SAND2007-4131C

# RITS-6 OUTPUT PULSE MODIFICATIONS

**Joshua Leckbee†, Bryan Oliver, John Maenchen, Sal Portillo, Mark Johnston, Kelly Hahn, Dean Rovang, Isidro Molina, and Steve Cordova**
*Sandia National Laboratories*, PO Box 5800, Albuquerque, NM 87185 USA*

**David L. Johnson**
*L3 Communications - Pulse Sciences, San Leandro, CA 94577 USA*

**David M. Van De Valde**
*EG&G Technical Services, Inc., Albuquerque, NM 87119 USA*

*Abstract*

The RITS accelerator was upgraded from three pulse forming lines (PFL) and inductive voltage adder (IVA) cells to six PFLs and IVA cells during 2005 with radiographic diode experiments beginning in 2006 [1], [2]. The original RITS-6 accelerator configuration is capable of operation at voltages greater than 10 MV with a 80-Ω magnetically-insulated transmission line (MITL). Low impedance diodes such as the self-magnetic pinch (SMP) diode are not matched well to the high impedance MITL and decrease the diode voltage to about 5 MV. A low impedance MITL has been designed and tested with an operating impedance of about 40 Ω at the output end. Experimental results with both MITL impedances will be presented.

The output pulse shape of the RITS-6 accelerator can be modified to emulate other accelerators and to investigate the impact of various pulse features on radiographic diode performance. Simulations and experimental results are discussed below.

## I. INTRODUCTION

When the RITS accelerator was upgraded from three to six inductive voltage adder (IVA) cells, the magnetically-insulated transmission line (MITL) was designed to operate at about 80 Ω and generate voltages up to about 11 MV. The PFLs that drive the six IVA cells have an impedance of 7.8 Ω each. The MITL was intentionally mismatched to the drive impedance to increase the output voltage as was the case with the high impedance MITL on RITS-3 [3]. The mismatching impedance results in higher voltages in the MITL and for high impedance diodes will greatly increase the dose production which scales proportional to $IV^x$, where $2 < x < 3$. Low impedance diodes, such as the self-magnetic pinch (SMP) diode, are better matched to a lower impedance MITL. Flexibility in the accelerator architecture via changes in the MITL allows us to efficiently drive a variety of diodes with varying impedances.

Output pulse shaping can be used to determine the effects of various pulse shapes on diode performance. The ability to shape the drive pulse can also help to evaluate various theories about how diodes operate or to emulate other accelerators to better reproduce their results. Experiments and simulations of pulse modifications include increasing the peak output voltage, slowing the risetime of the output pulse, increasing pre-pulse, and adding a ramp to the flat-top portion of the pulse.

**Table 1.** MITL Comparison at Maximum Charge Voltage

| | High Z MITL | Low Z MITL |
|---|---|---|
| Final $Z_{\text{vac}}$ | 102.8 Ω | 51.3 Ω |
| Final $Z_{\text{op}}$ | 80 Ω | 40 Ω |
| MITL Voltage | 12 $MV$ | 8.5 $MV$ |
| $I_{\text{total}}$ | 150 $kA$ | 213 $kA$ |
| $I_{\text{bound}}$ | 48 $kA$ | 67 $kA$ |

## II. COMPARISON OF HIGH AND LOW IMPEDANCE MITLS

The original MITL designed for the RITS-6 upgrade has an operating impedance of about 80 Ω based on parapotential flow theory for operation at 10 MV [4]–[6]. This MITL is also referred to as the high impedance MITL, as in Table 1. The MITL is mismatched to the PFL impedances to provide a step-up in voltage of about 28%. The increased voltage increases the dose rate production of radiographic diodes. High impedance diodes, such as

* Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.
† jjleckb@sandia.gov

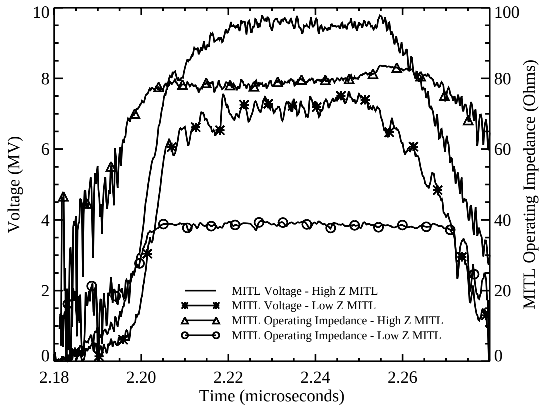


**Figure 1.** Experiments have shown that the MITL operating impedance is very flat throughout the main drive pulse with the low impedance MITL operating at 40 Ω and the high impedance MITL at 80 Ω.

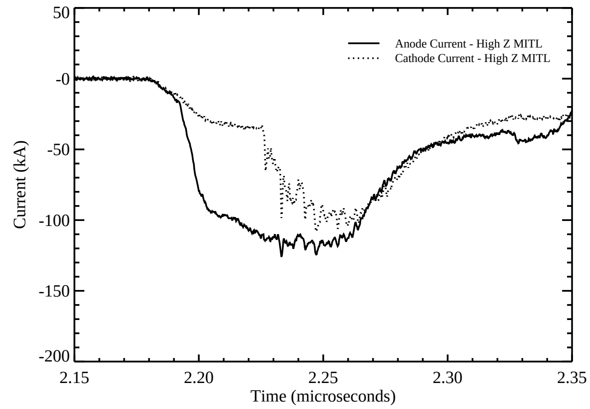


**Figure 3.** Experiments where the high impedance MITL is terminated with a low impedance LAD, 6 cm AK gap, result in a strong retrapping wave that quickly propagates back up the MITL.

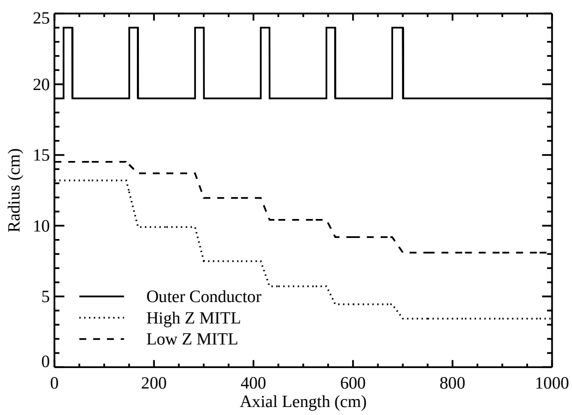


**Figure 2.** Drawing of the high and low impedance MITL dimensions. The vacuum power feeds from the IVA cells are shown as gaps in the anode diameter.

the Paraxial diode, draw less current than the bound cathode current provided by the 80-Ω MITL. Thus for high impedance diodes, the increased voltage produces more x-ray dose with no penalty due to the decreased current. A Marx bank charge of 65 kV produces a forward going voltage wave in the output MITL on RITS of about 9.5 MV and an operating impedance of 80 Ω as shown in Figure 1.

When driving the SMP diode or a large area diode (LAD) with small AK gap, the high impedance MITL does not provide enough current in the forward going wave. The MITL must retrap most or all of the sheath current while at the same time increasing the total current. The retrapping wave propagates back up the MITL and is seen as a step in the cathode current and a slight increase in total anode current as in Figure 3. The amplitude and velocity of the retrapping wave depend on the magnitude of the impedance mismatch at the load. As the retrapping wave causes the total current to increase, the MITL voltage decreases. If the diode impedance continues to decrease, the voltage must drop further to provide additional current to the diode.

A 40-Ω MITL was designed for RITS-6 to increase the MITL current and better match the impedance of the SMP diode. The low impedance MITL is approximately matched to the PFL impedances and thus more energy is coupled from the PFLs to the MITL. The physical dimensions of the MITL were chosen such that the operating impedance of the line with electron sheath current is about 40 Ω when operated at 7.5 MV, as shown in Figure 1. The physical dimensions of the high and low impedance MITLs are shown in Figure 2.

For a Marx bank charge of 78 kV, the 40-Ω MITL produces about 7.5 MV and 190 kA. When coupled to a LAD with a small AK gap, the MITL must only retrap a small amount of current. The result is a very weak retrapping wave that propagates much more slowly than in the case of the 80-Ω MITL. Figure 4 show the MITL currents for an experiment with a 6-cm AK gap LAD. At the end of the pulse the retrapping wave causes a small spike in the cathode current. The low impedance MITL shows no apparent benefit when used with high impedance diodes as the driving voltage is decreased from that produced by the 80-Ω MITL and the diode is not capable of making use of the additional current.

## III. PULSE SHAPING

Circuit simulations and a limited set of experiments have explored the ability to modify the shape of the RITS-6 output pulse.

New laser triggered gas switches will be installed this summer to improve switch performance at higher charge voltages. This should allow us to reliably operate the

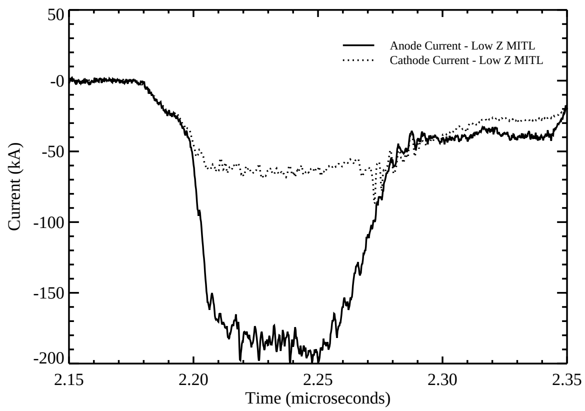


**Figure 4.** When the low impedance MITL drives a low impedance LAD, 6 cm AK gap, little or no retrapping occurs. This plot shows a slight increase in bound cathode current at the end of the pulse 2.5 m from the diode.

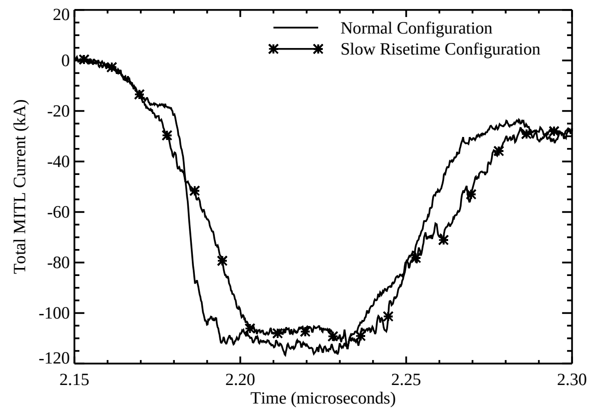


**Figure 5.** Plots of data from a normal RITS-6 shot with the high impedance MITL and a shot where the PFL timing is adjusted to increase the pulse rise time.

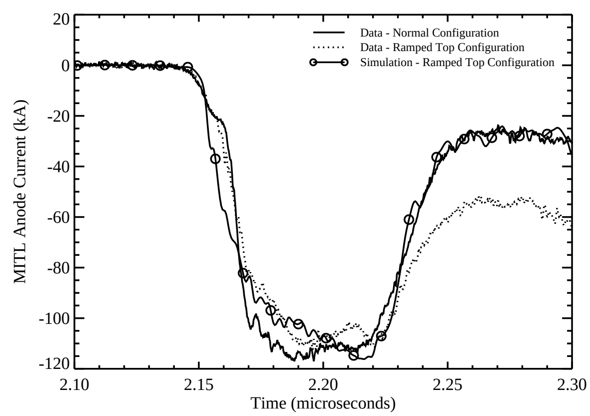


**Figure 6.** MITL current from a normal shot is compared to a shot where the flat-top portion of the pulse has a slight ramp. A simulation of the ramped top shot is also shown.

accelerator up to about 12 MV with the high impedance MITL or about 8.5 MV with the low impedance MITL. This will facilitate voltage scaling experiments over a wider range.

The timing of individual PFLs can be adjusted by changing the length of the water switch gaps. For a normal pulse, the PFLs are timed to fire sequentially with a delay from one line to the next that is equal to the transit time along the MITL of the drive pulse from one IVA cell to the next. Using this configuration, the drive pulses from each cell arrive at the load at the same time and the resulting pulse has a fast rising front edge followed by a relatively flat top. During a limited series of experiments, the PFL timing was intentionally changed so that the pulses arrive at the load at different times. This slows the rising edge of the pulse without significantly changing the pre-pulse or peak output current as shown in Figure 5. Additional circuit simulations indicate that the pulse risetime can be increased to about 60 ns without causing significant voltage reversal on any of the IVA cells.

The RITS PFLs have three switches: a self break water switch, a water peaking switch, and an oil pre-pulse switch [1]. A pulse with a ramped top can be produced by decreasing the switch gaps in all of the main self break water switches so that they fire before the PFLs are fully charged. In this case, energy from the intermediate storage capacitors continues to charge the PFL while it is discharging. The result is that the output voltage rises slowly throughout the pulse. Simulations predict that if the switches close about 50 ns early the voltage will rise throughout the pulse. Two shots were fired where the PFL switches closed as much as 30 ns early to test this pulse configuration. Figure 6 compares the MITL current from a normal shot to the shot where the PFL switches fired 30 ns early and a simulation of a shot where the PFL switches fire 30 ns early. Further experimentation and PFL switch adjustment should result in a ramp that continues throughout the pulse duration and has an increased slope.

The effects of pre-pulse on the performance of various diodes can be tested by shorting the oil pre-pulse switches. Increasing the switch gap length of the water peaking switches will also increase the duration of the pre-pulse. It may also be possible to adjust the amplitude of the pre-pulse by making adjustments to the switches in varying numbers of the six PFLs.

The pulse shaping techniques described above can be combined to produce pulses with one or all of the described features. This could be used to better emulate the pulse shape of another accelerator or to produce a more desirable pulse shape if these pulse features improve diode performance.

## IV. SUMMARY

The design and construction of a new lower impedance MITL has greatly increased the operating range of the RITS-6 accelerator. With a high impedance MITL, the accelerator can be configured to produce greater than 10 MV when coupled to high impedance diodes such as the Paraxial diode. Low impedance diodes such as the SMP diode can be efficiently driven by the low impedance MITL to improve diode performance. With the new laser triggered gas switches, RITS-6 can produce forward going voltages ranging from 6.25 MV to 8.5 MV with a 40-$\Omega$ MITL or 9-12 MV with a 80-$\Omega$ MITL.

Adjustments in the PFL timing and switch configuration allow the RITS-6 accelerator to produce a range of pulse shapes with varying risetime, pre-pulse amplitude and duration, and voltage pulse slope. These features will be used to evaluate their impact on the operation of various radiographic diodes.

## V. REFERENCES


[1] D. Johnson, *et al.*, "Status of the 10 MV 120 kA RITS-6 inductive voltage adder," in *Proc. 15th IEEE Int. Pulsed Power Conf.*, Monterey, CA, 2005, pp. 314–317.

[2] D. L. Johnson, J. J. Leckbee, B. V. Oliver, N. Bruner, and V. Bailey, "Power flow in the RITS-6 accelerator," in *Proc. 16th Int. Conf. on High-Power Particle Beams*, Oxford, England, 2006.

[3] V. L. Bailey, *et al.*, "Design of a high impedance MITL for RITS-3," in *Proc. 14th IEEE Int. Pulsed Power Conf.*, Dallas, TX, 2003, pp. 399–402.

[4] J. M. Creedon, "Relativistic brillouin flow in the high $\nu/\gamma$ diode," *J. Appl. Phys.*, vol. 46, no. 7, pp. 2946–2955, 1975.

[5] C. W. Mendel and S. E. Rosenthal, "Modeling magnetically insulated devices using flow impedance," *Phys. Plasmas*, vol. 2, pp. 1332–1342, 1995.

[6] P. F. Ottinger and J. W. Schumer, "Rescaling of equilibrium magnetically insulated flow theory based on results from particle-in-cell simulations," *Phys. Plasmas*, vol. 13, p. 063109, 2006.