DEVELOPMENT OF A PULSED INJECTION STRIPLINE FOR DIAMOND-II

R. Fielder*, A. Lueangaramwong, A. Morgan, Diamond Light Source, Oxfordshire, UK

Abstract

Diamond-II will use a single bunch aperture sharing injection scheme. This applies a strong kick to both the injected and the targeted stored bunch with a very short duration (ideally <3 ns, if disturbance to the adjacent bunches is to be avoided). We have developed a design for the stripline kickers that can meet these requirements while minimising internal reflections and beam impedance. We show an analysis of the electric and magnetic fields produced by the stripline and simulations of the effects on injected and stored beam, and analysis of the wakefields and impedance of the structure.

INTRODUCTION

Diamond Light Source is a third generation light source which uses a standard four kicker bump injection method. The kickers have a pulse length of 6 µs, giving some kick to the target bunch both the turn before and after injection, and affecting the entire bunch train even during single bunch injection. In theory this could have zero impact on the stored beam, but difficulty in precisely matching the full length of the four kicker pulses, plus other effects due to non-uniformity in the coating on the ceramic vessels make this difficult. Efforts have been made to reduce the measurable effects of injection on beamlines at Diamond [1, 2], but there can still be some significant impact.

The Diamond-II upgrade [3] will have greatly reduced dynamic aperture compared to Diamond, making injection even more challenging. At the same time, reduced beam size and more advanced beamline detectors and optics greatly reduce the acceptable levels of beam disturbance. Diamond-II will therefore use stripline kickers which can provide pulse lengths on the order of nanoseconds to allow true single bunch injection without disturbing the bulk of the stored beam. This allows an aperture sharing injection scheme, as described in [4, 5].

STRIPLINE DESIGN

The injection stripline design was initially based on the multibunch feedback stripline kickers and influenced by the SLS 2.0 design [6]. This has since been greatly modified to meet the requirements. A large vacuum chamber is used, with a smaller pipe with pumping grills to provide RF continuity and match radius to the incoming and outgoing beam pipe, shown in Fig. 1 with the outer vacuum chamber hidden. The stripline profile is a mix of circular arc with a flat central section to provide better field quality, but with a notch cut out to avoid synchrotron radiation (Fig. 2); a notch is also included on the inboard side for symmetry. The gaps between the charged and grounded elements have been kept as large as possible to reduce the chance of arcing. All edges are rounded for the same reason.

There will be four stripline modules in total, at the downstream end of the mid-straight following the injection straight. The striplines are 150 mm long, with a module length of 180 mm including the surrounding structure. The curved portion of the stripline has a radius of 7 mm, while the flat part is 6.2 mm from the beam horizontally, however, the notch and hybrid shape means there is not a clearly defined gap between the striplines. The striplines are made of copper, while the rest of the chamber will be stainless steel, with ceramic spacers in the input feeds. The striplines will likely be supported inside the chamber by additional ceramic posts, but the mechanical design is not finalised yet. The total required kick of 175 µrad can be provided by a peak voltage of 12.8 kV in each module. The rise time requirement of 0.6 ns leads to a bandwidth requirement of >0.8 GHz. The voltage requirement is 20 kV, driven by the desire to be resilient against a single module failure.

The ends of the striplines are designed to minimise longitudinal field roll off and also to minimise reflections and wake impedance. Alongside tuning of the conical coaxial transitions to the ports, the best overall solution has been found with no overall tapering of the curved section combined with strong tapering of the central flat section.

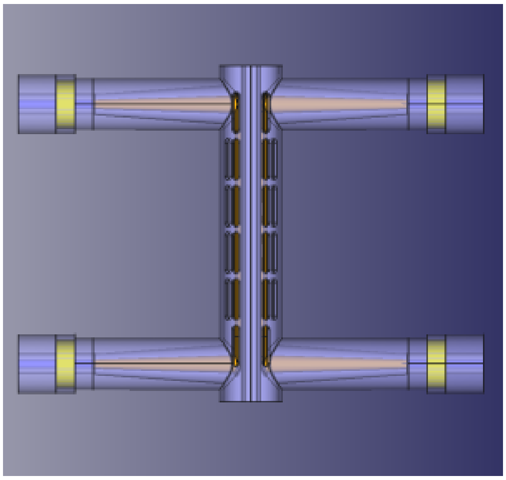

Figure 1: Top down view of stripline with vacuum vessel hidden.

Wakefield and Impedance Simulations

Wakefield and impedance simulations for the stripline were carried out using GdfidL [7] and CST Studio [8]. Impedance simulated with a 0.5 mm drive bunch is shown

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* richard.fielder@diamond.ac.uk

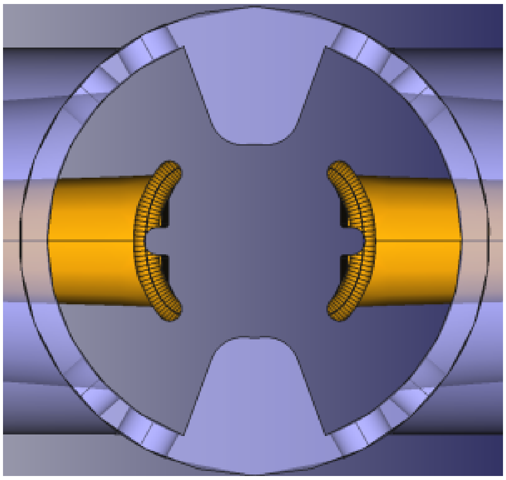

Figure 2: End view of stripline.

in Fig. 3. Impedance in the vertical and longitudinal planes is a similar magnitude to the BPM assemblies and not a cause for concern. Horizontal impedance is larger, but still comparable to other components such as dipole vessels, and likely cannot be reduced significantly without increasing the separation of the striplines. The distribution of energy loss per bunch into each component is shown in Fig. 4 and a schematic identifying these components is shown in Fig. 5. As the expected operating repetition rate is 5 Hz, the thermal load induced by the applied voltages are minimal compared to the beam induced thermal loading.

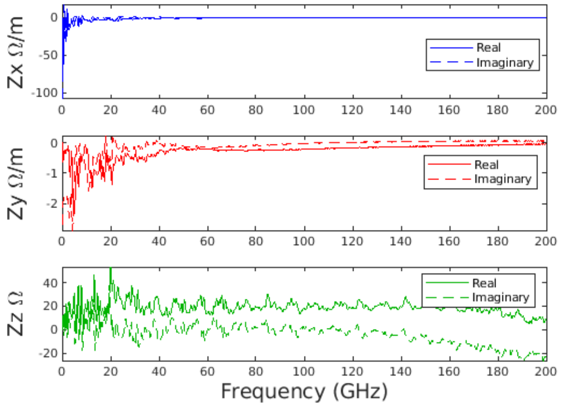

Figure 3: Real and imaginary impedance for horizontal (top), vertical (middle) and longitudinal (bottom) planes for the Diamond-II stripline module.

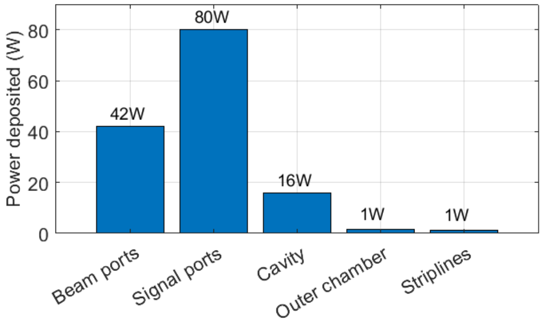

Figure 4: Power loss distribution calculated for a 300 mA full fill. Components not shown have negligible power deposited.

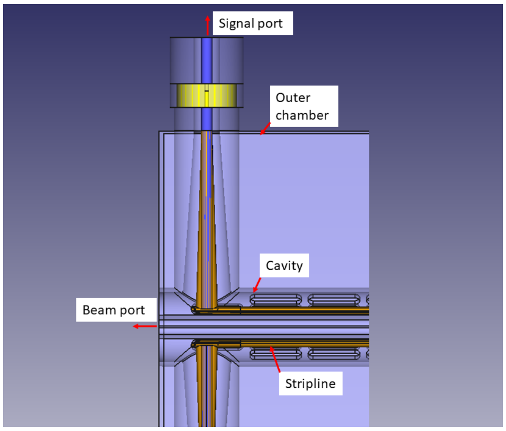

Figure 5: The main components with significant energy deposition.

Field Simulations

Electric and magnetic fields were simulated in GdfidL and CST Studio. Simulations were carried out using a representative trapezoidal pulse with 0.6 ns rise time, 1.4 ns flat top and 0.7 ns fall time, shown in Fig. 6, top. $t = 0$ is defined as the moment the pulse enters the co-axial input feed. Full 3D fields, for both electric and magnetic field, resulting from this were calculated for the volume inside the stripline radius for 5 ns from the beginning of the input pulse, along with voltage between the striplines at the centre of the beam pipe (Fig. 6, bottom). The time delay between the two plots is due to the travel time of the pulse to the location of the monitor. It can be seen that while the initial part of the pulse is closely reproduced in the voltage seen by the beam, the later part can deviate significantly due to reflections within the striplines.

Simulations were also carried out using a short pulse of 0.1 ns rise and fall time with no flat top to analyse the reflections in more detail. It was determined that these reflections primarily come from the ends of the striplines themselves, and not from a mismatch in impedance to the feedthroughs.

Particle Tracking

The field simulation results, see Fig. 7, are converted to kickmaps and used as input into particle tracking simulations using Accelerator Toolbox [9, 10]. The field is synchronized to the top-up bunch arrival time, with the particle entering the stripline module just as the peak of the voltage pulse arrives at the upstream end of the stripline, at $t = 1.74$ ns; see details in [11].

Figure 8 shows a plot of the horizontal phase space of the injected and stored beams at the middle of the injection straight for the first 50 turns after injection, using the kickmaps from the EM simulations. The grey rectangle

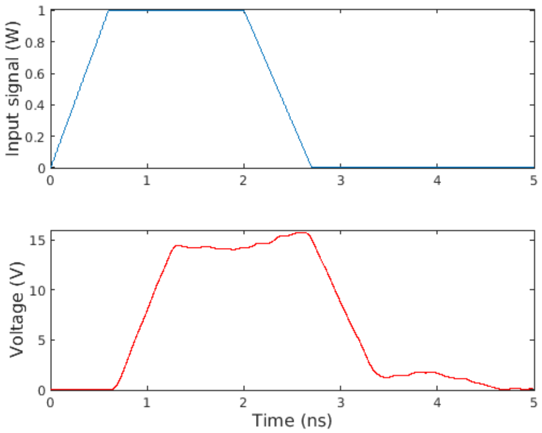

Figure 6: Top: Pulse input to stripline with rise time 0.6 ns, flat top 1.4 ns and fall time 0.7 ns, normalised to 1 W input power. Bottom: Resulting voltage between striplines at centre of module.

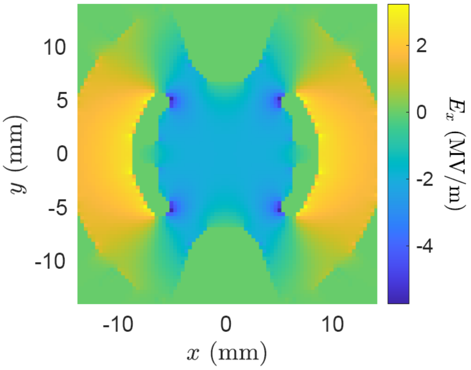

Figure 7: Slice through field map of horizontal component of E-field at centre of stripline module at 2.34 ns.

shows the injection septum plate. A static chicane is included to allow the distance between stored beam and septum plate to be adjusted [12], with a nominal offset of +2 mm.

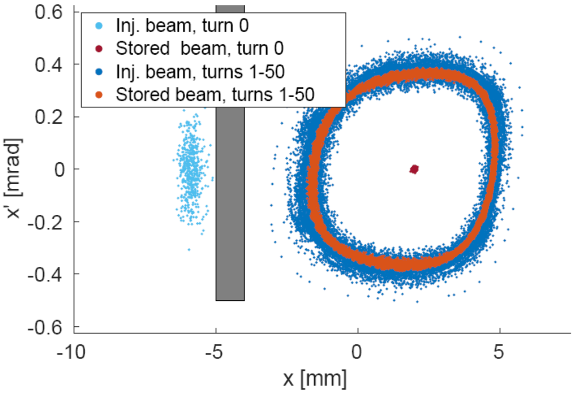

Figure 8: Horizontal phase space at the middle of the injection straight during first 50 turns after injection.

PROTOTYPE STRIPLINE

A prototype stripline with similar design has been developed for testing. This will initially be assessed on a test bench before being installed first in the Diamond booster-to-storage ring transfer line and finally in the Diamond storage ring. The prototype is rotated by 90°to allow off-axis injection and avoid synchrotron radiation, and has a larger aperture of 9.5 mm. The prototype will also allow us to validate the performance of the required high voltage, high bandwidth feedthroughs which are required for this application.

PULSER DEVELOPMENT

A pulser design is currently under development by Kentech Instruments [13]. The proposed design utilises several arrays of voltage avalanche cards, each with relatively modest voltage output. A total of 16 cards in 4 stacks would provide 5 kV per stack to meet the total 20 kV requirement. This design does not rely on a single high-voltage switching device, and would allow cards to be individually disabled or replaced, giving good fault tolerance and easy repair. Output from a proof of concept single avalanche stage is shown in Fig. 9, demonstrating the ability to produce a 1 ns pulse width at 3 kV. It is anticipated that the post-pulse ringing can be significantly reduced with passive pulse forming as part of the ongoing development work.

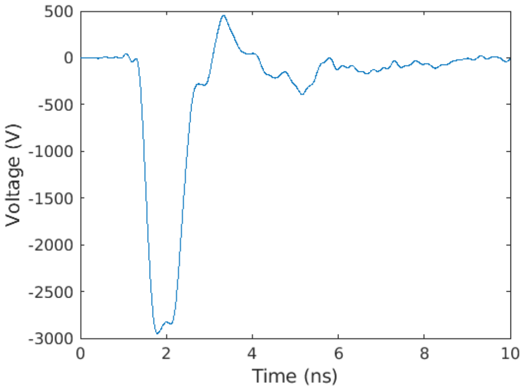

Figure 9: Output of proof of concept avalanche voltage stage.

CONCLUSION

A fast injection stripline kicker has been developed for Diamond-II. Full electromagnetic simulations have been carried out, with the output used as kickmaps for particle tracking studies. A pulser is also under development and is expected to meet the requirements for both high voltage and short pulse. A prototype will be tested at Diamond before the start of the dark period to verify simulations and perform tests in an active ring.

ACKNOWLEDGEMENTS

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