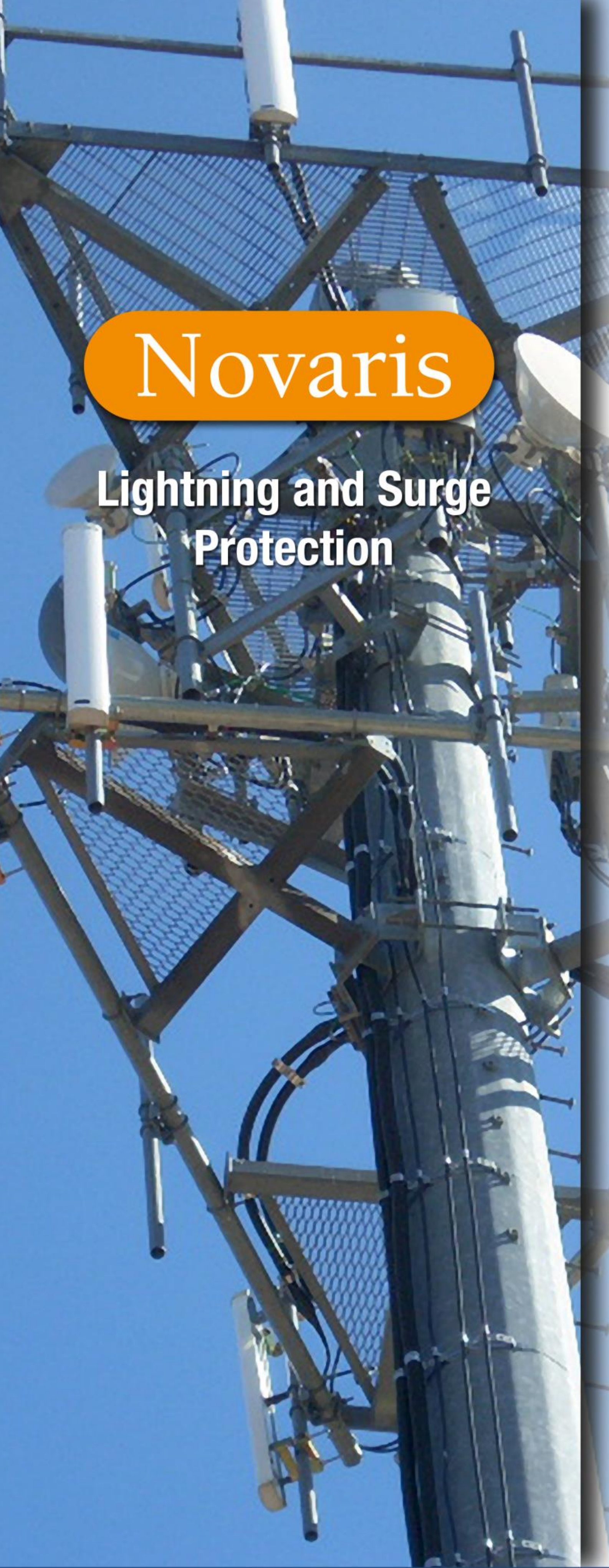

Overvoltage Protection for Remote Radio Unit Sites

Design and Application

Phillip Tompson

Introduction

With the advent of Remote Radio Units (RRU) at cellular basestations there is a need to supply power to these external units located at the top of the tower. Currently 48V DC power is supplied from the station battery. This means that the risk of damage to equipment within the building is greatly increased should lightning strike the tower as a proportion of the lightning current will enter the building via the 48V supply cables.

This effect is even more potentially damaging than a strike a power line where the rectifiers provide some degree of isolation from the 48V supply.

This paper considers this phenomenon, analyses the likely effects and presents a design that will prevent damage to equipment within the building. This paper also presents test results on some existing protection units and compares these with the Novaris design. This paper clearly shows that existing designs are deficient because the special characteristics of the 48V DC supply have not been considered. A final design that will effectively protect RRU sites is presented.

Sources and effects of lightning damage

Equipment may be damaged by either direct lightning strikes to the structure, in this case the tower, direct lightning strikes to the power line or from indirect strikes caused by cloud to ground or cloud to cloud strikes. These latter events cause induction and earth potential rises. It should be noted that transient electrical disturbances similar to lightning may be caused by power switching operations and power line faults.

Whether lightning enters via the power line or through a strike to the tower the effect will be the same. There will be earth potential rises and unless precautions are taken lightning current will flow through conductors, including earth conductors, within the building. A proper design is essential to prevent current flow through the building.

Lightning current flow through conductors creates potential differences primarily as a result of that conductor's inductance, not its resistance. The voltage is given by:

$$V_L = L \times dI/dt$$

Figure 1 shows the significance of this effect. The voltage drop across 1 meter of different conductor types is shown when a 10,000A lightning impulse (with an 8/20µs waveform) is applied. For the average earth conductor (35sqmm) used at a site expect around 1000V per meter. It is therefore obvious that lightning current must be kept out of the building and diverted to earth at the building point of entry.

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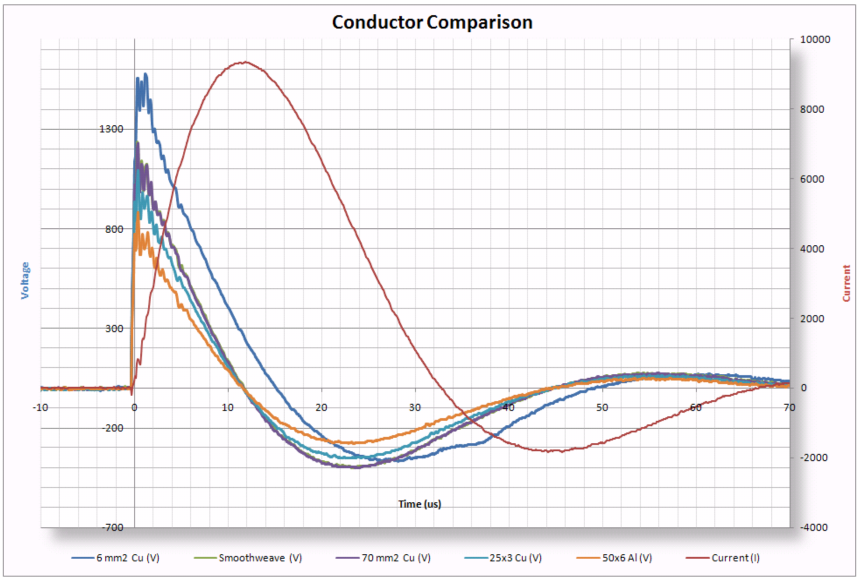

Figure 1. Conductor voltage drop for 10kA 8/20µs impulse

Lightning Risk

To assess the risk of a direct lightning strike to a basestation tower it is necessary to calculate its attractive area. For a tall slender mast the attractive area is given by:

$$A = 4h^2\pi \qquad \text{(ref.1)}$$

Where A = attractive area in km^2
h = height in km

For a 30m mast this equates to an attractive area of $0.0113km^2$. To obtain the number of strikes per annum this is multiplied by the ground flash density N_g. As an example figure 2 shows the ground flash density map for Australia derived from AS/NZS1768-2007.

For a ground flash density of 1, $N_g = 1$, this equates to 0.0113 strikes per annum or approximately one strike every 88 years. Alternatively over 88 sites expect one strike per annum. Over 500 sites expect around 6 sites to be struck per annum. For $N_g = 10$, this would rise to 60 sites per annum.

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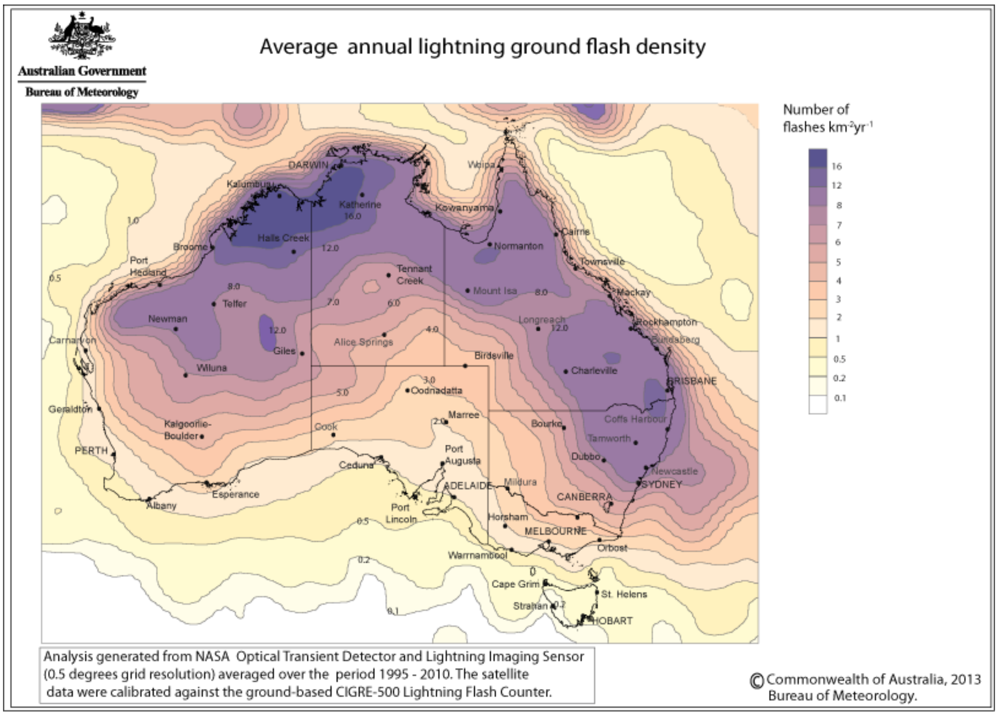

Figure 2. Australia ground flash density updated 2013

Design Parameters

According to the lightning protection standards the magnitude of an average lightning strike is 30kA (AS/NZS1768-2007). In Australia it is normal commercial practice to design lightning protection systems to capture strikes of 10kA and to be able to safely conduct strikes of up to 100kA. This accounts for 93% of all lightning strikes. Therefore to design a suitable protection unit we must allow for a 100kA strike to the tower. The lightning current may be modelled by a 10/350µs impulse in accordance with IEC62305-1.

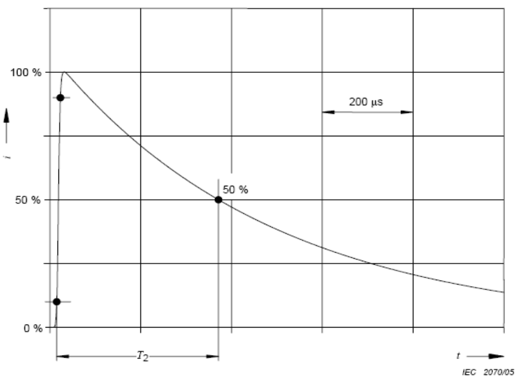

Figure 3. 10/350µs waveform from IEC62305-1

When lightning strikes a structure that is properly earthed the majority of lightning current will flow directly to earth but a proportion will flow in all other conductors such as antenna feeders and the 48V power distribution cables to the RRUs. The surge protection devices (SPDs) in the RRUs will operate and electrically "clamp" these conductors to the body of the tower. Without SPDs the RRUs must internally flash over.

In the absence of any quantitative detail IEC61643-12 recommends a conservative approach by assuming that 50% of the lightning current flows directly to earth and the other 50% flows equally across all other cables. This assumption results in a very conservative design.

For the purpose of this analysis assume there are 6 other current paths; three of these are cables to the RRUs and three coaxial feeders to other antennas, possibly 3G. For a 100kA strike, 50kA will flow to earth and 8.3kA through each of the other current paths.

In each RRU cable there are 9 conductors: four positive, four negative and one screen. This accounts for 0.93kA per conductor.

It is common practice to divide RRU cables across two separate 48V supplies; thus two separate surge protection circuits are needed. Each circuit will therefore terminate 12 conductors (6 positive and 6 negative). This is shown in figure 4 below.

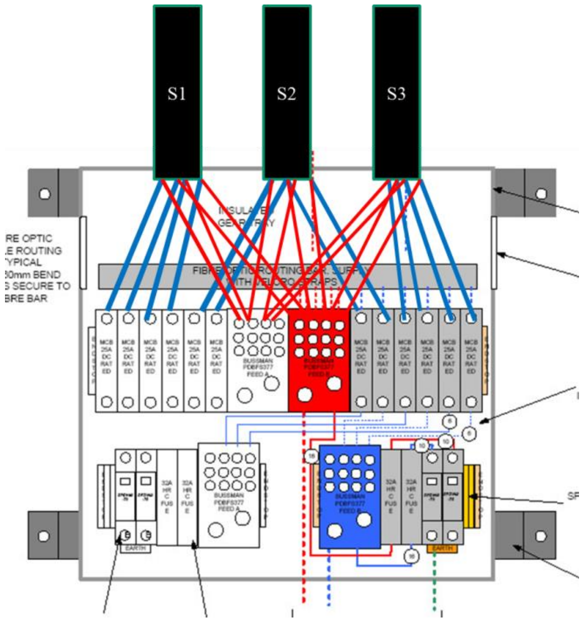

Figure 4. Cable configuration from a typical distribution/protection unit (SPD Box)

Although the positive is earthed at the battery it is not earthed in the protection unit. Novaris recommends an SPD configuration with MOV between negative and positive and a gas discharge tube between positive and earth. This results in the lowest transverse mode clamping voltage and from positive to earth a virtual short circuit for the duration of the gas tube firing cycle.

Existing configurations with MOV based SPDs connected negative to earth and positive to earth provide very poor transverse mode (negative to positive) protection.

The surge rating of the SPD can be calculated as follows:

1. Each of the two SPDs terminates 6 negative conductors with a total surge current of 5.5kA.

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2. The 8/20µs equivalent current for a 5.5kA 10/350µs current is 82.5kA (a ratio of 15, reference tests carried out on actual MOVs using Telstra Research Laboratory equipment). Allowing for some unequal sharing of current use 3 x 40kA MOVs in parallel = 120kA.
3. The gas discharge tube from positive to earth must carry 11kA. The 8/20µs equivalent current for a 11kA 10/350µs current is 74kA (a ratio of 6.7, reference Citel gas tube specifications). Use a 100kA gas discharge tube.

It is clear that existing MOV based SPDs with a 40kA rating are insufficient to handle a lightning strike of 100kA to the tower. They do not meet these design criteria.

Performance

The purpose of the distribution/protection box (SPD box) is to provide protection against a lightning strike to the tower and to provide 48V distribution. The SPD design must be such that the voltage let through to the internal equipment is reduced to a safe level. Far more importantly the current let through to the building internal wiring must also be reduced to a safe level.

Attached as appendix 1 are three drawings showing a typical SPD box containing an SPD comprising MOV devices. A 35sqmm earth conductor connects the SPD Box to the feeder earth bar (FEB). This is typically located at the feeder point of entry on the outside wall of the building. Based upon the design considerations discussed above a maximum current of 22kA (10/350µs could flow through this conductor, marked in green). It is noted on the drawing that a maximum of 3m is allowed for this cable. Reference to figure 1 shows that the voltage drop along this cable could reach 6,000V effectively raising the potential of the SPD Box with respect to the FEB to which other internal cables are connected.

Tests to confirm this were carried out in our laboratory. Appendix 2, Test Series 1 shows the results, summarised below:

Earth Cable Potential Rise – injected current 22.5kA

Cable (35sqmm)	Potential rise (volts)
3m	6,400
1m	2,040
2 x 1m in parallel	1,000

3m of cable from the SPD Box to the FEB will not provide effective protection and probably result in flashovers between equipment powered by 48V DC and the AC equipment earth. Cable lengths must be much shorter; no more than 1m is recommended and to further reduce the voltage drop two separate cables in parallel will further improve matters.

The optimum location for the SPD Box is either outside the building adjacent to the FEB or on the inside wall of the building directly inside from the FEB.

There are three possible scenarios that must be considered should lightning strike the tower. The SPD will conduct current to earth (FEB). However the fact that the internal cables, negative and positive, provide a low impedance loop back to the FEB means that a proportion of the surge current will flow through these cables and hence there are likely to be significant earth potential differences within the building. These three scenarios are:

1. Current flow through the negative conductor via the battery and the earth connection to the FEB. Appendix 1, figure 1 blue current path.
2. Current flow through the positive conductor and the earth connection to the FEB. Appendix 1, figure 2 red current path.

A strike to the tower will cause current to flow in both the negative and positive conductors so these two events will always occur together.

3. A transverse mode disturbance where current may flow through the negative conductor via the battery and to the positive terminal of the SPD. Appendix 1, figure 3, yellow current path. This is highly unlikely but will result in maximum current flow through the battery.

Appendix 2, Test Series 2 and 3 provide tests on an SPD box simulating a typical MOV only design and the Novaris design respectively.

Note: When tests were carried out on the typical design the 32A SPD backup fuses exploded before the surge was complete so in reality this would perform more poorly than the results below might indicate. Following the fuse failure the tests were carried out with the fuses replaced with a link.

The battery was simulated by a length of nichrome wire equal to the battery's internal resistance.

The tables below summarise the results:

Common mode (neg + pos to FEB) – injected current 22.5kA

	MOV based simulation	Novaris
Negative loop current (through battery)	1,460A	270A
Positive loop current	1,920A	168A
Earth return to FEB (sum)	3,360A	324A

Transverse mode (neg to pos) – injected current 22.5kA

	MOV based simulation	Novaris
Loop current (through battery)	5,820A	172A
Battery volts	128V	4.8V

There are significant differences between the results. Neither the typical design nor any other design relying upon just shunt connected SPD components will provide effective protection. This is because the battery loop impedances are so low that a shunt connected SPD can never reduce the loop current sufficiently. Some series impedance is required and this forms the basis of the Novaris design along with a properly designed and configured DC SPD.

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Conclusion

Typical shunt connected MOV based SPDs cannot provide adequate protection for the 48V DC supply. With a tower lightning strike such designs will cause equipment damage within the building due to circulating current and earth potential rises.

The Novaris solution has been analysed, designed and tested using a lightning simulator with sufficient energy to provide meaningful results.

The Novaris SPD/filter distribution unit provides a cost effective solution to the protection of equipment having its DC power shared with tower top DC powered RRU equipment.

Phillip Tompson is a Chartered Professional engineer. He holds an honours degree in electrical engineering from the University of Queensland. He is a Fellow of the Engineers Australia, a Member of the Institute of Engineering and Technology (UK) and a Member of the Institute of Electrical and Electronic Engineers (US).

After a career in the telecommunications and the power industries, he established Novaris Pty Ltd in 1993. Novaris is a designer and manufacturer of professional lightning and surge protection equipment.

Phillip has been consulting and designing lightning protection systems for over 20 years.

He currently represents Engineers Australia and is secretary of the Australian standards committee EL-024, Lightning Protection. He represents Standards Australia on a number of IEC lightning protection standards committees.

Appendix 1.

Appendix 1, figure 1. Negative loop current through the battery and back to FEB

Appendix 1, figure 2. Positive loop current to battery positive and back to FEB

Appendix 1, figure 3. Transverse loop current through negative, battery and return via positive.

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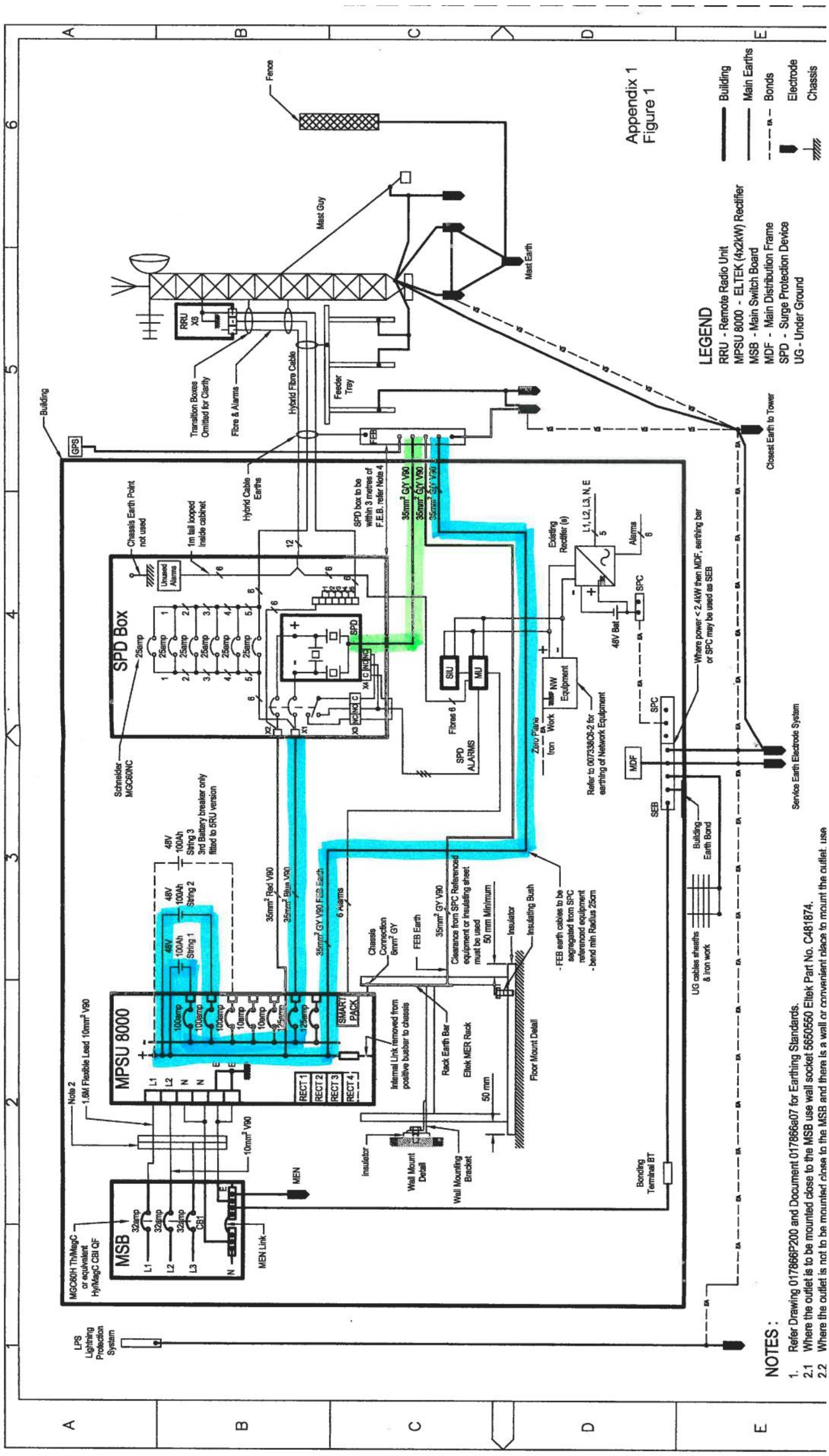

Figure A1: Common mode current through negative supply, battery and earth to FEB.

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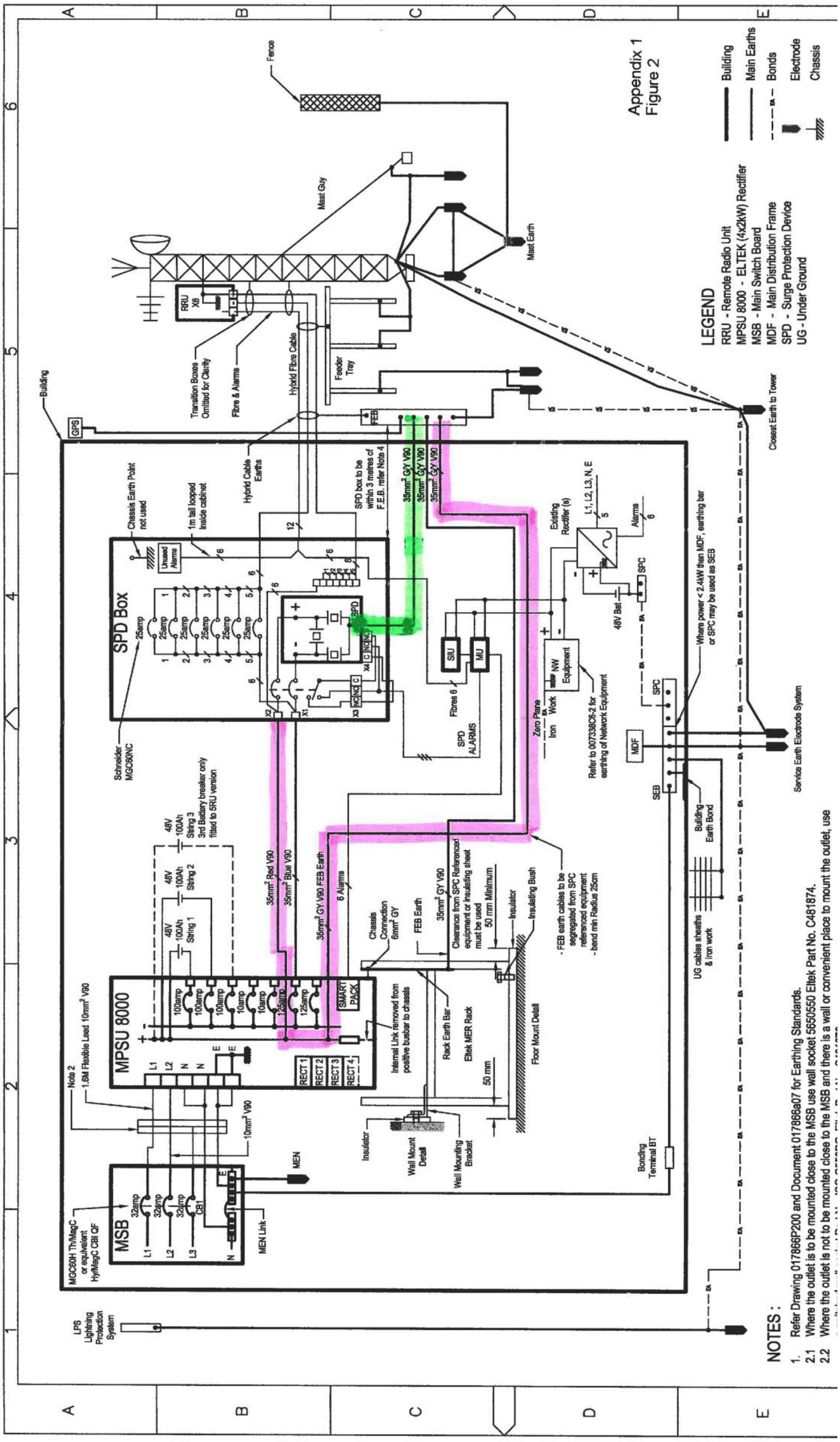

Figure A2: Common mode current through positive supply and earth to FEB.

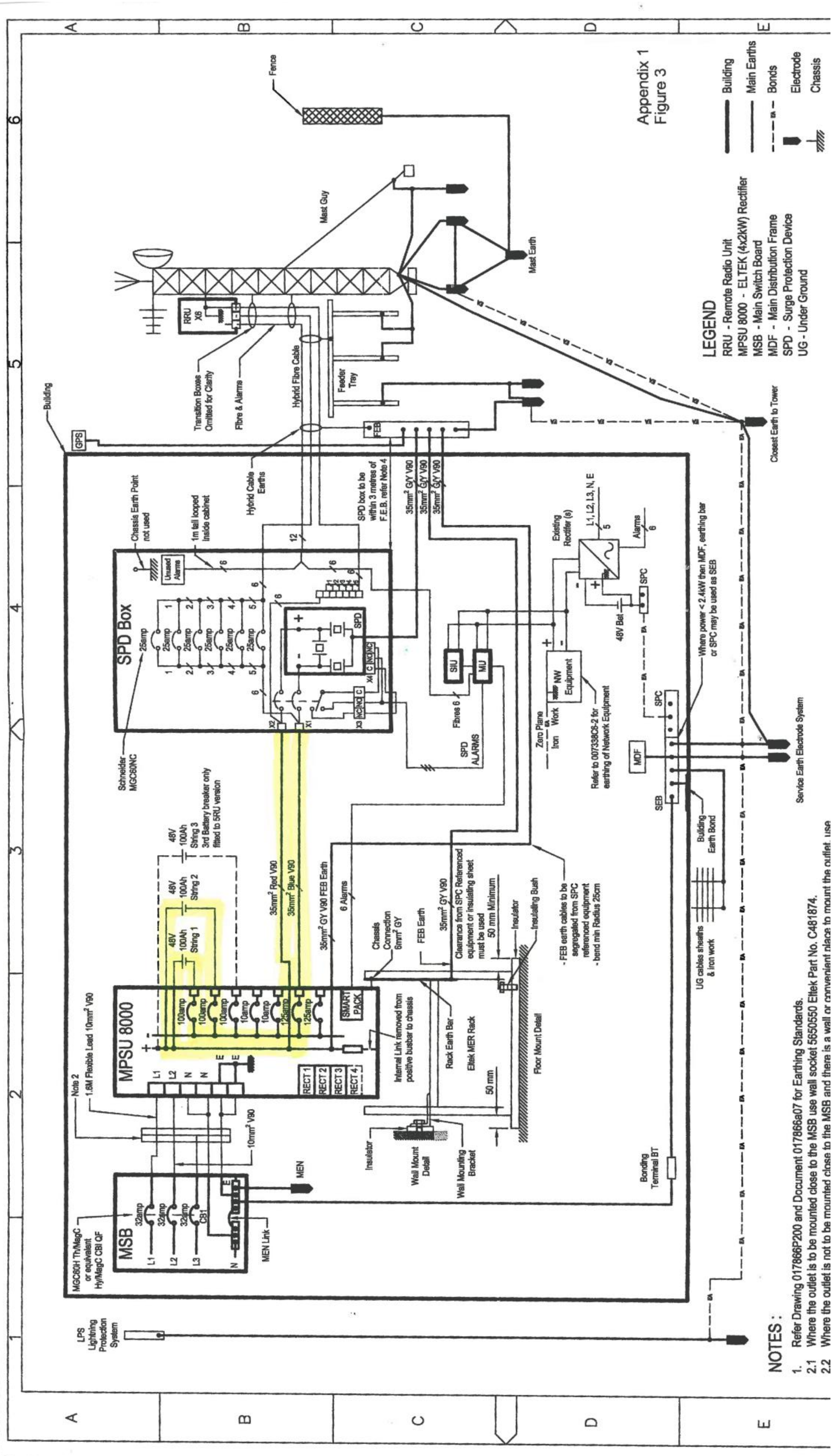

Figure A3: Transverse mode current through negative back through positive.

Appendix 2.

Test Series 1

This series of tests examines the voltage drop along 35sqmm cable as would be used to connect the SPD Box to the FEB. The waveform is an 8/20µs current impulse. It has a slower rise time than a true 8/20µs impulse and a longer duration, hence higher energy.

Figure A4 shows a 21kA current impulse applied to 3m of 35sqmm cable. The peak voltage is 6.4kV as predicted from figure 1 in the body of this report.

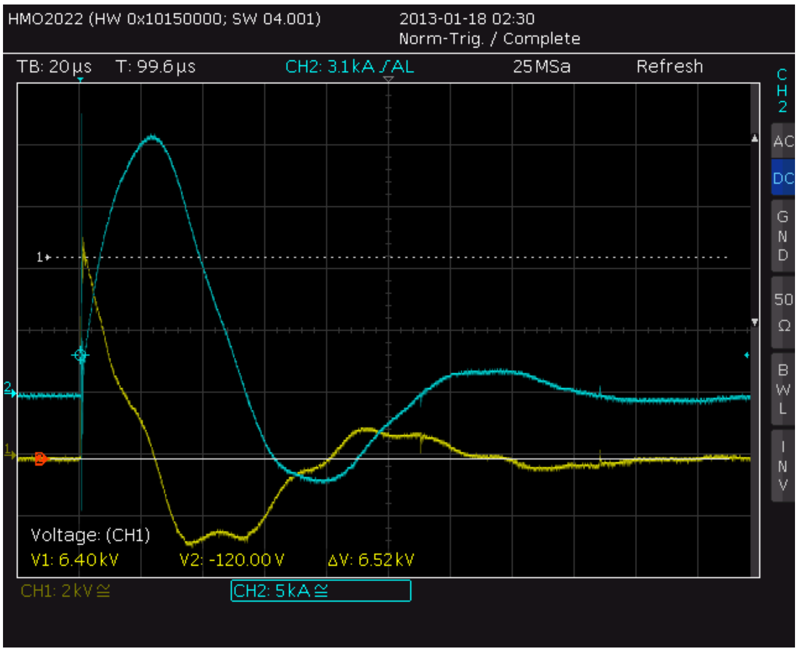

Figure A4. 21kA applied to 3m of 35sqmm cable

Figure A5 shows a 22.5kA current impulse applied to 1m of 35sqmm cable. The peak voltage was 2.04kV.

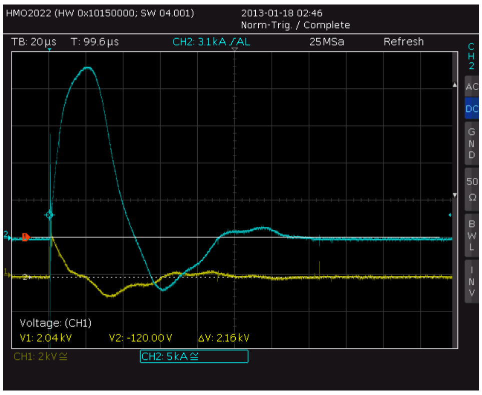

Figure A5. 22.5kA applied to 1m of 35sqmm cable cable

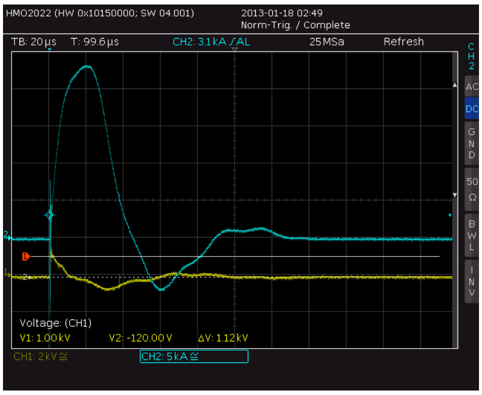

Figure A6. 22.5kA applied to two lengths of 1m of 35sqmm

Figure A6 shows a 22.5kA current impulse applied to two parallel lengths of 1m of 35sqmm cable. The peak voltage was 1kV.

The importance of short cable lengths and parallel connection providing for inductance in parallel is evident.

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Test Series 2

This series of tests simulates the typical MOV based shunt protectors by using two 40kA 75V MOVs. The simulation included 3m of negative cable and 3m of positive cable to a nichrome wire simulation of the battery internal resistance. Then 3m of 35sqmm from the battery positive to the FEB. We used one meter of 35sqmm earth cable from the SPD Box to the FEB.

Common mode impulses were injected between negative and positive connected together and the FEB.

Transverse mode impulses were injected between negative and positive.

Initial tests included backup 32A fuses as used in typical MOV based units. With 22kA applied these fuses exploded before the completion of the impulse. Figure A7 shows a damaged, disintegrated fuse. This effectively provides no protection and the current let through into the building is thousands of amps.

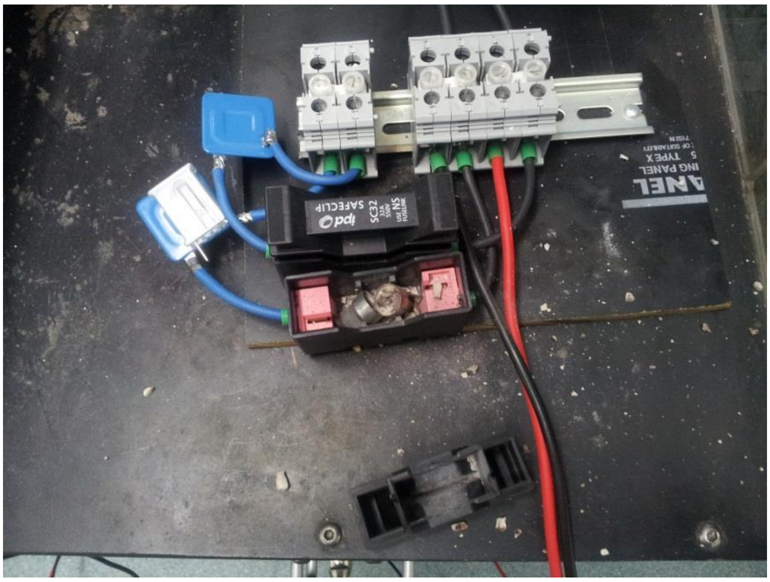

Figure A7. 32A fuse destroyed after one 22kA impulse

Tests were carried out with the fuses replaced with a link. The first tests injected common mode impulses into the SPD. Figure A8 shows the negative loop current. The peak was 1.46kA. Figure A9 shows the positive loop current. The peak was 1.92kA.

Figure A10 shows the sum of these two, the earth return current back to the FEB. The peak current was 3.36kA.

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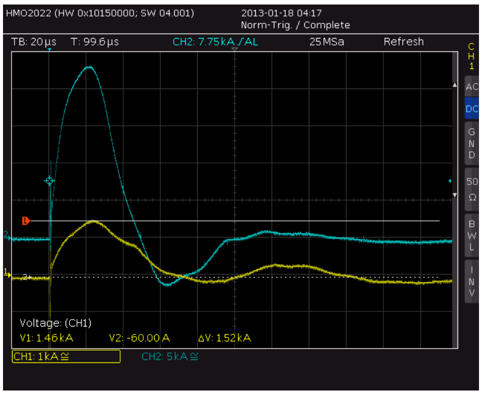

Figure A8. Negative loop current

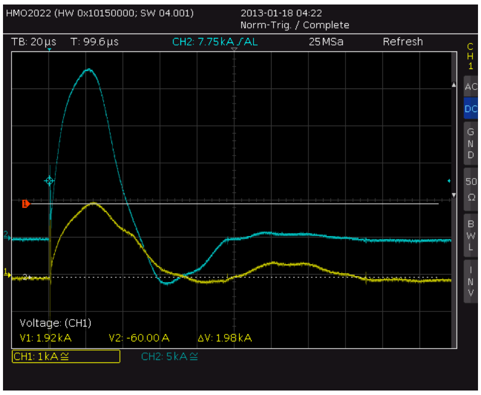

Figure A9. Positive loop current

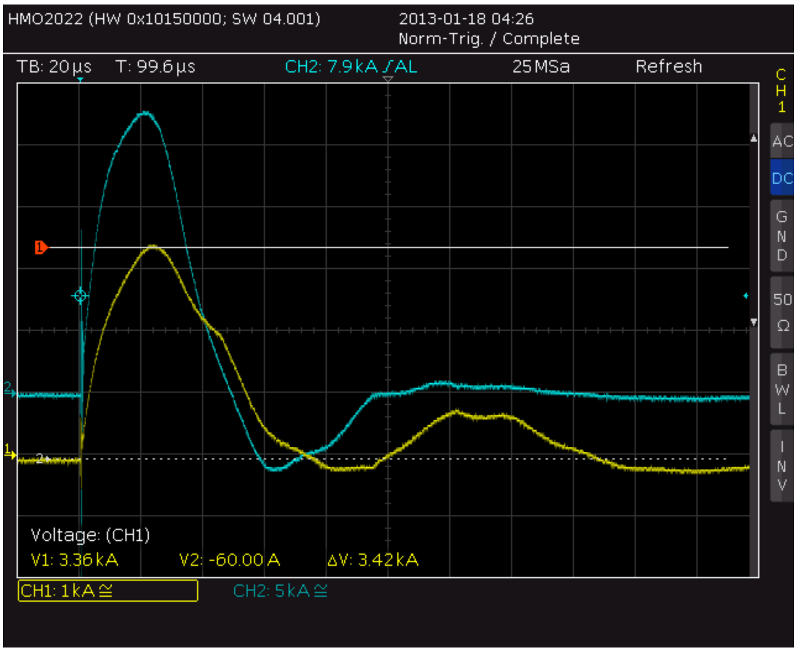

Figure A10. Common mode earth return current

The second tests injected transverse mode impulses between negative and positive. This is unlikely in practice but would cause most stress to the batteries. The peak loop current was 5.82kA and is shown in figure A11. For this current the battery voltage was 128V, figure A12.

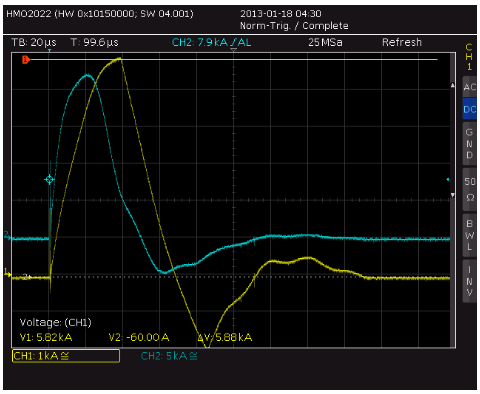

Figure A11. Transverse loop current (through battery)

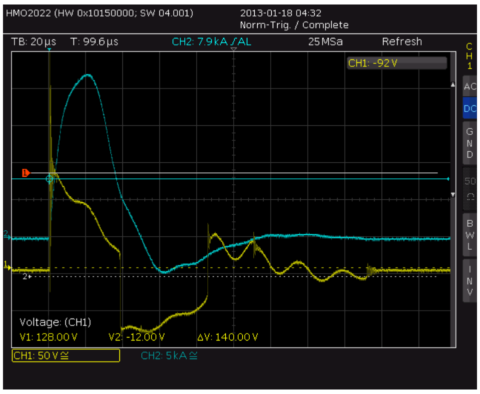

Figure A12. Battery voltage

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Test Series 3

The same series of tests were performed on the Novaris SPD filter and distribution unit, model number RRU2+2-125-65DC. This unit is shown in figure A13.

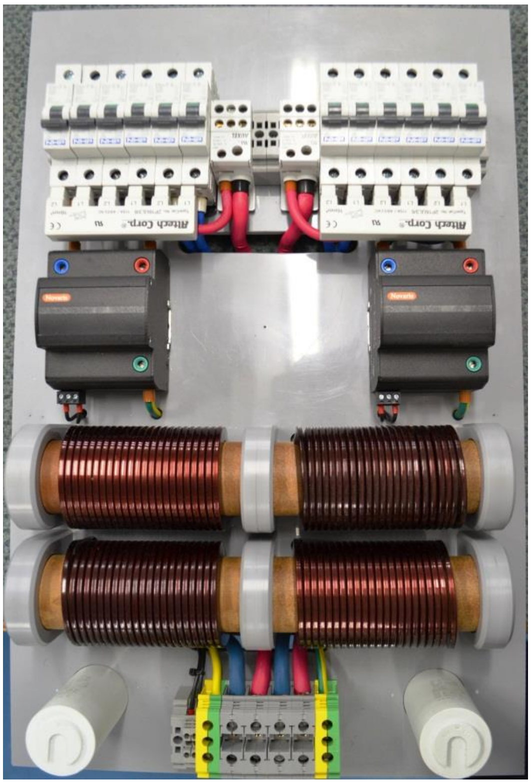

Figure A13. Novaris RRU2+2-125-65DC

The first tests injected common mode impulses into the SPD. Total injected current into the SPD was 24kA. Figure A14 shows the negative loop current. The peak was 270A. Figure A15 shows the positive loop current. The peak was 168A.

Figure A16 shows the sum of these two, the earth return current back to the FEB. The peak current was 324A.

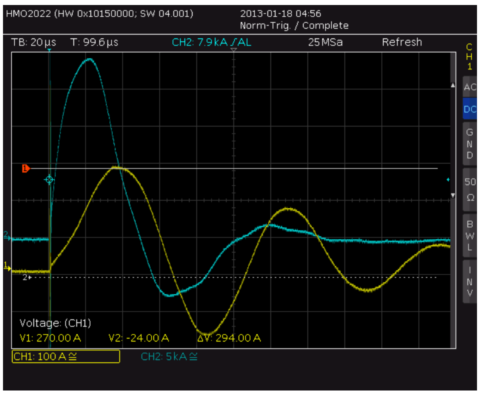

Figure A14. Negative loop current

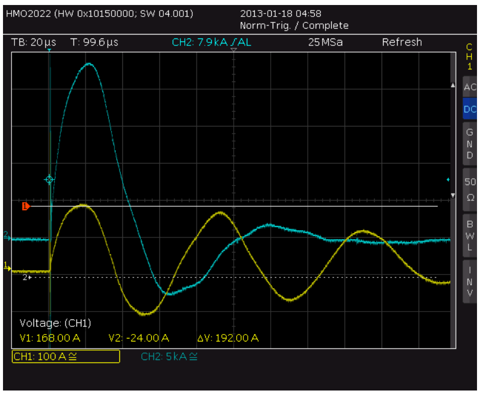

Figure A15. Positive loop current

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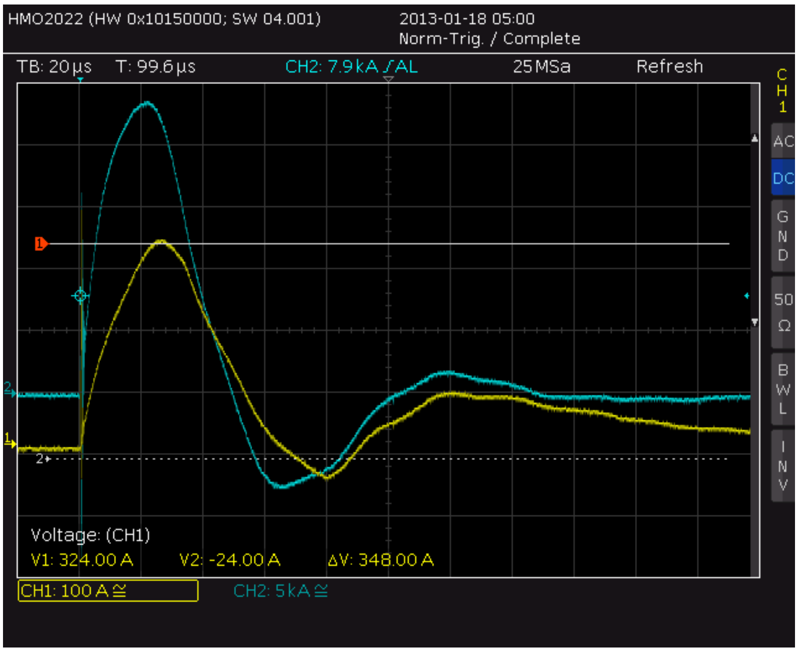

Figure A16. Common mode earth return current

The second tests injected transverse mode impulses between negative and positive. This is unlikely in practice but would cause most stress to the batteries. The peak loop current was 172A and is shown in figure A16. For this current the battery voltage was 4.8V, figure A17.

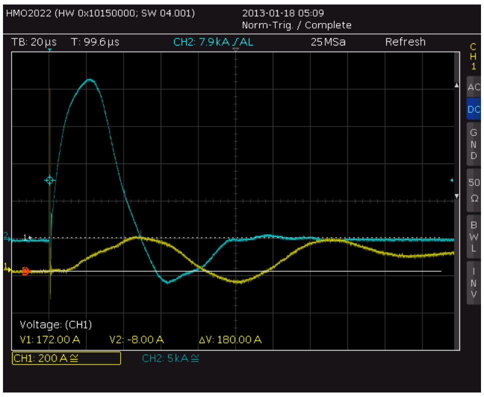

Figure A16. Transverse loop current (through battery)

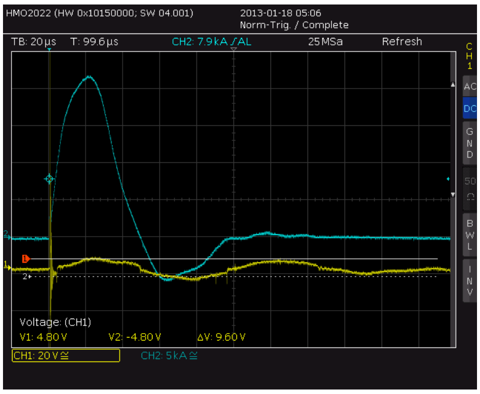

Figure A17. Battery voltage

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Appendix 3.

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