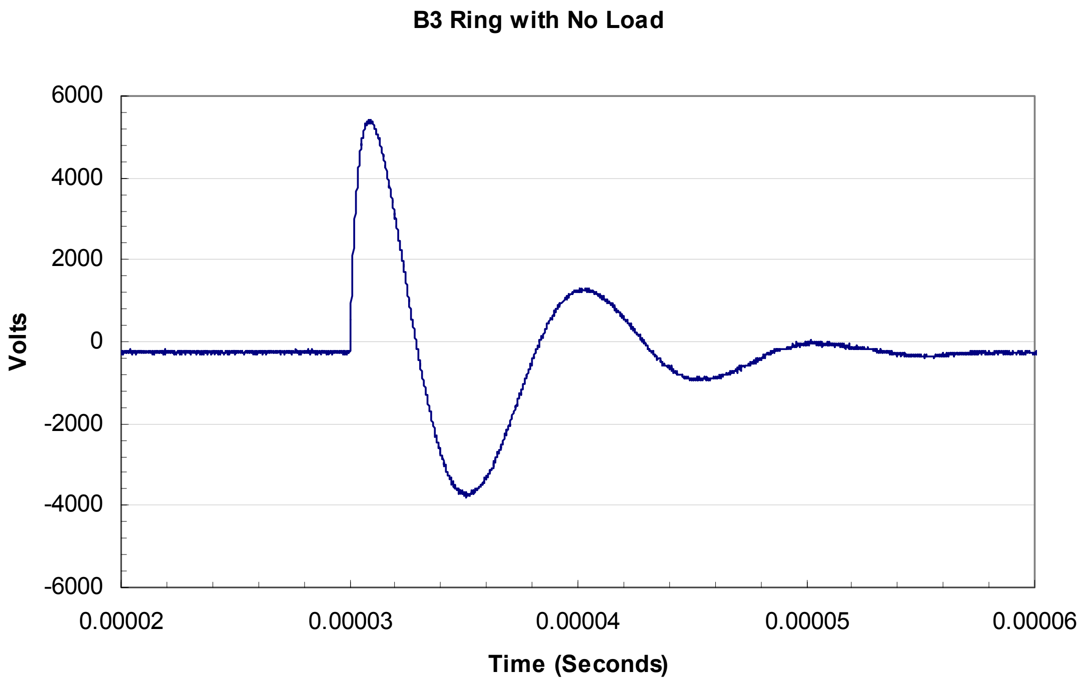

Figure 5. Base B3 Ring Wave with no Devices Connected.

This waveform shows the B3 Ring Wave from IEEE C62.41, Category B3 (high system exposure). That wave has a .5uS voltage rise time with 100 kHz ring, a 6 kV peak voltage under open circuit, and supplying 500 A under short circuit conditions. We see that the wave did not peak at exactly 6kV, but appears close enough for comparison efforts. This open circuit test was run several times to verify repeatability of the same peak voltage and ring.

3.4.6 B3 Ring Wave Applied at Peak of Fundamental Wave

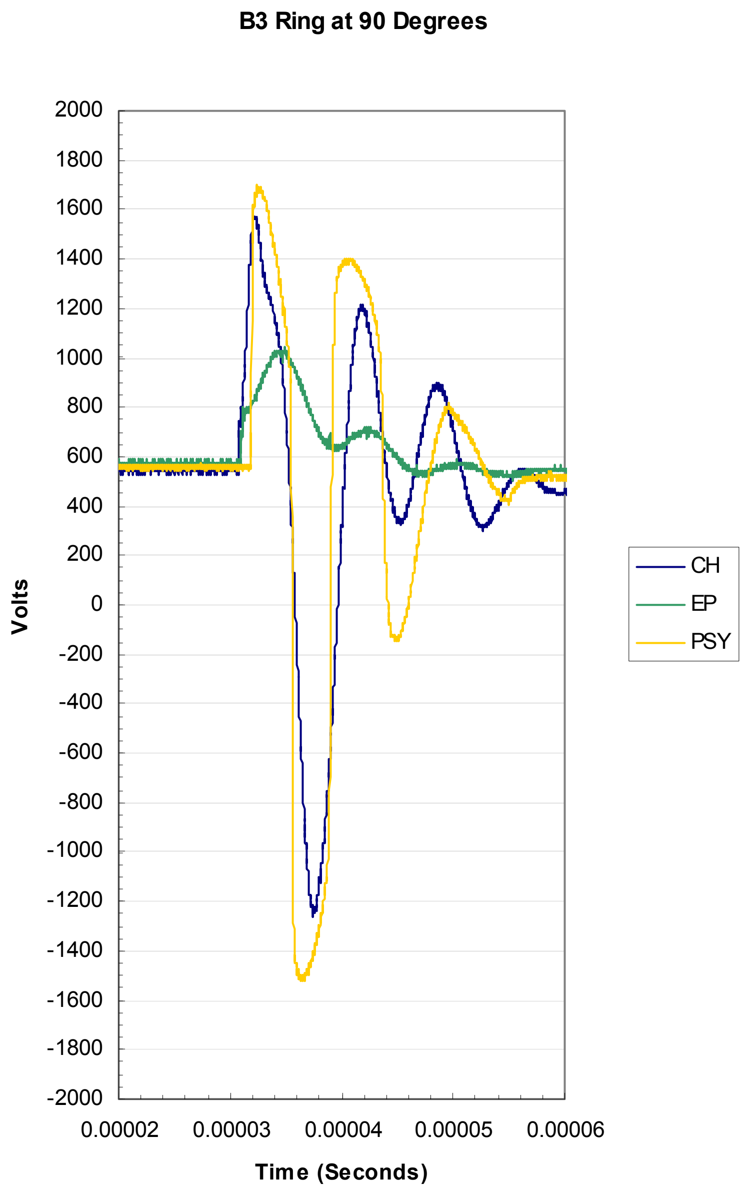

Figure 6. B3 Ring Wave Applied at Peak of Fundamental (90°).

The more sever B3 ring wave causes both the Cutler Hammer and Psytronics unit to swing negatively excessively while the EP2000, as with the A1 ring wave, has the best absorption.

3.4.7 B3 Ring Wave Applied at Zero Cross of Fundamental Wave

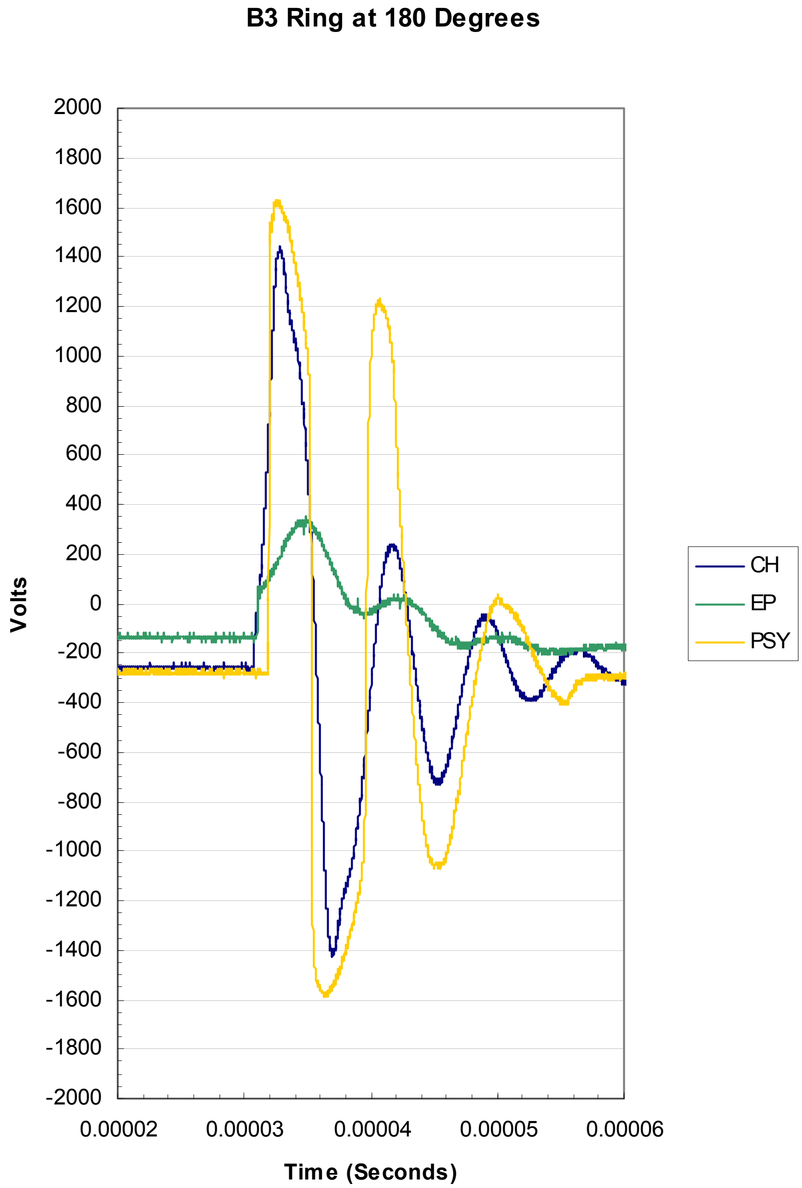

Figure 7. B3 Ring Wave Applied at Zero Cross of Fundamental (180°).

The more sever B3 ring wave causes both the Cutler Hammer and Psytronics unit to swing excessively while the EP2000, as with the A1 ring wave, has the best absorption.

3.4.8 B3 Ring Wave Applied at Negative Peak of Fundamental Wave

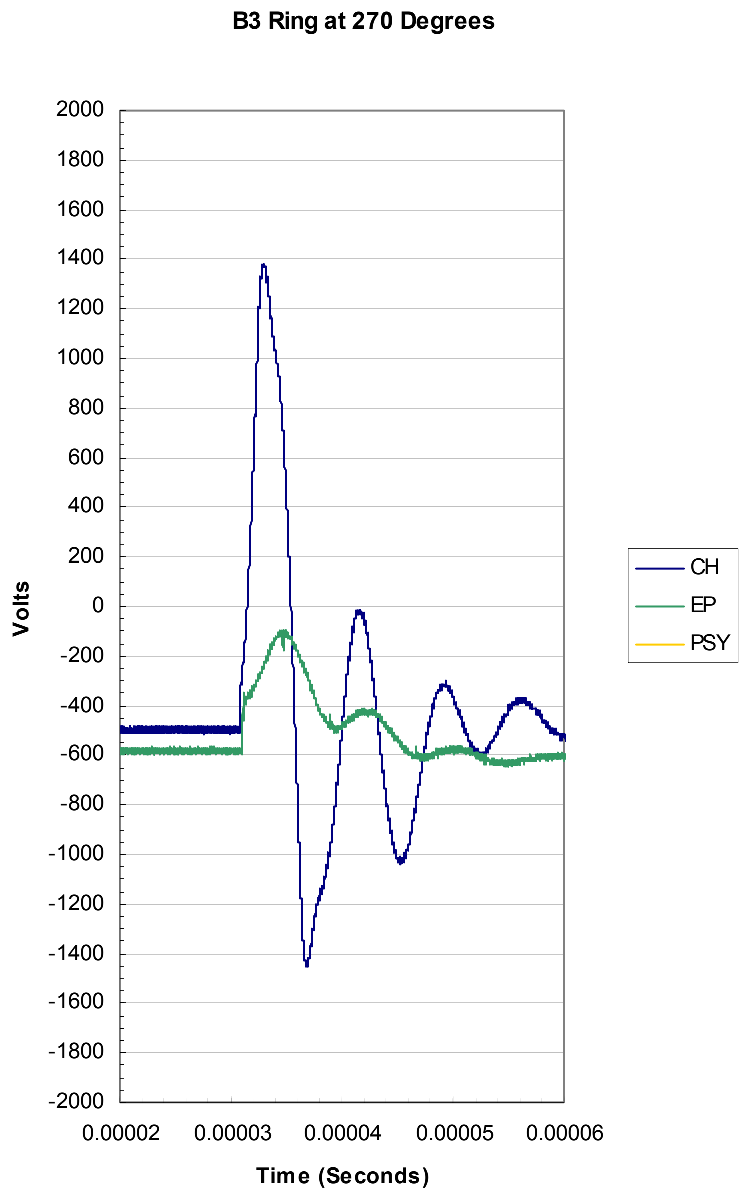

Figure 8. B3 Ring Wave Applied at Negative Peak of Fundamental (270^{o}).

The more sever B3 ring wave again causes the Cutler Hammer unit to swing excessively while the EP2000, as with the A1 ring wave, has the best absorption. We expect the Psytronics to behave as previously. Data for this Psytronics test is the only data lost due to a corrupt file saved by the Tektronix scope.

3.4.9 Base B1 Combination Wave

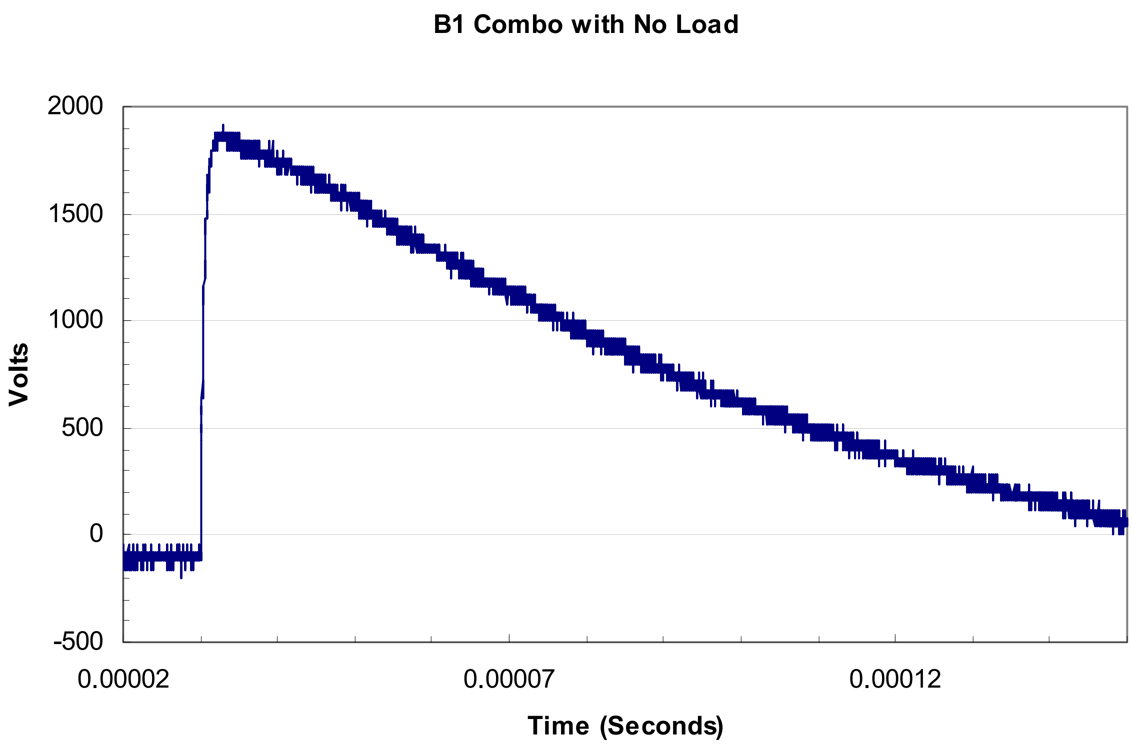

Figure 9. Base B1 Combination Wave with no Devices Connected.

This waveform shows the B1 Combination Wave from IEEE C62.41, Category B1 (low system exposure). That wave has a 1.5 uS rise time and 50 uS decay time voltage wave with a 2 kV peak voltage under open circuit, and an 8 uS rise time with 20 uS decay time current wave at 1000 A peak under short circuit. We see that the wave did not peak at exactly 2kV, but appears close enough for comparison efforts. This open circuit test was run several times to verify repeatability of the same peak voltage and decay.

3.4.10 B1 Combination Wave Applied at Peak of Fundamental Wave

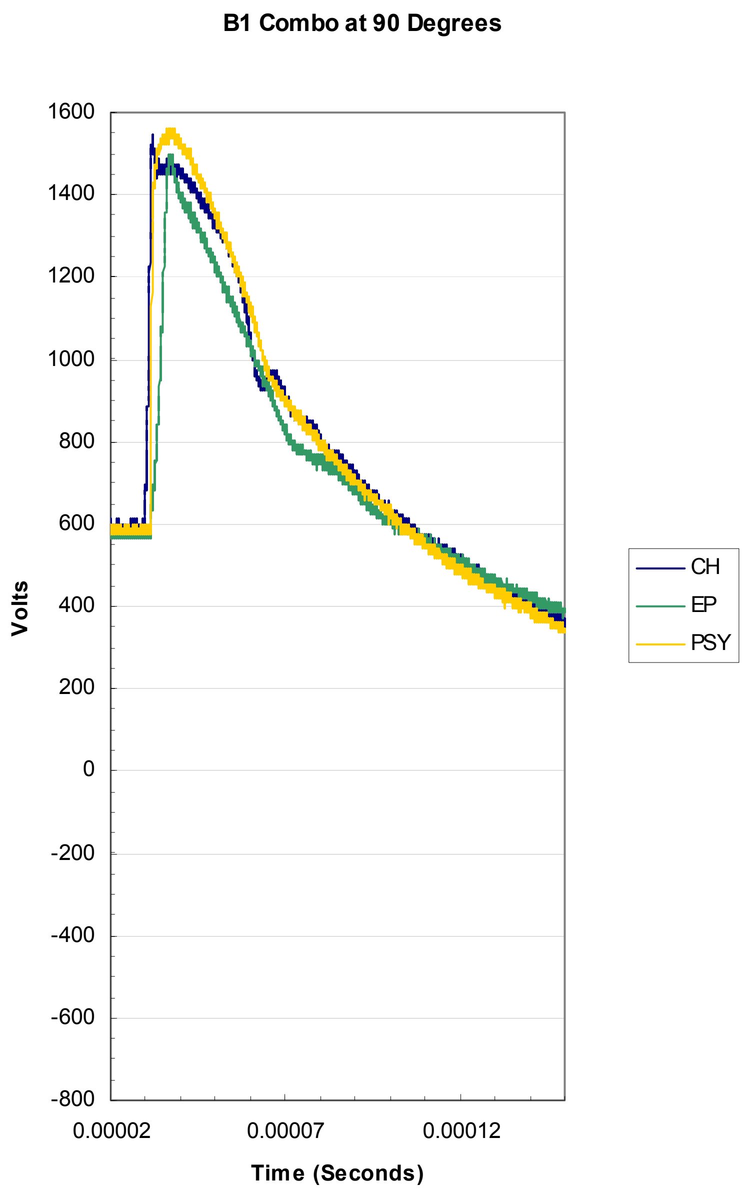

Figure 10. B1 Combination Wave Applied at Peak of Fundamental (90^o).

Each of the units show a similar response to the B1 Combination Wave. As noted earlier, this is intended to simulate an externally caused event like lightning, and will most likely invoke voltage clamping components that are used in each device. Due to the nature of the waveform, the filtering action (seen to be very effective in the ring wave tests) has less effect in reducing let-through. However, the EP2000 clearly has reduced the slope on the voltage wave, thus lowering dV/dt. As seen in Tables 5 and 6, the EP2000 has the least dV/dt let through of the three units under test.

3.4.11 B1 Combination Wave Applied at Zero Cross of Fundamental Wave

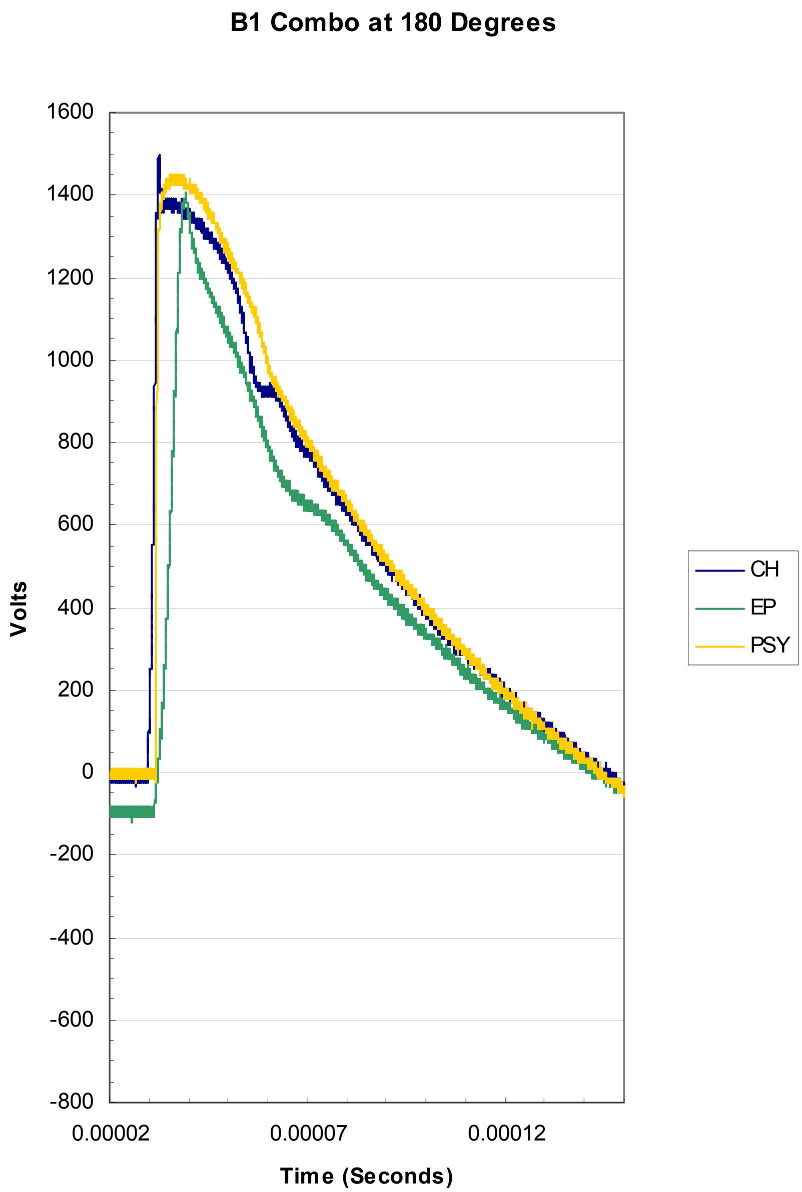

Figure 11. B1 Combination Wave Applied at Zero Cross of Fundamental (180°).

The comments for Figure 10 apply here as well.

3.4.12 B1 Combination Wave Applied at Negative Peak of Fundamental Wave

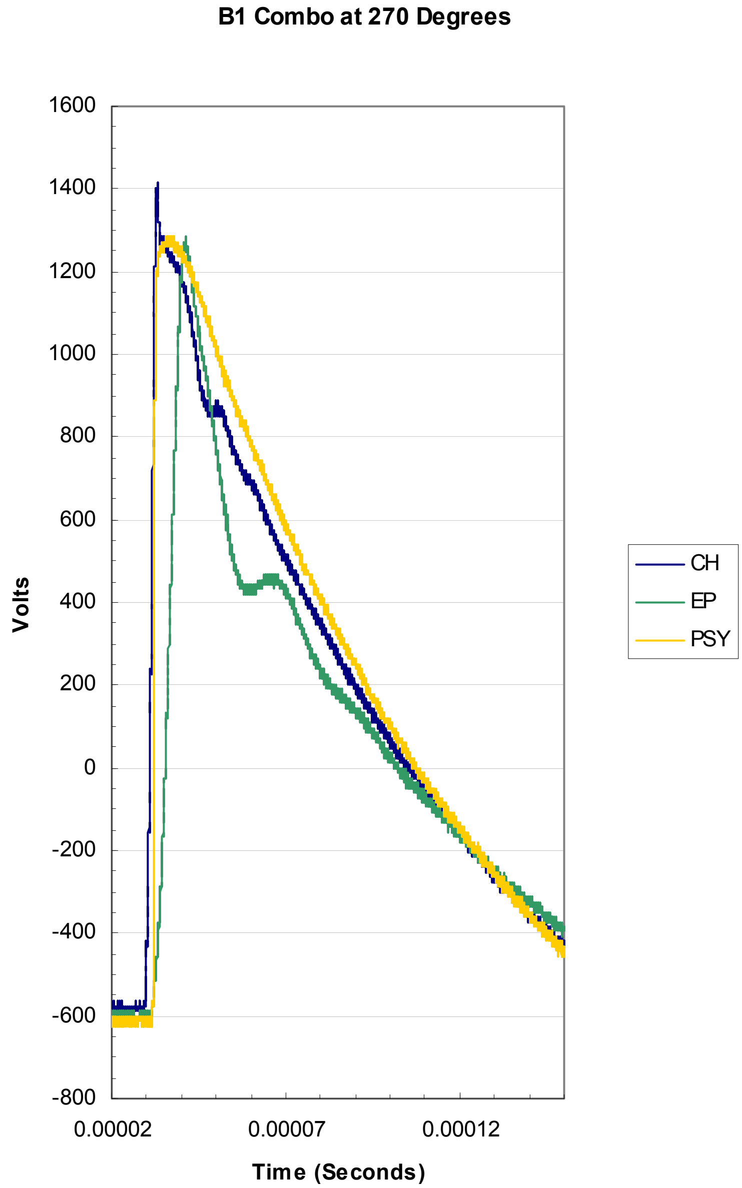

Figure 12. B3 Combination Wave Applied at Negative Peak of Fundamental (270°).

The comments for Figure 10 apply here as well.

3.4.13 Base B3 Combination Wave

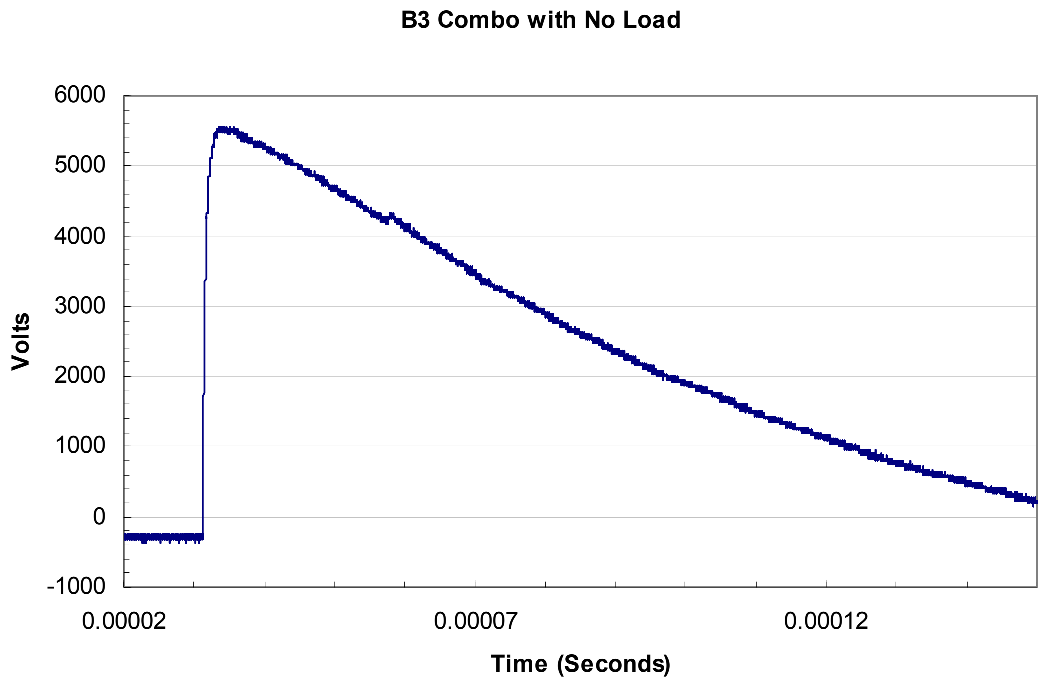

Figure 13. Base B3 Combination Wave with no Devices Connected.

This waveform shows the B3 Combination Wave from IEEE C62.41, Category B3 (high system exposure). That wave has a 1.5 uS rise time and 50 uS decay time voltage wave with a 6 kV peak voltage under open circuit, and an 8 uS rise time with 20 uS decay time current wave at 3000 A peak under short circuit. We see that the wave did not peak at exactly 6kV, but appears close enough for comparison efforts. This open circuit test was run several times to verify repeatability of the same peak voltage and ring.

3.4.14 B3 Combination Wave Applied at Peak of Fundamental Wave

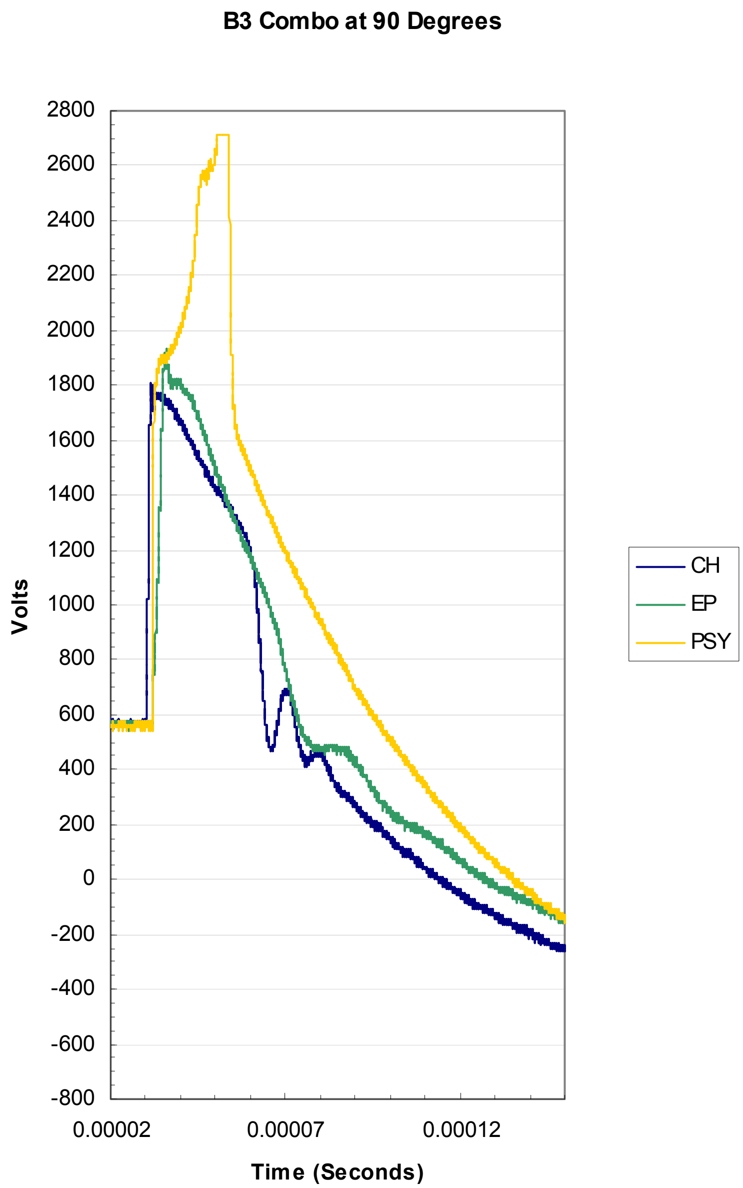

Figure 14. B3 Combination Wave Applied at Peak of Fundamental (90^o).

The Cutler Hammer and the EP2000 show a similar response to the B1 Combination Wave. As noted earlier, this event is intended to simulate an externally caused event like lightning, and will most likely invoke voltage clamping components that are used in each device. Due to the nature of the waveform, the filtering action (seen to be very effective in the ring wave tests) has less effect on this event. The Psytronics unit failed in this test, and its waveform can be seen to clip the input range of the oscilloscope as it increases beyond 2700 V. Again, the EP2000 has reduced the voltage waveform slope the most and produces the lowest let through dV/dt.

3.4.15 B3 Combination Wave Applied at Zero Cross of Fundamental Wave

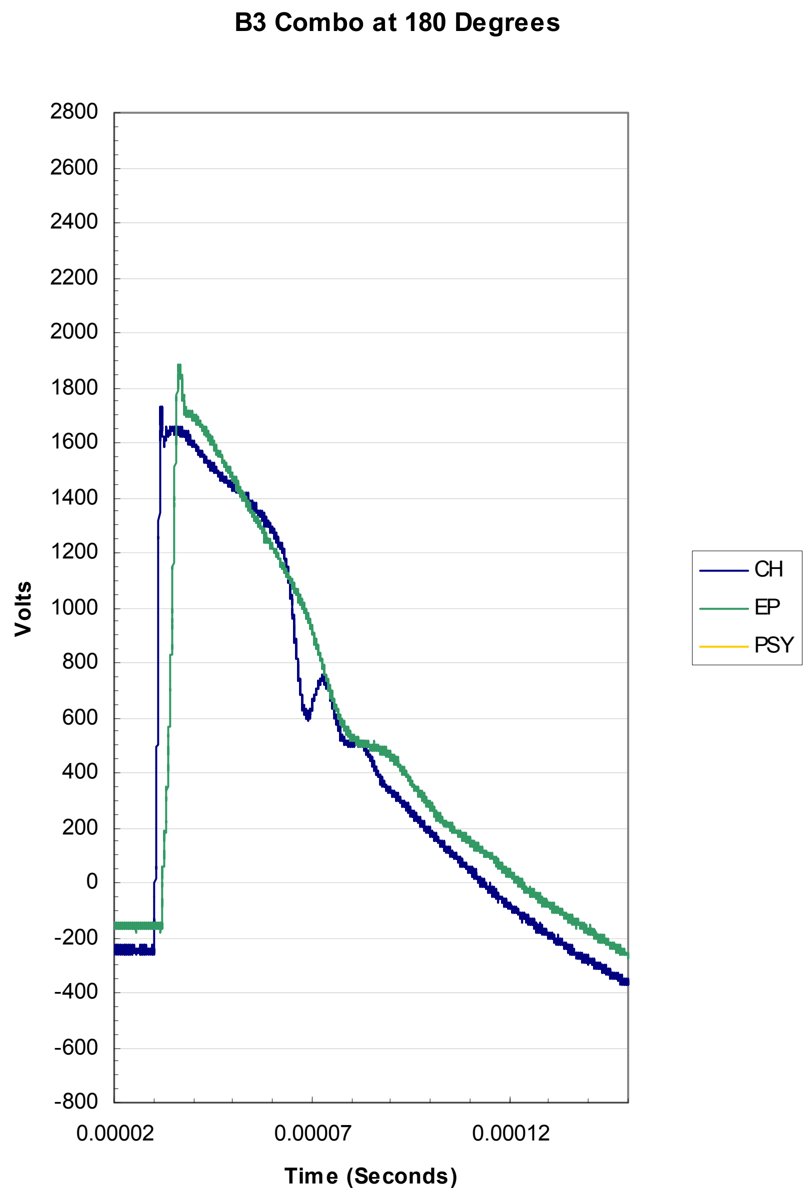

Figure 15. B3 Combination Wave Applied at Zero Cross of Fundamental (180°).

The Cutler Hammer and EP2000 comments for Figure 14 apply here as well.

3.4.16 B3 Combination Wave Applied at Negative Peak of Fundamental Wave

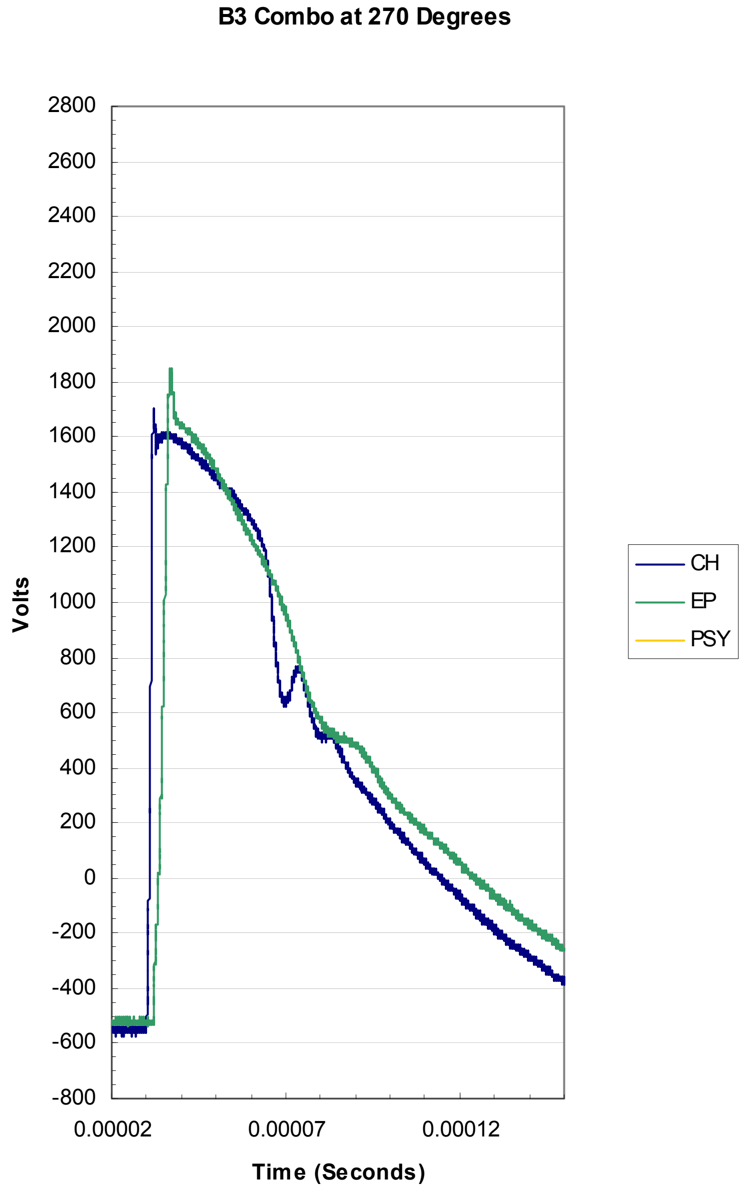

Figure 16. B3 Combination Wave Applied at Negative Peak of Fundamental (270°).

The Cutler Hammer and EP2000 comments for Figure 14 apply here as well.

3.5 Noise Testing Spectral Content with Comments

3.5.1 Cutler Hammer Frequency Response

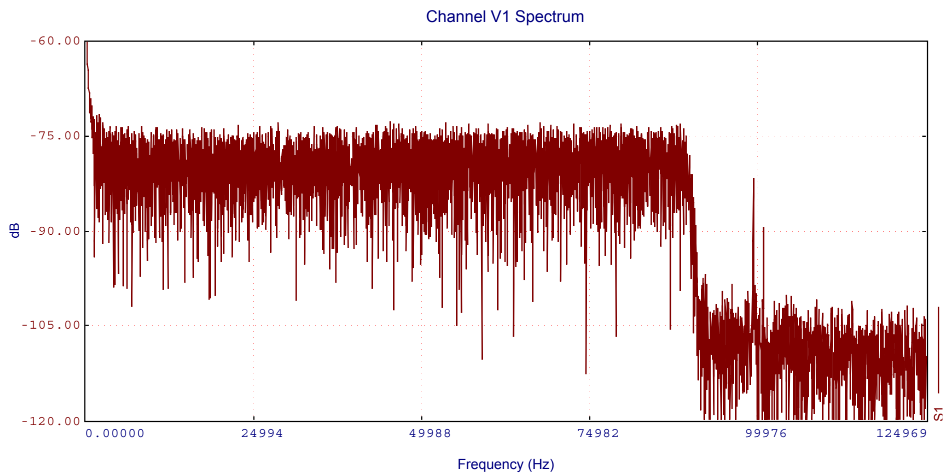

Figure 17. 1 kHz to 90 kHz Uniform Noise with Cutler Hammer Disconnected.

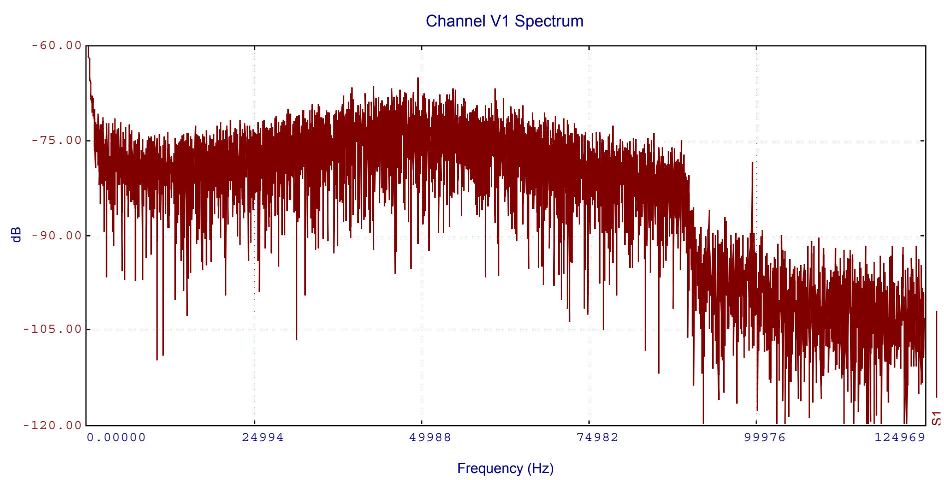

Figure 18. 1 kHz to 90 kHz Uniform Noise with Cutler Hammer Connected.

Noise tests were performed to discover any filtering action or adverse resonant conditions. Figure 17 shows the 1 kHz to 90 kHz uniform random noise spectrum when no device is connected. This noise was superimposed on a 60 Hz fundamental waveform. The response of the Cutler Hammer is shown in Figure 18. It has a broad resonant peak centering around 48kHz. At its peak, it amplifies (due to resonance) the signal about 2 times. The Cutler Hammer is not performing any filtering action in this range of frequency (typical drive switching frequency and switching frequency harmonics), as there is no drop of the noise significantly below -75dB, the level of the noise alone with no device connected.

3.5.2 EP2000 Frequency Response

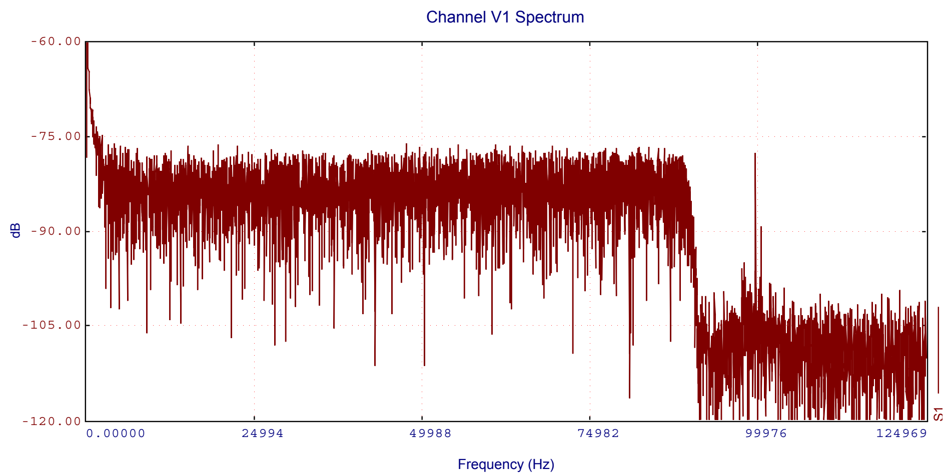

Figure 19. 1 kHz to 90 kHz Uniform Noise with EP2000 Disconnected

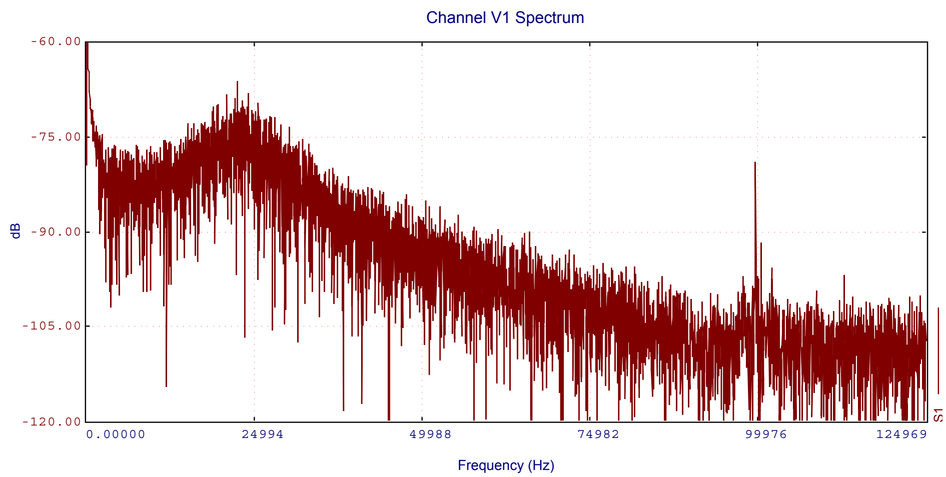

Figure 20. 1 kHz to 90 kHz Uniform Noise with EP2000 Connected.

The EP2000 on the other hand shows a very clear high frequency filtering response as seen in Figure 20. As with the Cutler Hammer, it too has a resonant peak, but it is centered at about 24kHz, is much narrower, and will cause less amplification of a broad range of frequencies. The magnitude of the resonance is approximately the same as the Cutler Hammer, and generates an amplification of about 2 times. The EP2000 shows significant filtering as the noise spectrum drops well below the -77 dB point. By the time we reach 70 kHz we are 19 dB lower than –77dB and are thus have a nearly 10X reduction in noise.

3.5.3 Psytronics Frequency Response

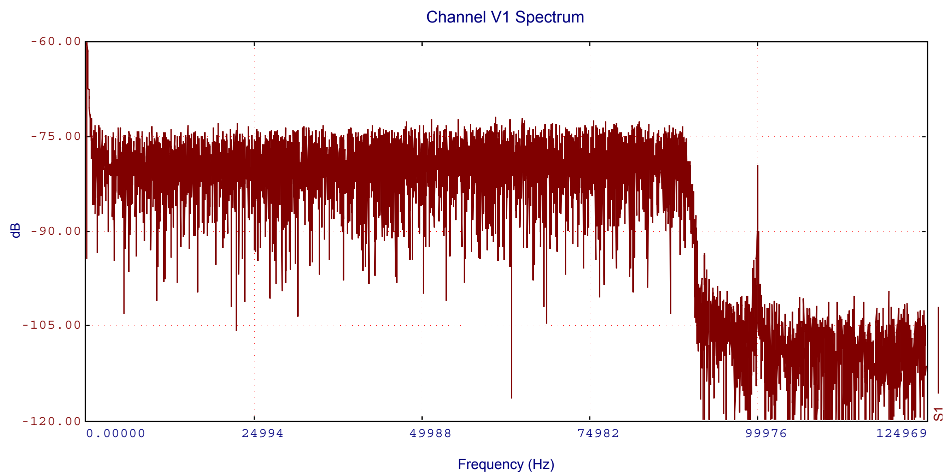

Figure 21. 1 kHz to 90 kHz Uniform Noise with Psytronics Disconnected.

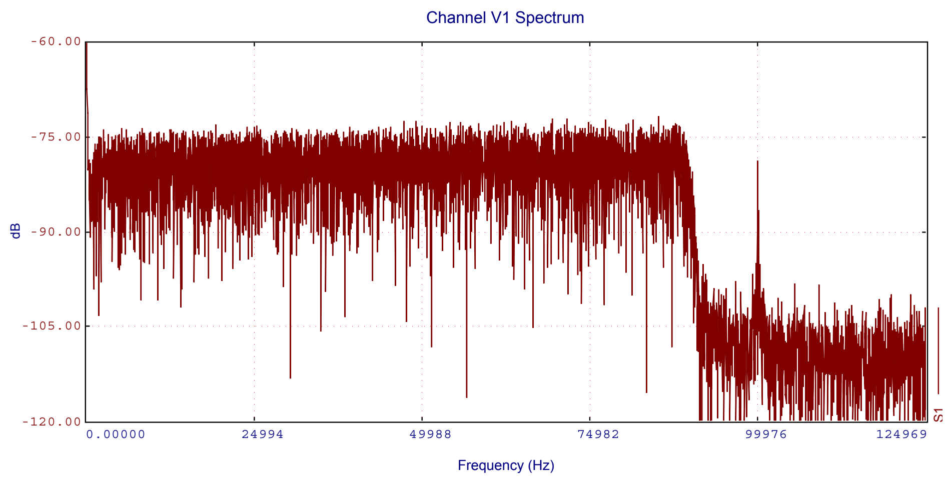

Figure 22. 1 kHz to 90 kHz Uniform Noise with Psytronics Connected.

Comparing Figures 21 and 22, we see that the Psytronics unit offers no filtering and appears as an open circuit in the 1 kHz to 90 kHz range.