Shielding effectiveness of a copper box against laser driven electromagnetic pulses

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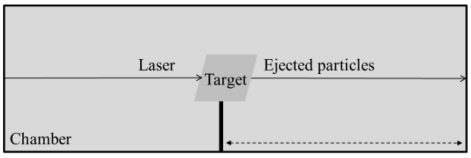
Introduction

Electromagnetic pulses (EMP) are generated during high energy laser interactions. As a result of this, trying to characterise the radiation and its effects have become an important part of laser diagnostics [1].



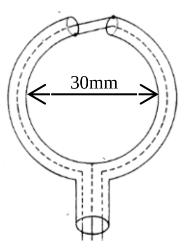
They are thought to be produced in two main ways. The first is due to the highly energetic ejection of ionised particles from the target through Target Normal Sheath Acceleration (TNSA) interacting with the chamber walls. As the charged particles hit the chamber walls, a portion of them return to ground through the path shown above. This happens multiple times back and forth at high speed, similar to acoustic resonance, leading to a quickly changing electric field being generated [2].

The second method is due to the target ionising. As the target ionises, the front surface becomes more positively charged due to the ejection of electrons from the material, producing a charge gradient between the front and back surfaces of the target. This leads to electrons moving to try and equalise the difference. This movement creates a rapidly changing electric field, otherwise known as EMP.

This report focuses on defining and measuring the shielding effects of copper boxes on the detected electric field strength.

How to measure the EM field

To measure the changing electric field Mobius loops were used in conjunction with a 13GHz Lecroy Wavemaster 813Zi-B oscilloscope. Mobius loops work on the principle of using two turn circular dipole antenna and a common mode rejection circuit which added the two signals to measure the changing electric field. During this experiment frequencies below two GHz were being examined, due to limitations of the RG223 cable type being used (BNC). EMP noise was minimised through changes made after an initial dataset was taken. (Appendix A)



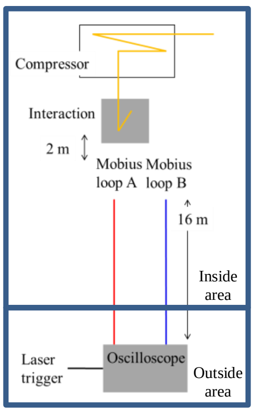


Figure 1 – To the left diagram of a Mobius loop antenna [3], to the right locations and distances of diagnostics

Effectiveness of EMP shielding

During the latter half of the experiment a dataset trialling copper boxes as faraday cages was collected. The idea of using faraday cages to act as protection against electromagnetic fields has been around for some time, therefore applying it as a preventative measure around electronics in the target areas is a logical step. The design was made to fit a standard computer, with ports and mesh covers to allow one to run without constant management or external cooling, while maintaining it as a cost effective and easily deployable solution.

Two Mobius loops which will be referred to as loops A and B were placed alongside each other to initially test their responses. Once it was ascertained that they produced a similar output, as can be seen in figure 5, the next stage was to test the shielding properties of the box.

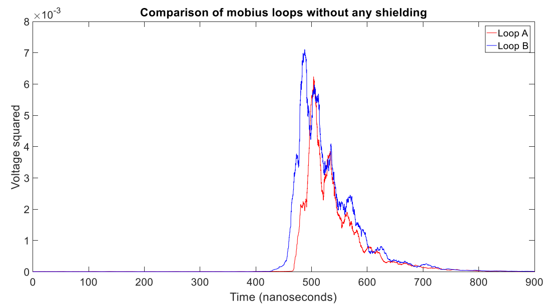


Figure 5 – Graph comparing the similar signals of the two Mobius loops with no shielding when placed side by side

To do this loop A was placed inside the copper box while loop B was left outside as a control. Both were kept as close to their original positions as possible. A picture of the copper box and loop positioning can be seen in figure 6.

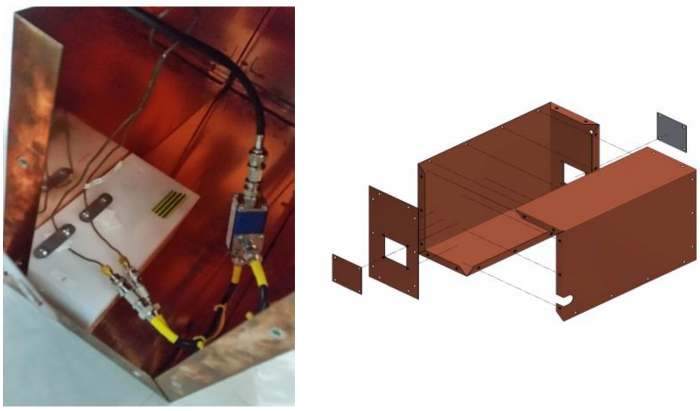


Figure 6 – To the left picture of loop A inside box with side panel removed to show position of Mobius loop, to the right schematic of the box. The box was ~50 x 40 x 20 cm, and was made of 1 mm thick copper. The hole is 3 x 4 cm in size where the power cables would usually go

With a sealed box acting as a faraday cage the values showed a marked difference when compared to the unshielded values, which can be seen in figure 7. This trend was present for each of the shots taken with the shielding surrounding loop A. When characterised numerically by using the integrated energy of the signal over 1000ns, the reduction was always above a factor of 25 difference between loops A and B (B was 25x larger than A).

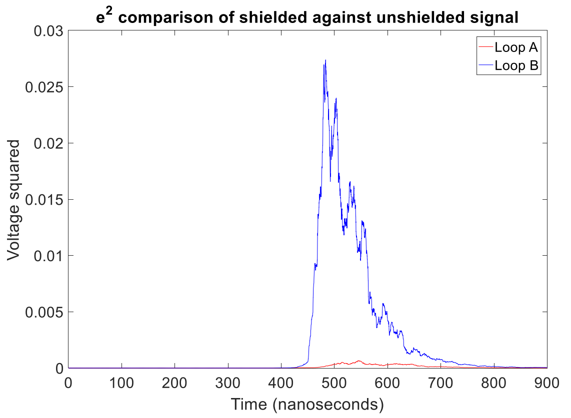


Figure 7 – Graph comparing loop A's shielded signal to loop B's unshielded signal

Due to the low level of loop A's signal inside the box, the final step was to compare the signals of a terminated cable at the box's location against the signal inside the box. This could not be performed at the same time due to the space being in use, however as the results of two comparable shots show in figure 8, the background noise level picked up on loop A's cable while it was terminated was lower than loop A's signal in the box by a significant amount. The terminated cable picked up a peak voltage of ~20mV which is in line with the values found in the earlier tests, while the antenna detected ~80mV signals.

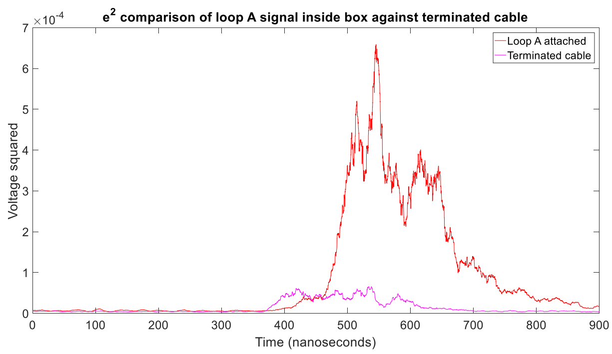


Figure 8 – Graph comparing loop A's shielded signal against the background signal picked up by a terminated cable in the same area

After all the data was collected, using Fast Fourier analysis it was possible to determine which frequency ranges saw the greatest reduction when using the copper box. Figure 9 is the analysis from one such shot, showing a ~3x reduction to frequencies below 1GHz and a far higher reduction for frequencies above 1GHz between the shielded loop A and unshielded loop B. There are some notable exceptions between 2 and 3 GHz, 200MHz and 750MHz though the reason for this is currently still being examined.

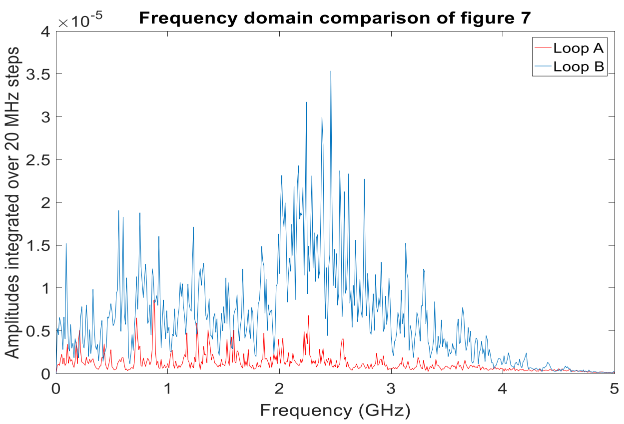


Figure 9 – Graph of a frequency comparison of figure 7 (loop A's shielded signal and loop B's unshielded signal)

Conclusions

After minimising the various sources of background signals (See appendix A), it was shown that the copper shielding reduced the electric fields detected by a factor of ~25x, from which it can be concluded to be a very effective method for shielding computers or diagnostics.

The shielding effect was shown to be greater at frequencies greater than 2 GHz and the reason for this is still being investigated.

Acknowledgements

Thanks must go to Phil Bradford and the experimental group as a whole for helping to run the diagnostic during the experiment while also providing a valued second opinion on the findings. The CLF staff were also invaluable with their help and expertise during the experiment.

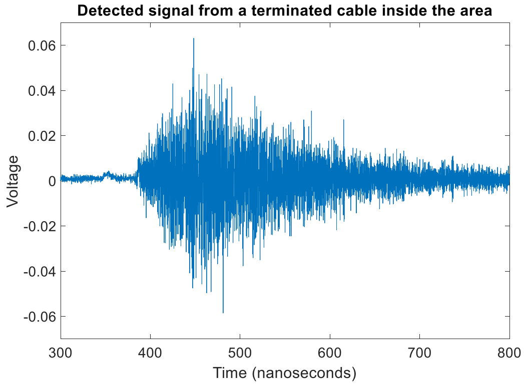
References

1. M.J. Mead et Al (Atomic Weapons Establishment, 2004), Review of Scientific Instruments, Vol. 75, p. 4225.
2. A. Poyé et Al (University of Bordeaux, Oct 2015), Physical Review Letters, Vol. 92, 043107 (2015)
3. P.H. Duncan, Jr., SSN 183 - Analysis of the Moebius Loop Magnetic Field Sensor (McDonnell Douglas Corp, Sep 1973), p. 7.
4. Data collected by R. Clarke, from the CLF, Science and Technology Facilities Council.

Appendix A - Sources of EMP noise

As one might expect, EMP can induce rapidly fluctuating voltages in many different components. An example of was when an oscilloscope was set up to record data seven metres away from the target interaction. From this location all of the channels showed a peak voltage in the ~400mV region, which was often higher than the signal from antennas themselves when using passive detection methods. The methods of reduction explored included removing the scope from the target area, trying to shorten the cable length, and trying to use a steel cage to further reduce the background signal once the oscilloscope was outside the area.

Once the scope was removed from the target area the signal pickup within the scope was lessened due to the removal of direct induction along the line of sight from the target. However, there was still signal pickup above the jitter of the scope, on the order of ~10mV when only the trigger and power cables were connected. After shielding the scope using a steel cage outside the area, there was no noticeable change to the detected signal. This suggested that it was an external problem rather than an internal one produced by induction in the scope. A possible cause would be a change in the ground level of the scope, entering through the power supply as the grounding lines between the control room and the target area are connected, which when considered with the fact that measurements from previous years support the notion that EMP pulses have an effect on grounding lines [4].



In further tests cables terminated in the area produced higher background signals, accounting for signals of ~30mV. The cables acted as extremely long antennas, which allowed them to pick up signals. A method often used to counter is to lengthen the cables, working on the notion that as the cable lengthens it acts as a low band pass filter, preventing higher frequencies from being detected. However, this does come at the cost of higher frequency monitoring, and a reduction in signal amplitude as the distance increases. For the later datasets a cable length of 25m was selected, which provided a reasonably good balance.

While varying the cable length to try and ascertain how cable pickup would be affected an interesting effect was noted. The background pickup always occurred at the same time while the cable length was varied over a range of ~15m, which suggested that the source of the signal had to originate from within a fixed point in the system. A possible point of entry was originally thought to be the patch panels; however these were discounted as a possible source of the signal as it was seen across all channels, including the one which did not pass through them.

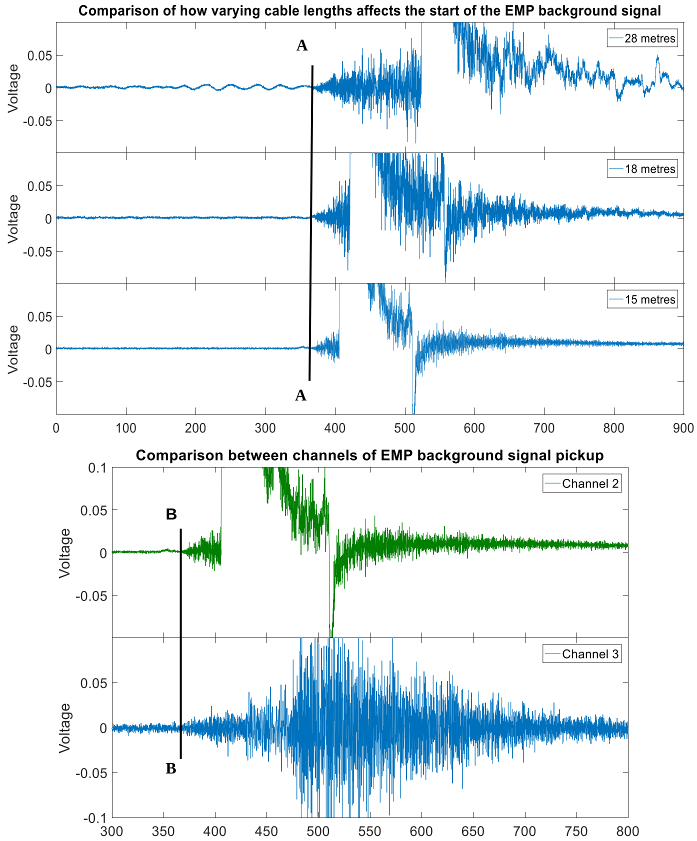


Figure 4

A. **Effects of cable length on signal pickup - The channel showed the same starting point for the signal between different shots while the the attached cable length was varied. Please note that for the blue line, the data was collected while passing through a patch panel.**

B. **Effects of patch panel on signal pickup – The starting point between two channels, channel two a direct connection, and channel three through a patch panel, both having signal pickup at the same point.**

A final test which we would have liked to perform would have utilised an Uninterruptable Power Supply, acting as an isolated source of power; however none had sufficient capacity to run the oscilloscope during the experiment.