Effects of Pulse Duration, Energy and Target Type on the frequencies of Electromagnetic Pulses in a Petawatt laser system

Contact: david.carroll@stfc.ac.uk

M.E.Read, D.C.Carroll, M.P.Bone, and D.Neely
Central Laser Facility, STFC,
Rutherford Appleton Laboratory,
Oxon OX11 0QX, United Kingdom

Investigation into the effects of pulse duration, energy and target type on Electromagnetic Pulses (EMP) using high temperature Petawatt laser-target interactions with time-dependent nyquist limited fourier transform analysis containing varying bin sizes. Due to oscilloscope limitations and cabling attenuation all diagnostics had a bandwidth upto a 1GHz frequency. Equipment included Moebius Loop, B-Dot sensor and D-Dot sensor.

1 Introduction

The problem of high powered laser-target interactions emitting Electromagnetic Pulses (EMP) has been an ongoing problem for lasers systems such as Vulcan. *Poye et al.*, in 2014, showed the laser pulse accelerates charged particles in the target over the duration of the pulse. This draws current I from the ground and into the target. Previous characterisation of the EMP produced by *Mead et al.* at Vulcan Petawatt found there to be 2 main modes, one at 59MHz and the other at 63MHz. In this paper the EMP was found to have modes close to the frequencies described in the *Mead* paper. However, this experiment investigated the scaling of EMP with pulse duration, laser energy and target.

Analysis of the raw data was done via a Fourier Transform program using the Nyquist Theorem, this technique is presented in a separate report [1].

2 Setup

Measurements on this experiment were taken on the south end of the vacuum chamber (*as seen in Figure 1*). The diagnostics were placed outside the chamber at TCC level with sight to the target. The laser parameters were energies ranging from 64J-608J and pulse duration ranging from 1ps-18ps. The parabola used to focus the beam was f/3 with focal length of 180cm, a diameter of 60cm and the laser wavelength of 1056nm.

The Prodyn B-Dot Sensor, Prodyn D-Dot sensor and the Moebius Loop diagnostics were wired up using BNC cables via patch panels from the target area to the oscilloscope. The diagnostics were situated outside a 320mm window port on the south side of the Target Area Petawatt vacuum chamber at TCC level, with all diagnostics positioned side by side and in view of the target.

A Tektronix 12.5GHz Oscilloscope was placed outside the target area (in the control room) to avoid EMP pick up in the scope itself, which often occurs when situated inside the target area. Due to using BNC cables and having the oscilloscope outside the Target Area, attenuation in the cables diminished the bandwidth of the frequency received severely (more details in *appendix (6.2,6.3)*).

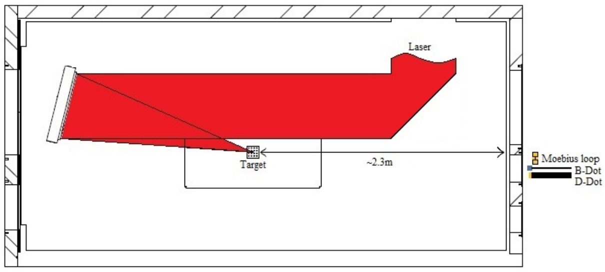

Figure 1: Top view of diagnostic setup surrounding the Pettawatt target area

Targets used on the experiment were gold (Au) targets with a mixture of CD and CH coating. They also varied between trimmed and untrimmed targets (*see Figure 7 for dimensions*).

Initial shots were used for characterising the optimum attenuation, time domain and resolution. The system set-up was tested to investigate frequency attenuation in cable, length of cabling and time domain *(see Appendix for equipment testing)*.

2.1 Moebius Loop

The Moebius Loop consists of two copper wires with two circular arms that are split at the top with a very small gap compared to loop dimensions, the centre conductor is connected to the shield of the opposite arm [2]. The two ends of the copper wires are connected to a matching box optimised for 1GHz frequency, which due to the cable attenuation was sufficient.

The loop detects the magnetic field passing through the circular arms, the magnetic field(B) (*shown in equation (1)*) is converted to the voltage output (V). Derivation of the B verses V relationship and more detailed analysis of the Moebius Loop has been discussed by *Dun-*

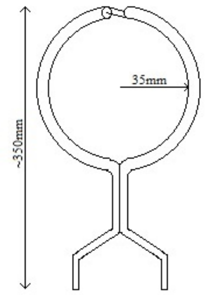

Figure 2: Diagram of the Moebius Loop, signals are combined in the matching box circuit

can in his paper on the *Analysis of the Moebius Loop Magnetic Field Sensor [2].*

$$V(t) = 2A\frac{dB(t)}{dt} \tag{1}$$

2.2 B-Dot

Configured of two parts the Prodyn B-24 B-Dot Sensor and the Prodyn Balun (Figure 3) together detects the time rate of change in the Magnetic field (*as shown in equation (2)*, where A(eq) is the sensor equivalent area and B is the magnetic flux density vector). Built on rigid output arms and attached to the balun via SMA connectors, the Prodyn Balun BIB-100G circuit is essentially a bridge network from the sensor to the cabling, with frequency response of up to 10GHz and a bandwidth of 3dB [6].

$$V(0) = A(eq).(dB)/(dT) \tag{2}$$

2.3 D-Dot

The Prodyn D-Dot probe measures the time rate-of-change of the electric field component of the Electromagnetic waves. The FD-5 model sensor has a detector area of $\approx 1.54 \times 10^{-}5m^2$ and a frequency response of up to 50GHz. The relationship between the voltage and Electric field can be seen in equation (3), where V(0) is the sensor output and D is the magnitude of the electric displacement vector.

$$V(0) = RA(eq)(dD)/dt \tag{3}$$

3 Results and Analysis

Pulse duration, energy and target type were the three variables analysed. The modes and frequencies seen coincide with the physics and characterisations made in previous papers, including *Mead et al., Poye and Tait.*

3.1 Pulse Duration

Using the *Time-Dependent Nyquist limited Fourier Transform* [1] program to analyse the effect of pulse duration on the frequency, produced interesting results on the bands emitted from the target.

The two shots used for the analysis were a $\approx 1ps$ shot and a $\approx 18ps$ shot, both using gold untrimmed targets and with a difference of $\approx 100J$ (*see 3.2 for why difference in Energy is expected to have little effect on outcome*).

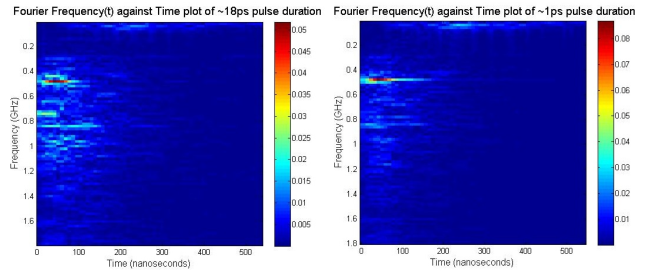

Figure 3: Comparison of the 1 ps pulse (*right*) and the 18ps pulse (*left*) using the Nyquist Fourier Transform Program [1]

As seen in figure 3, the difference in the two pulses shows a higher intensity and distribution of frequencies in the 18ps pulse with modes of 0.5GHz, 0.75GHz and 0.85GHz, showing the highest intensity band at 0.5 GHz. The lower frequencies at $\approx 60MHz$ is visable in the shorter pulse at approximately 250ns. Characterised in past papers by *Mead et al.* the lower frequencies are still visible but due to looking at a wider bandwidth the resolution is lower and therefore shows the 59MHz and 63MHz modes as one.

3.2 Energy

The amount of Electromagnetic pulses (EMP) being generated during a laser interaction is affected by the energy. However, the increase in energy required to make a significant difference needs to be on the order of ten. An increase in energy could cause an increase in the current oscillations between the ground and target and therefore causing an increase in EMP [3,4].

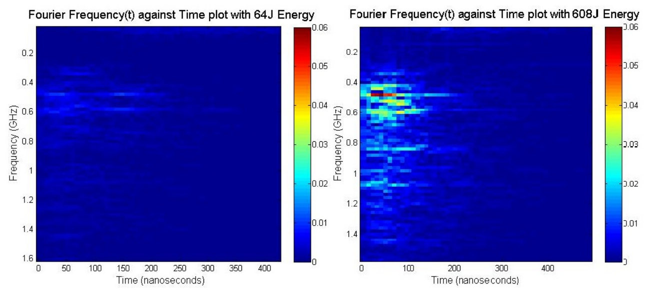

Figure 4: Comparison of the 64J pulse (*left*) and the 608J pulse (*right*) using the Nyquist Fourier Transform Program [1]

Comparing the two graphs in Figure 4, using two example points at around 0.5GHz around 50ns there are points of high intensity on both graphs. The 64J energy pulse has an intensity of 0.02 and the 608J energy pulse has a intensity of 0.06, for a factor of 10 increase in energy there is a factor of 3 increase in intensity.

3.3 Target Type

Comparison between the trimmed and untrimmed targets shows that the area of the targets could be a significant contributor to the EMP emitted in both the Electric (Figure 6) and Magnetic (Figure 5) fields. Looking at the plots of both the D-Dot and B-Dot probes shows a decrease in the intensity of the frequency detected.

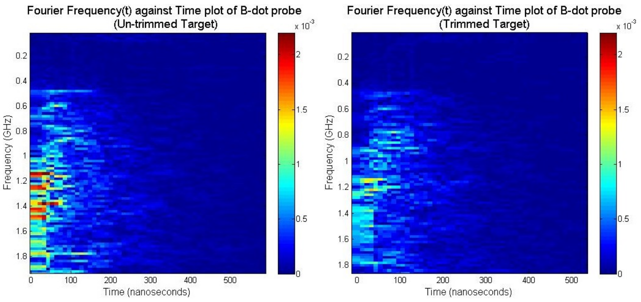

Figure 5: Comparison of Trimmed and Un-Trimmed targets using the D-Dot probe (*right*) using the Nyquist Fourier Transform Program [1]

Poye stated that the EMP is emitted from the target holder where the current, I, oscillates between the target and the ground. As a result a decrease in the surface area of the targets decreases the Q and I in the target which in turn decreases the EMP.

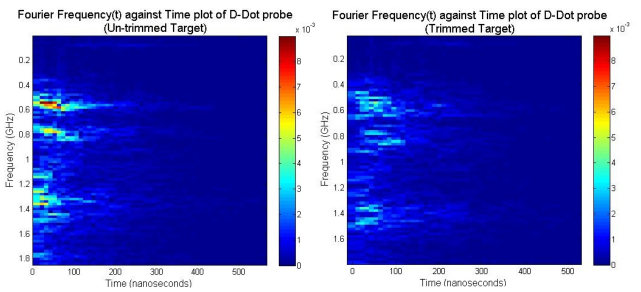

Figure 6: Comparison of Trimmed and Un-Trimmed targets using the B-Dot probe (*right*) using the Nyquist Fourier Transform Program [1]

Both B-Dot and D-Dot probes show a notable decrease in the amount of noise seen in the spectrum of frequencies of EMP emitted. The modes of the specific frequencies given off are still present in both plots, although more significant in the D-Dot probe. However, the trimmed targets seem to significantly decrease the EMP.

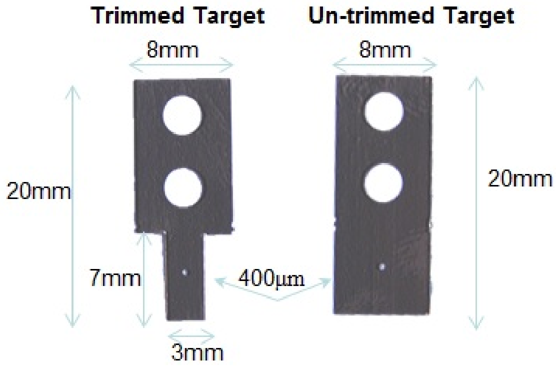

Figure 7: Photographic dimensions of both trimmed and Un-Trimmed Targets

4 Conclusion

There is a wide range of responses and effects in the frequency modes of the EMP when changing the pulse duration, energy and target type. When lengthening the pulse duration there was a significant rise in range of frequency modes seen. By increasing the energy of the pulse by just over a factor of ten we measured a large rise in the intensity and spectrum of frequencies. Changing to a trimmed target type decreased the EMP frequency intensity, although there are still traces of common frequency modes between the target types.

5 Acknowledgements

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References

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6 Appendix

6.1 Time Response of Cables

Comparing the difference between the response of BNC cables to the SMA cables show improved response due to the sharp pulse. The BNC cable shows a broad peak with large oscillations after the main pulse compared to the SMA cable with a narrower sharp pulse and less oscillations afterwards.(Figure 8) Using SMA cables in future experiments would mean a better cable response and a truer signal with less attenuation.

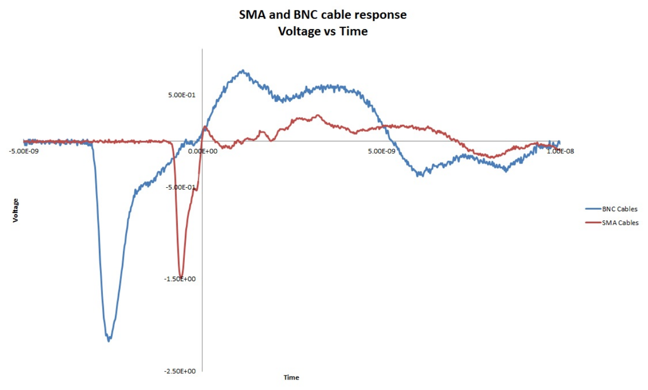

Figure 8: Cable response of both SMA and BNC cables

The Full Width Half Maximum of the BNC cables was 0.74×10^{-9} seconds. Compared with the Full Width Half Maximum of the SMA cables which was 0.3×10^{-9} seconds.

The equipment used to calibrate was a Kentech Central GO14 trigger generator, a Kentech Gated optical imager PS, and a Stanford Research systems 4 channel Digital delay pulse generator (Model DG535).

6.2 Length of cables

Post experiment measurements of the cable length were made as increasing the cable length increases the attenuation and therefore the bandwidth decreases.

$$(345 \times 10.46)/2 = 1,804.35cm = 18m \tag{4}$$

The cable length was measured by sending a trigger pulse down a cable channel that was unattached at the diagnostic end. Then recording the time it took to bounce back, was used calculate 18m (*as seen in equation (4)*)

6.3 Frequency Spectrum

Testing the effect of attenuation on the bandwidth when extending the cables from $\approx 2m$ to $\approx 18m$. Frequencies seen on the oscilloscope go from $\approx 5GHz$ to $\approx 1GHz$ (*Figure 9*), meaning the experiment could not record above 1GHz.

Ideally the oscilloscope would have been kept in the Target area so a larger bandwidth could be seen but due to the EMP pick in the scope itself it had to be moved.

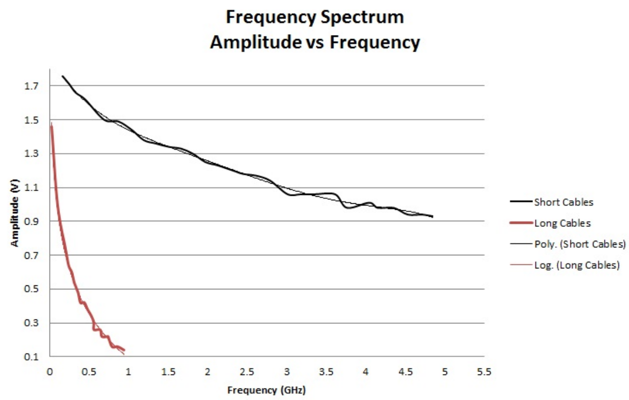

Figure 9: Frequency spectrum of Long and Short BNC cables

The equipment used for the characterisation of the frequency spectrum was a Hewlett-Packard 8620C Sweep Oscillator.