A non-intrusive, ultra-wideband, coaxial diagnostic for measurement of waveform directionality

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The Advanced Sources and Detectors project is constructing a multi-pulse linear induction accelerator capable of producing beam currents up to 1.45 kA with electron energies up to 22 MeV. This accelerator, named Scorpius after the brightest X-ray source in the observable universe, will be unique in its use of solid-state pulsed power (SSPP) for driving the injector and accelerator cells. The SSPP consists of approximately 1000 line replaceable units (LRUs) that each encompass 45 individually triggered LTD stages, allowing for direct control of the output voltage pulse.

One problem area that was identified while testing the LRUs was the presence of considerably large reflections (25% of peak voltage) when firing into a test load. These reflections must be kept to a minimum as they will negatively impact the performance of the accelerator. For example, reflections in the applied pulse waveform to the injector will generate off-energy electrons between pulses, which will incite stimulated ion desorption from the wall and lead to beam charge neutralization. These reflections can also constructively add to the pulse flat top, causing non-uniform electron emission from the thermionic cathode and energy variation/spread in the beam.

Presently, the diagnostics on the SSPP can measure the instantaneous voltage waveforms at the output of the LRU and at the accelerator cells. While these measurements provide information on the driving wave shape, it lacks information on directionality. The ability of directional measurements is crucial to determining manufacturing parasitics that were not identified during the design process. This measurement also allows for the use of transmission line theory to further characterize the system as a whole. The SSPP has modulation capabilities to reduce reflections but cannot do so efficiently without having measured data that discriminates the directionality of the waveforms.

To acquire this data and further improve the accuracy of the SSPP circuit model, we propose developing a non-intrusive, ultra-wideband diagnostic that can accurately discriminate the forward and reverse waves on the output cable of a single LRU. This diagnostic will be akin to a directional coupler, which is a well-studied passive diagnostic that is widely used in radiofrequency (RF) applications [1] [2]. For systems that employ coaxial cables, directional couplers are typically connected in-line (between source and load) to make measurements [3] [4] [5]. The design of our diagnostic will differ from traditional directional couplers as it will be non-intrusive. It is undesirable to use a design that requires an in-line connection with the carrier cable as there are over 10,000 cable connections and disconnecting/reconnecting the cables to make measurements will take time to carry out. A diagnostic that can simply be clamped onto the coaxial cable to make in-situ measurements is desired.

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The non-intrusive aspect of the diagnostic will pose a significant design challenge as the shielding of the carrier cable will need to be addressed. The planned approach for the design of the non-intrusive diagnostic is to inductively couple the signal from the carrier cable at two

reference points at a known electrical length of 1 ns. The constructive/destructive interference over time can be observed by measuring at these reference points. Forward and reverse waveforms can then be extracted from the measurements via post-processing. If the signal cannot be coupled adequately due to the carrier cable shielding, then an embedded diagnostic will be designed. The high amplitude signals traveling through the carrier cable should serve as a boon to our design, as we can incur large losses while still obtaining readable voltage signals (25 kV at ~1 kA per line). The design calls for capability of being wideband in the range of 1-100 MHz, as it must be able to measure variable pulse width of 20-80 ns and inter-pulse spacing up to 300 ns.

The plan of action for this project is to carry out a thorough literature review on directional couplers and current transformers in order to determine an appropriate design. A geometry of the diagnostic will be simulated in CST to assess important parameters over the required frequency range such as directionality, isolation, and return loss. Upon reaching a working design, a prototype of the diagnostic will be constructed. A diagnostic test bed consisting of a pulsed power source that can produce 20 ns pulses up to 60 kV into an unmatched load will be used to test the performance of the prototype, see Figure 1.

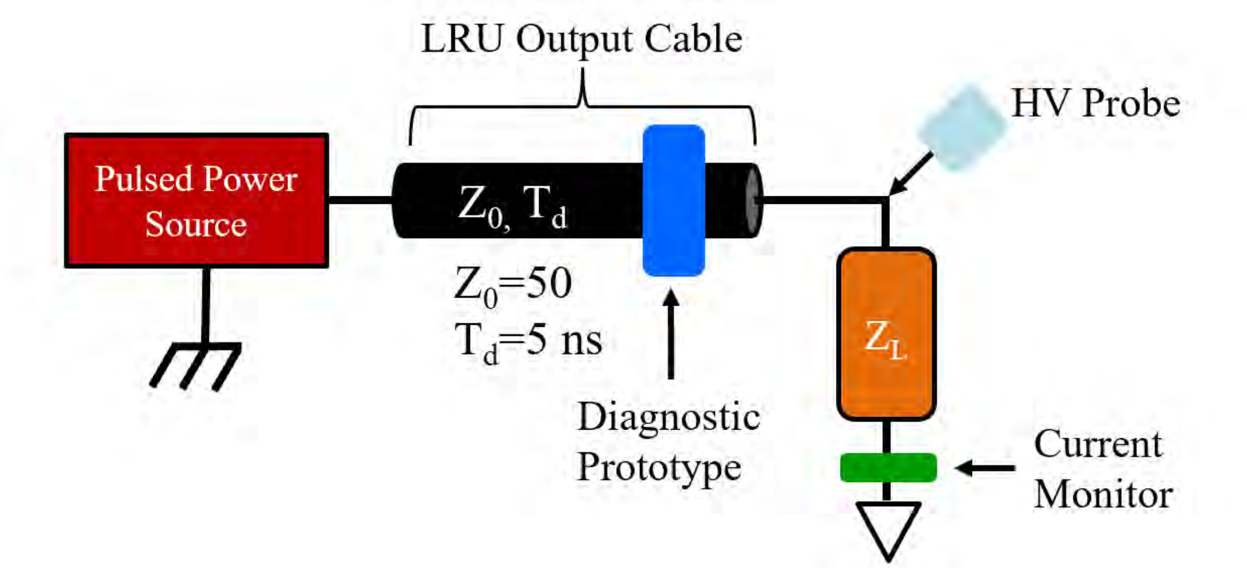

Figure 1: Diagram representation of the diagnostic test bed. The coaxial cable between pulsed power source and load would be the same as LRU output cable. Voltage and current monitor at the load are present to verify the signal integrity of the output waveform.

Voltage and current will be monitored on the dummy load to assess any deformation to the output waveform. After testing on the diagnostic testbed, verification on an actual LRU connected to a load akin to an accelerator cell would be carried out at Lawrence Livermore National Laboratory.

This diagnostic would serve as a powerful tool to boost the performance of the SSPP modulation and theoretical model accuracy of the Scorpius accelerator. Additionally, this would benefit the pulsed power community by creating a directional diagnostic that does not require direct modification to the coaxial cable and make in-situ measurements much like a Pearson coil.

References

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