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HIGH POWER DIELECTRIC DIODE STUDIES AT SANDIA NATIONAL LABORATORY*.

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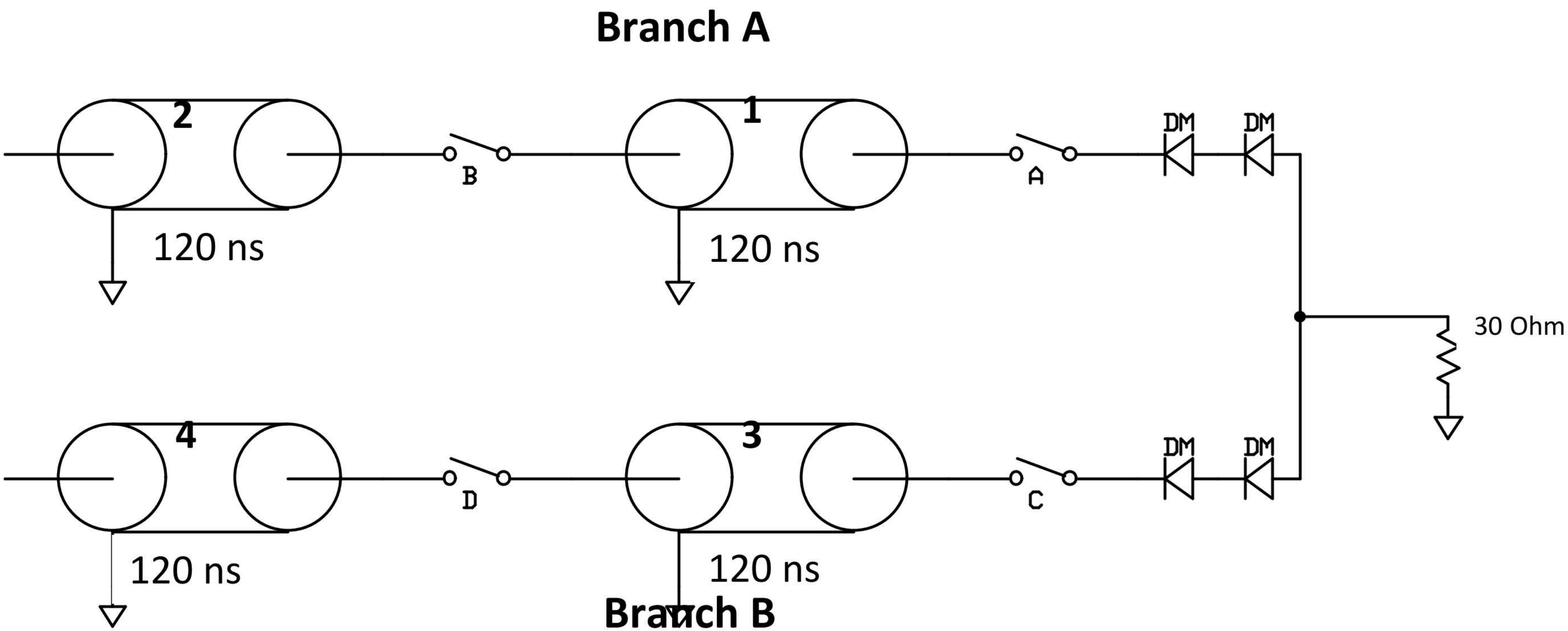
Schematic diagram of the four pulse CTS-II with the two diodes.

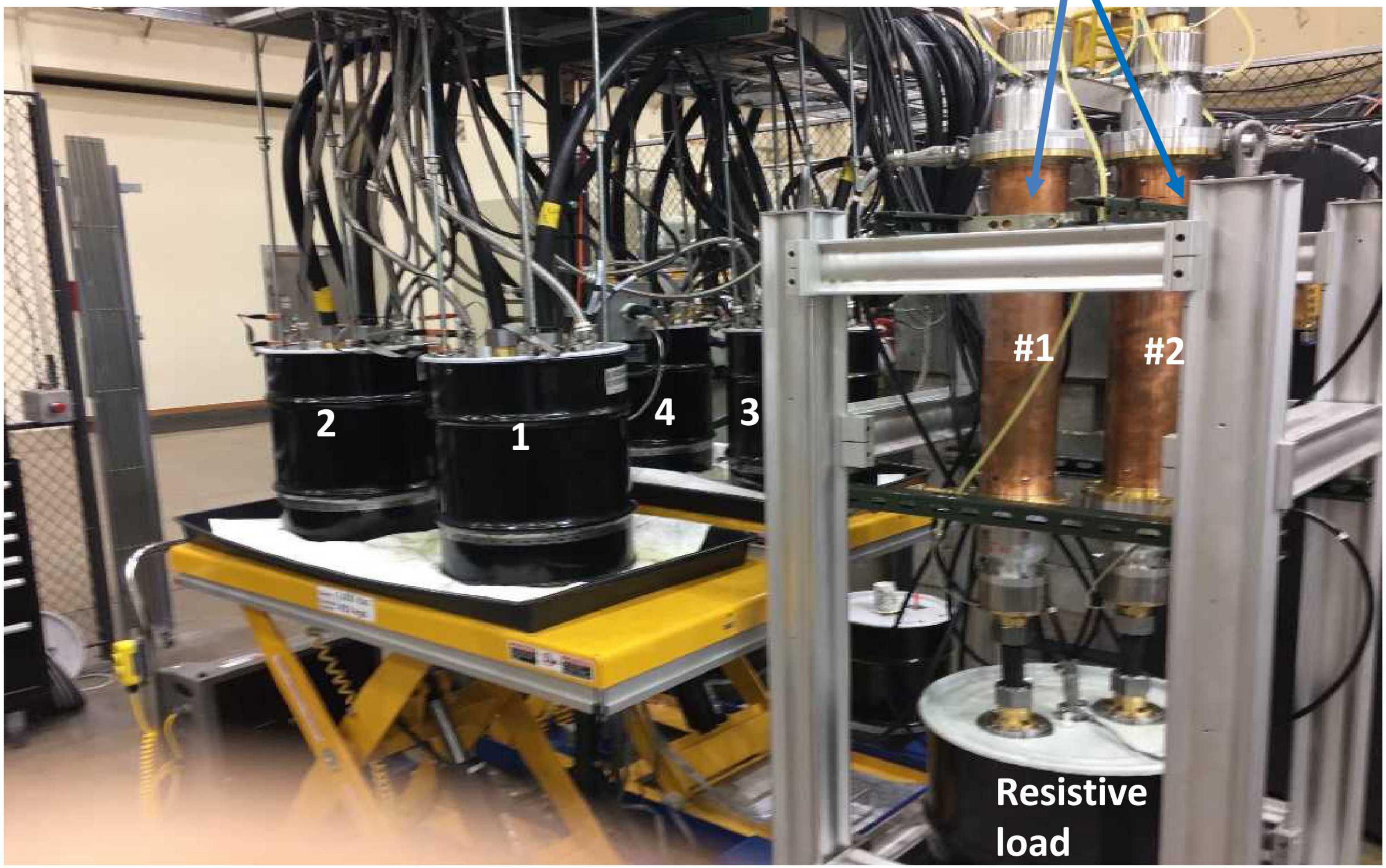


The cables are approximately 60 ns long (one way travel time). They will generate 120 ns wide pulses.

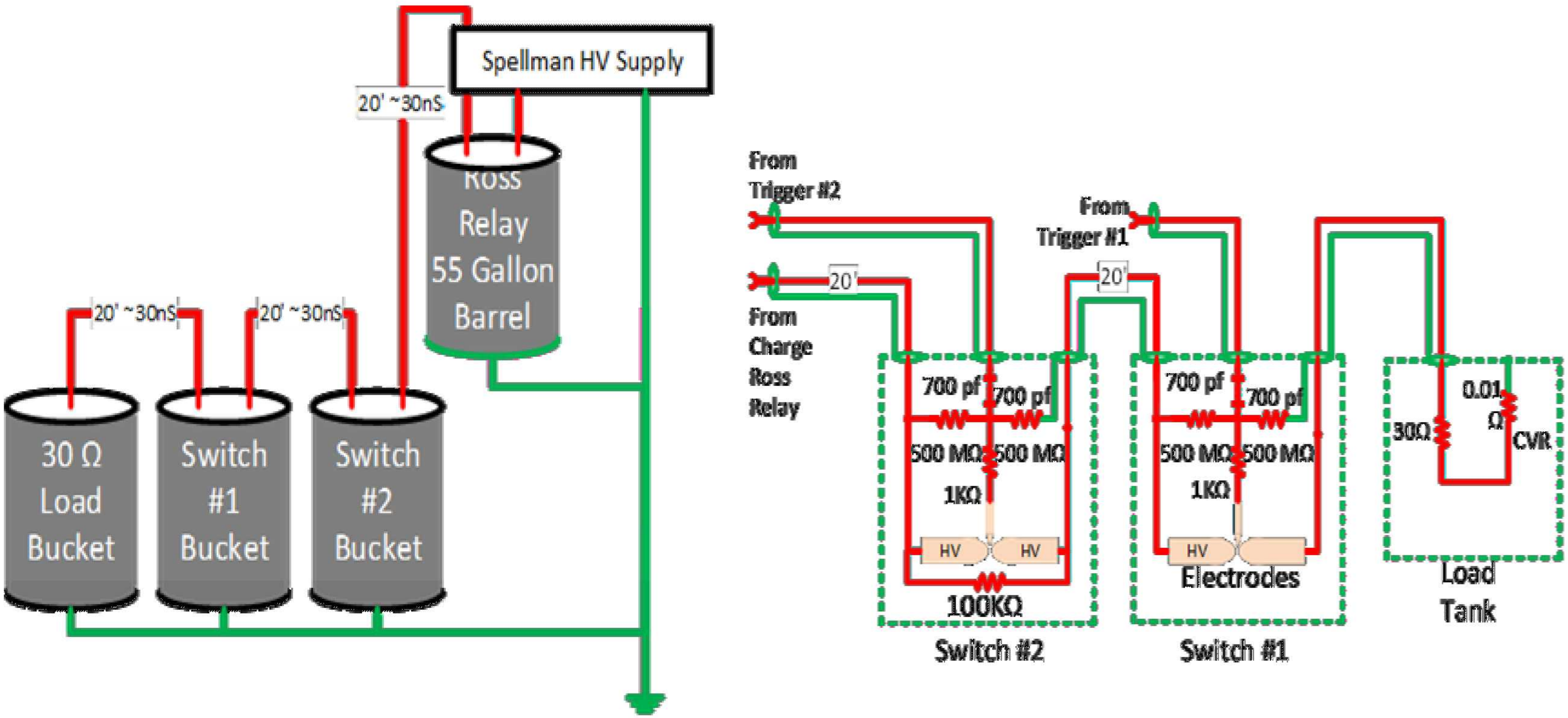
The 2x2 CYS-II Test Stand

- The set up is composed of four oil cylinders. They contain switches #1 # 2 , and # 3 and # 4. There are two more oil cylinders (not shown in the photo) containing the 30 Ohm load each for diagnostic calibration and timing testing.
- A seventh cylinder contains an isolation resistor and two relays to isolate the High Voltage DC power supply from the rest of the system.
- Two hydraulic tables can move up and down the cylinders for system maintenance.

CTS-II with the two Diodes

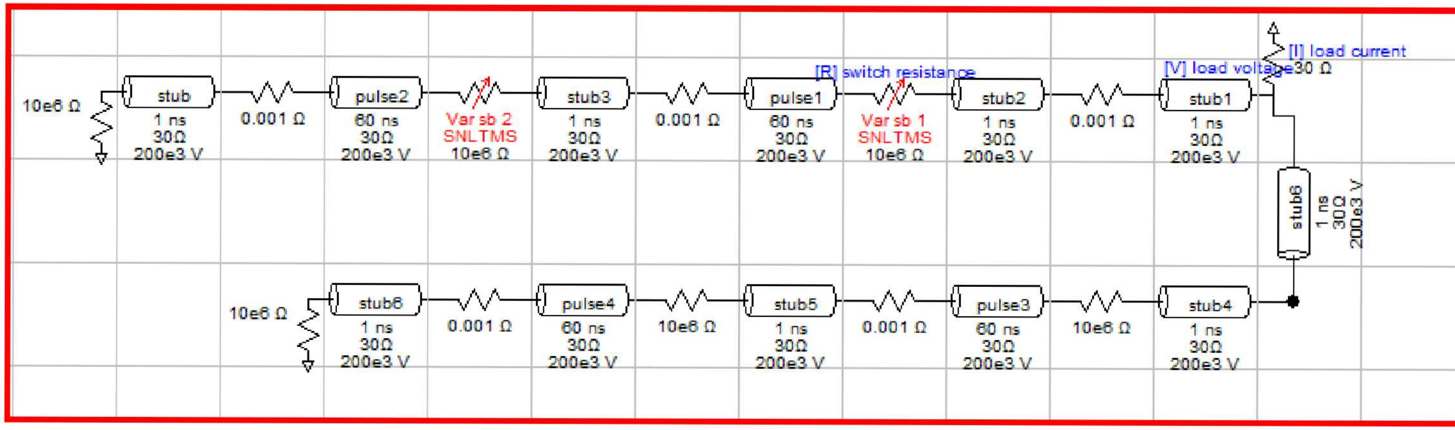


Block diagram of one of the two pulser branches.

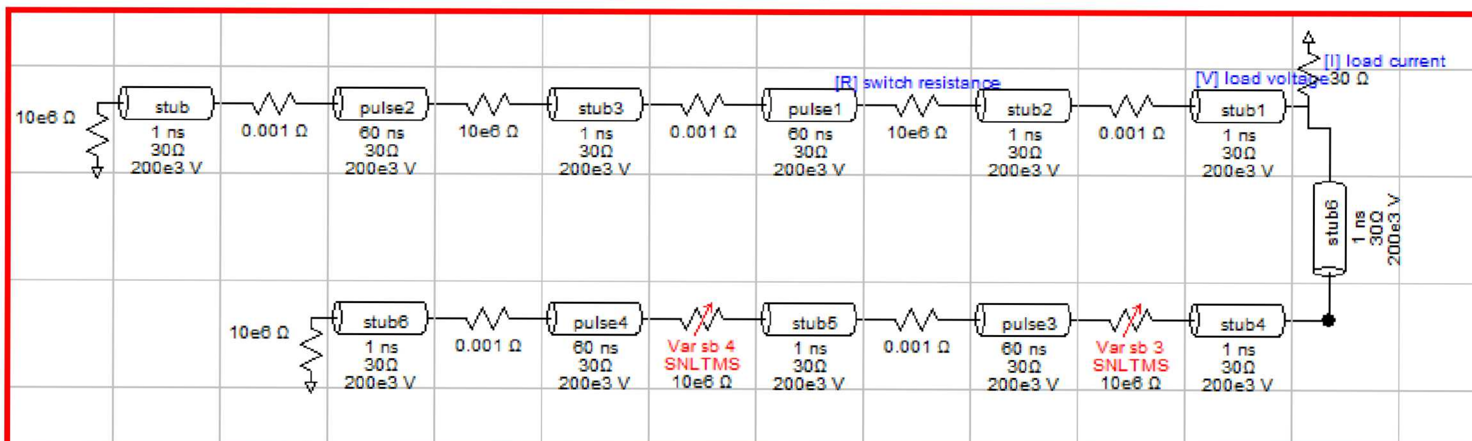


Prior of the experimental tests, to study the expected pulse profile and timing, we used the then available BERTHA and SCREAMER circuit codes. Neither of them had diode packages. However we improvised by simulating the ideal performance of the diodes (no reflections) in two steps for each firing sequence and then merge the results. We fired the switches of each branch separately with the proper timing. As an example we show below the 1234 sequence results

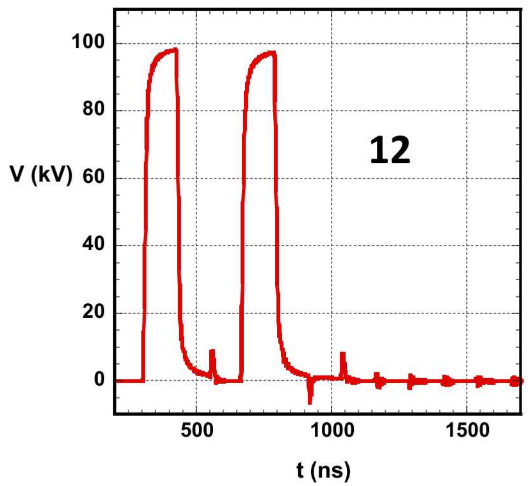
12 for 1234

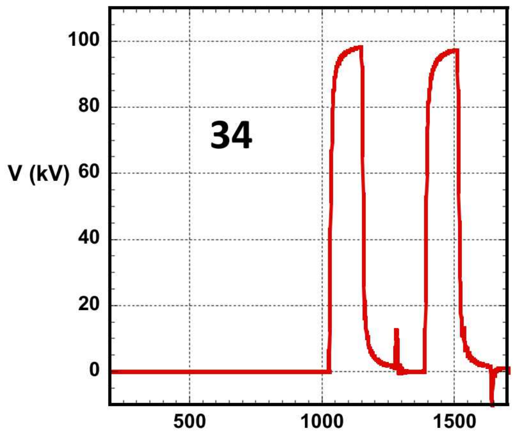


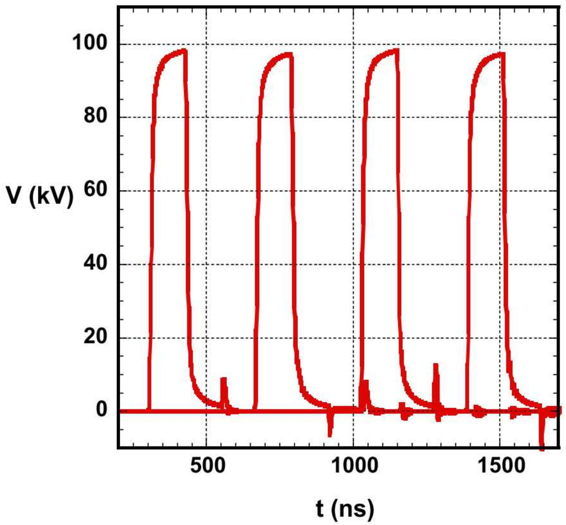
34 for 1234



We simulate the ideal performance of the diodes (no reflections) in two steps and then merge the results.







1234 combination

Switch trigger times   pulse arriving time to the load

#1 at 300ns   300ns

#2 at 600ns   660ns

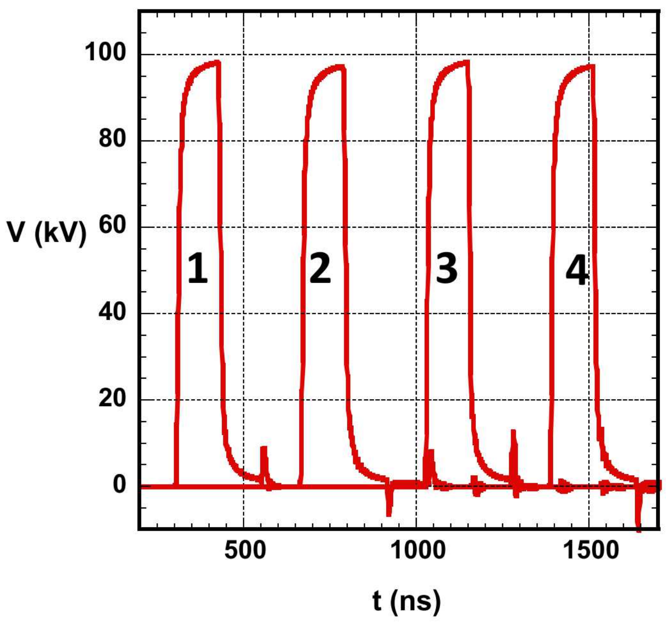
#3 at 1020ns   1020ns

#4 at 1320ns   1380ns

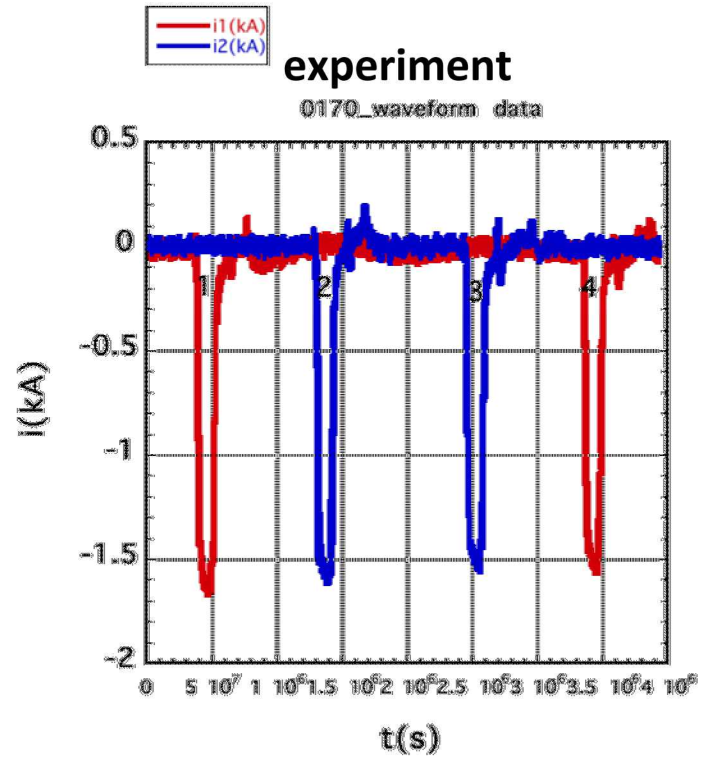
240 ns inter-pulse separation

The experimental results are similar to simulations

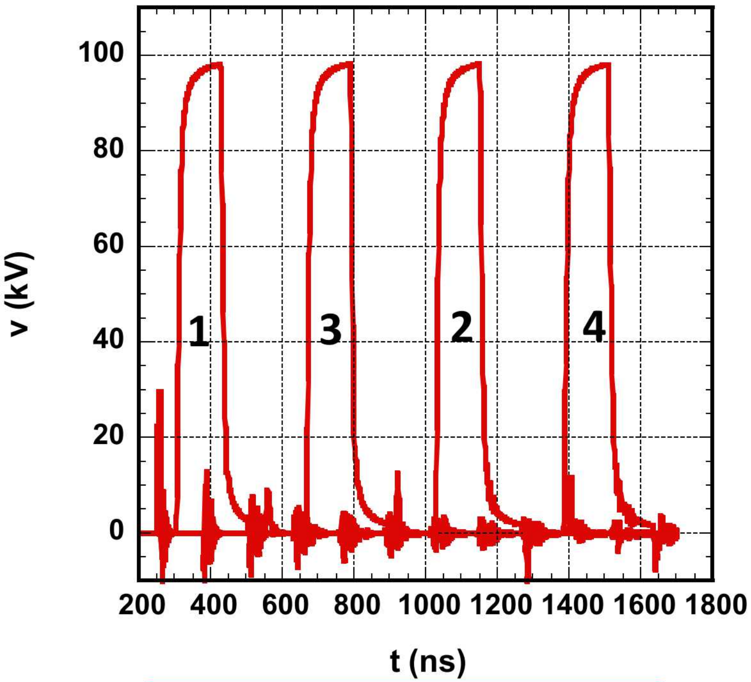
simulation



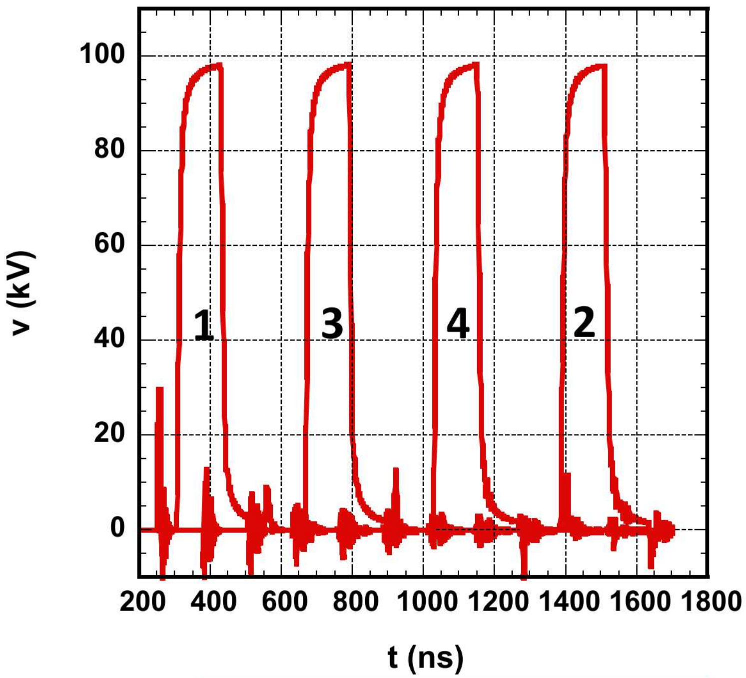
experiment



1324 Firing sequence

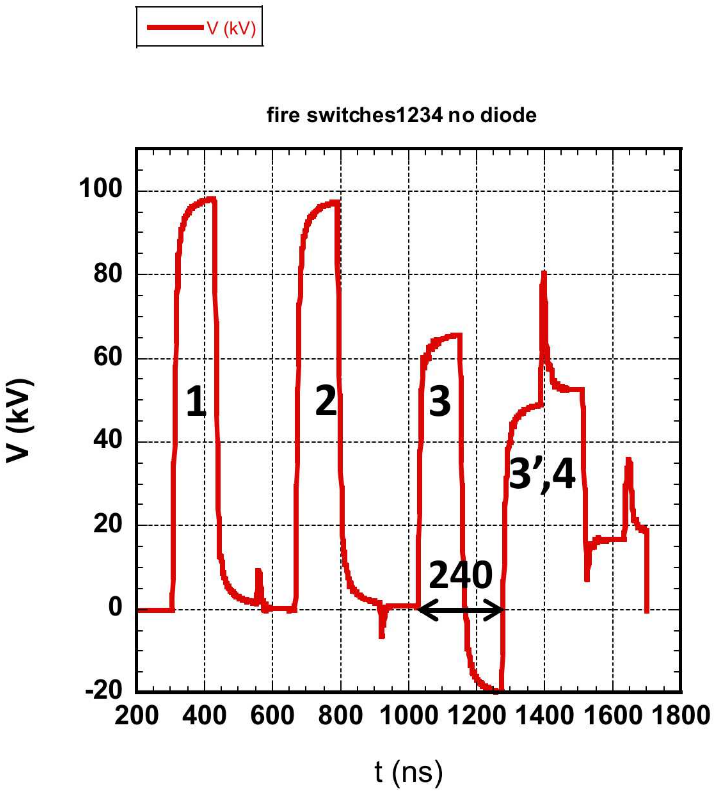


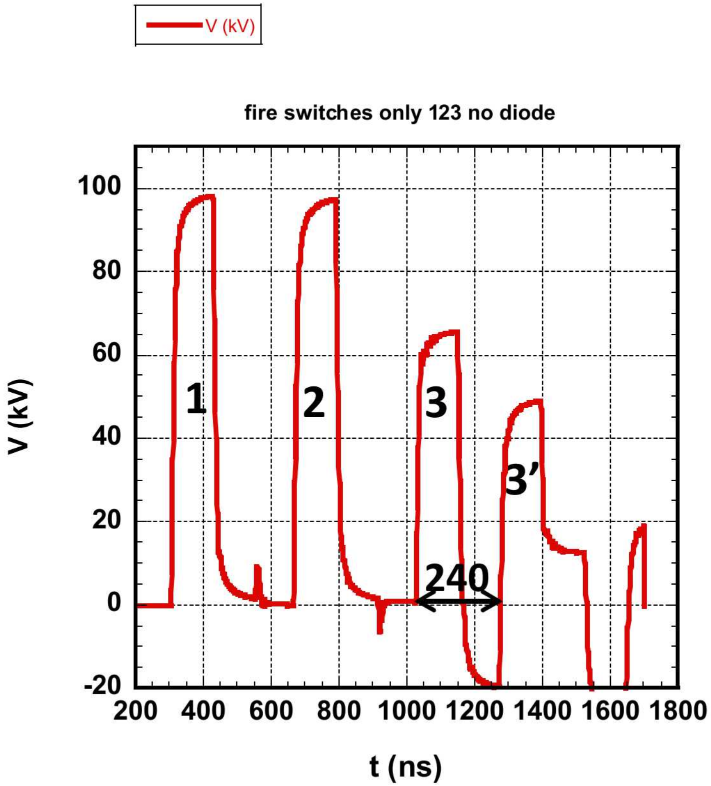
Switch trigger times
#1 at 300 ns
#3 at 660 ns
#2 at 960 ns
#4 at 1320 ns
240 ns inter-pulse separation



Switch trigger times
#1 at 300 ns
#3 at 660 ns
#4 at 960 ns
#2 at 1320 ns
240 ns inter-pulse separation

These simulations assume that the diodes of Branch A completelly become shorted following pulse #1 and # 2.





Experimental Results Summary

a.-- We studied the APP, DEAN, and LANL diode reverse blocking ability in a number of two and four pulse sequences. We fired a total of approximately 1454 shots with the APP modules . With the DEAN modules we fired three time fewer shots, about 538. With the LANL module, which is not encapsulated in epoxy, we fired a total of 290 shots, some of them were 9 kV overvoltaged, without a failure.

b. – We measured the amplitude of the reverse recovery current peak as a function of pulse separation between the diodes of A and B.

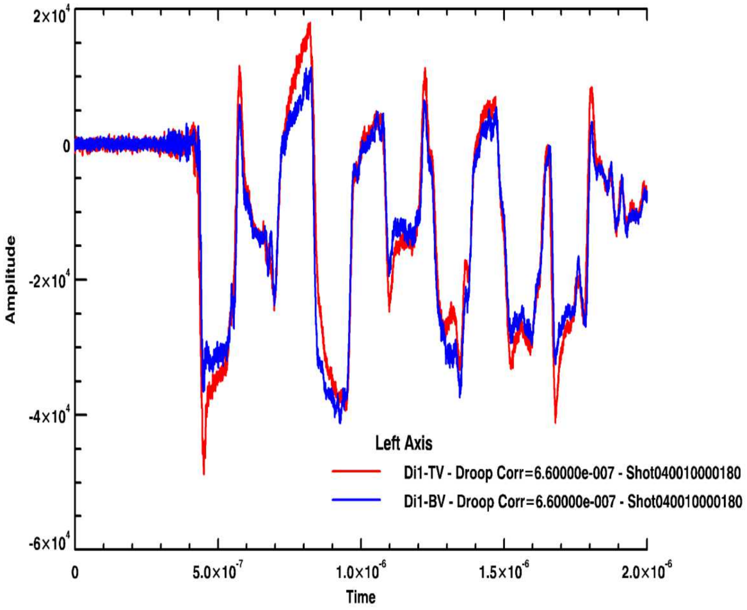
c.—We discovered that the reverse recovery current spikes increase exponentially with the decrease of inter-pulse separation between diodes A and B.

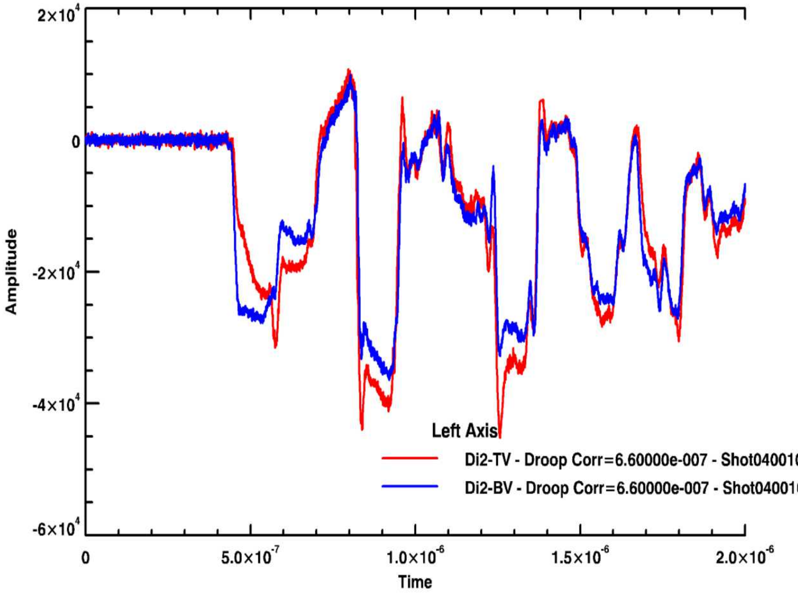
d.—We measured the voltage drop along the diodes utilizing the housing top and bottom capacitive pick-up probes (Ddots) as well as the estimated switch resistance. For examble, the voltage drop along one LANL cartridge was 2,555V. The switch resistance was 3.7 Ohm. Hence, the actual voltage applied on the diode module should be corrected by the voltage drop through the switches.

Experimental Results Summary Continues

f.—We measured the voltage drop along the diodes utilizing the housing top and bottom capacitive pick-up probes (Ddots) as well as the estimated switch resistance. For examble, the voltage drop along one LANL cartridge was 2,555V. The switch resistance was 3.7 Ohm. Hence, the actual voltage applied on the diode module should be corrected by the voltage drop through the switches.

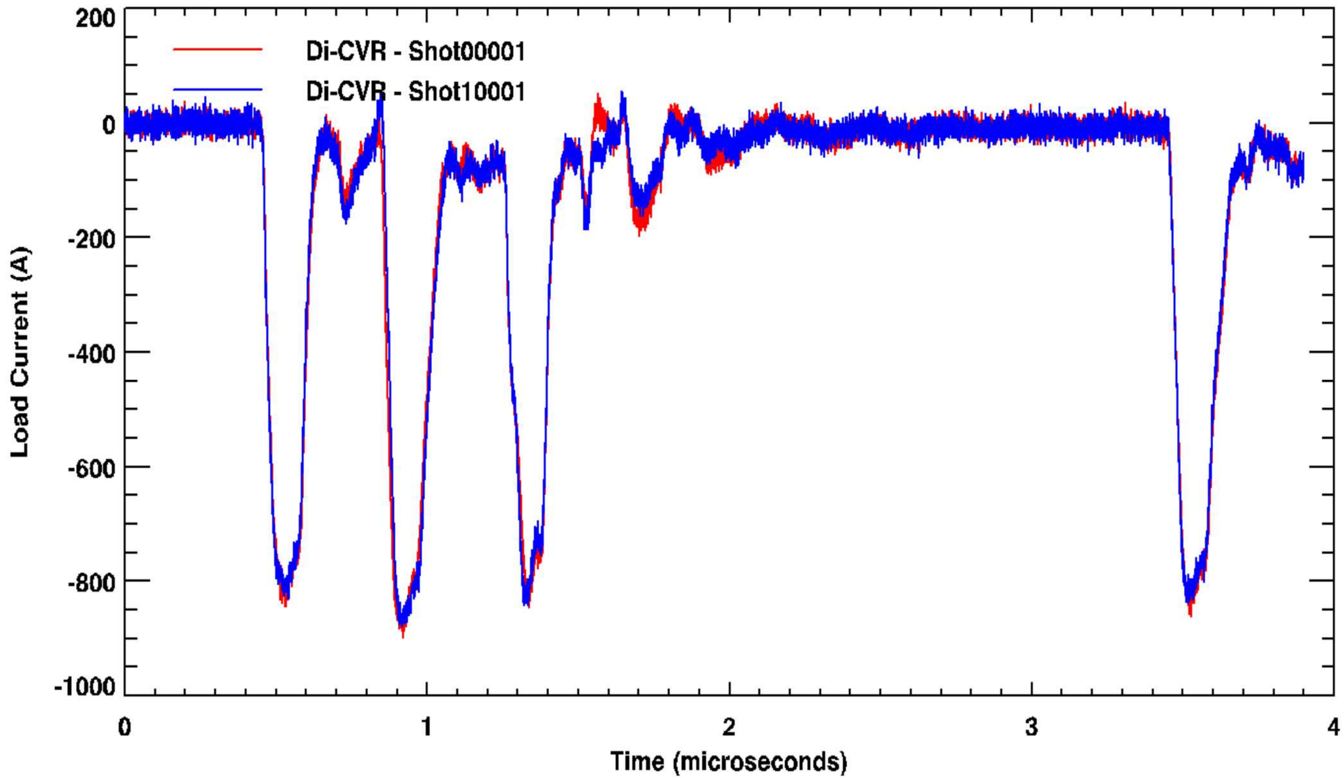
The APP diode cartridges (first batch tested) failed at the 180th shot.





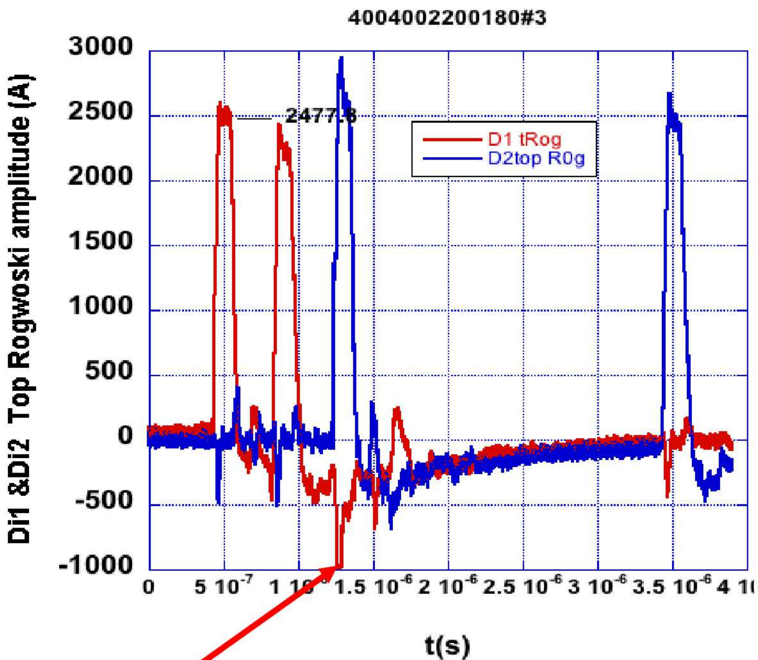
The first batch of APP diode cartridges failed at the 180th shot.

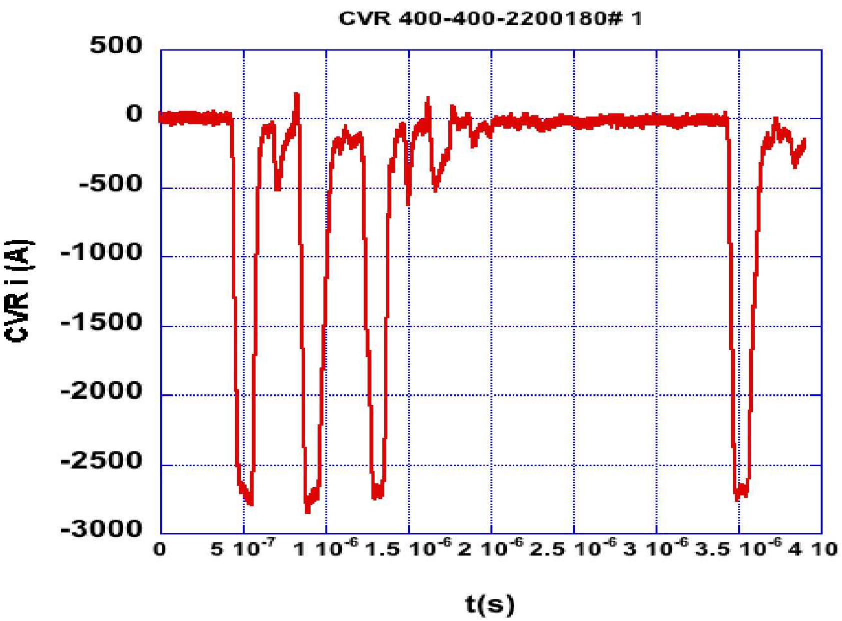
Overlay of APP and DEAN diodes. 400-400-2200 ns sequence



APP and DEAN diode cartridges performed equally well. Overlay of both DEAN and APP diodes at the 400-400-2200 sequence (CVR measurements).

The D-dot monitors were more sensitive to detect diode early failure



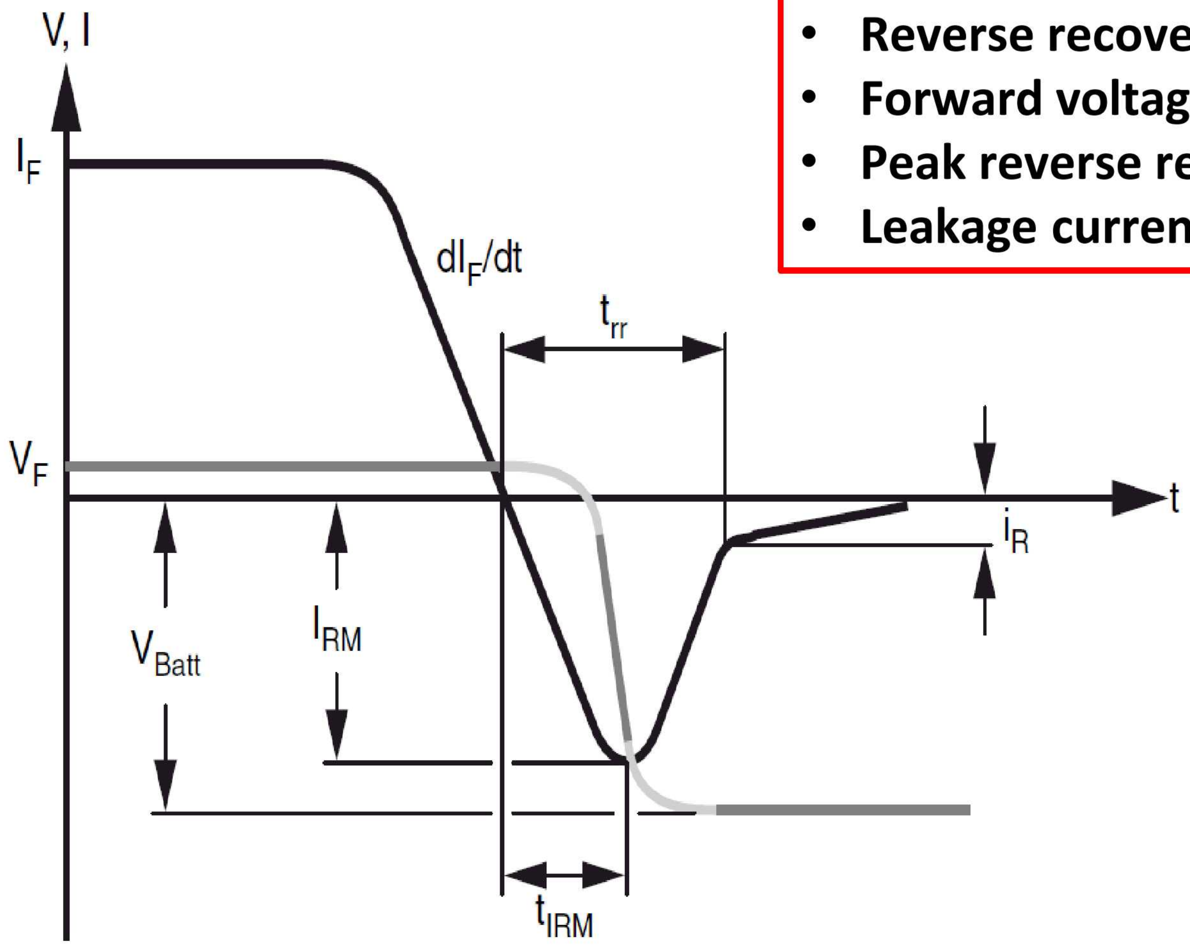


The diode #1 started failing. (large peak and pulse width of the reverse current).

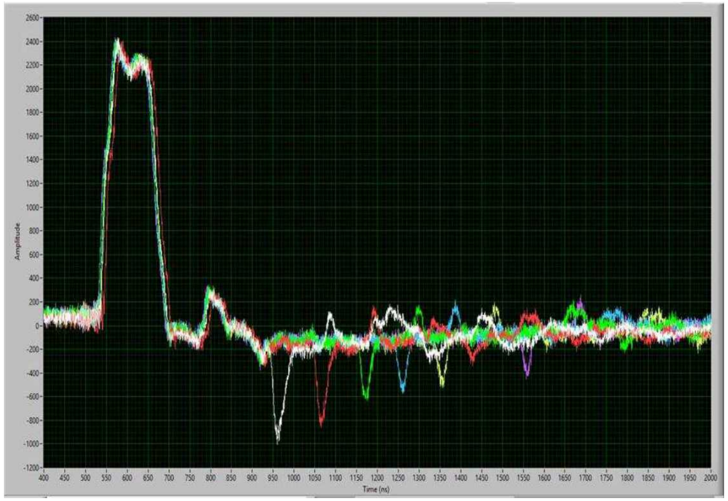
DEAN diodes at 180 kV charging (90 kV applied on the diodes).
Left hand trace is from Rogowski monitors inverted. The right hand trace is from CVR at the actual polarity.

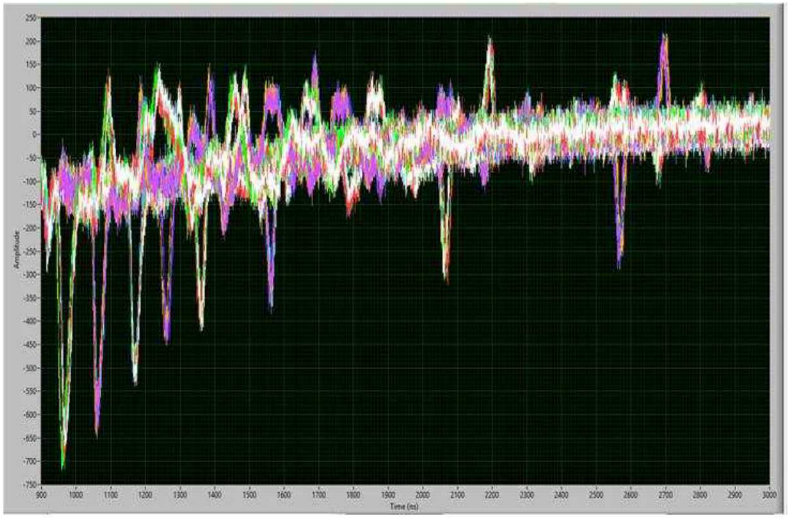
Diode reverse recovery times

- **Forward current (I_F)**
- **Reverse recovery time (t_{rc})**
- **Forward voltage drop (V_F)**
- **Peak reverse recovery time (I_{RM})**
- **Leakage current (I_R)**



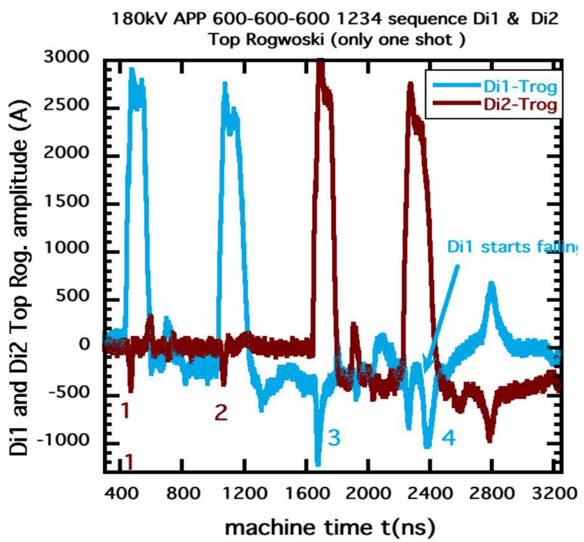
The reverse recovery peak amplitude increases as the inter-pulse separation decreases.

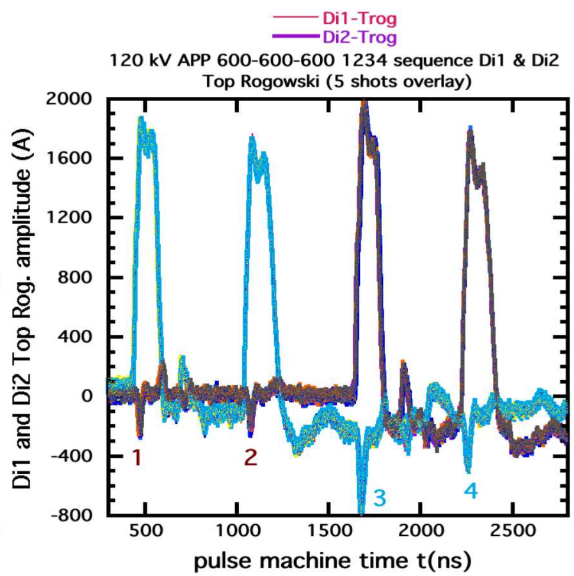


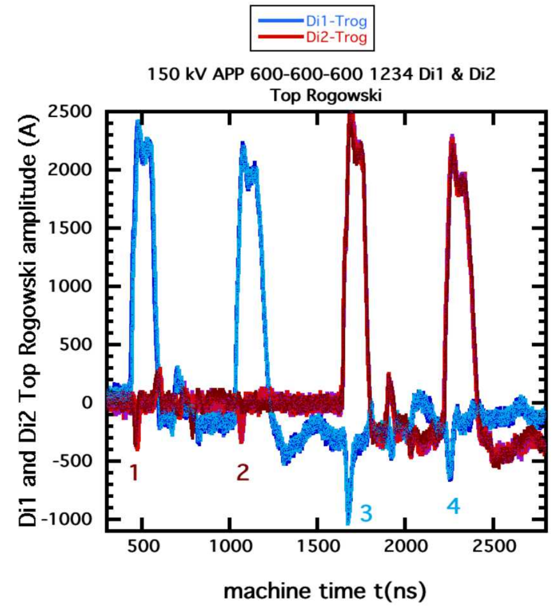


Overlay of a number of 1-3 sequences at 60 kV and 120 kV reverse recovery pulse shots. The 120kV charging sequences (right hand side) were at 2000, 1500, 1000, 800, 700, 600, 500, 400 separation, while the 60 kV series (left hand side) were at 1000-800,700,600,500, and 400.

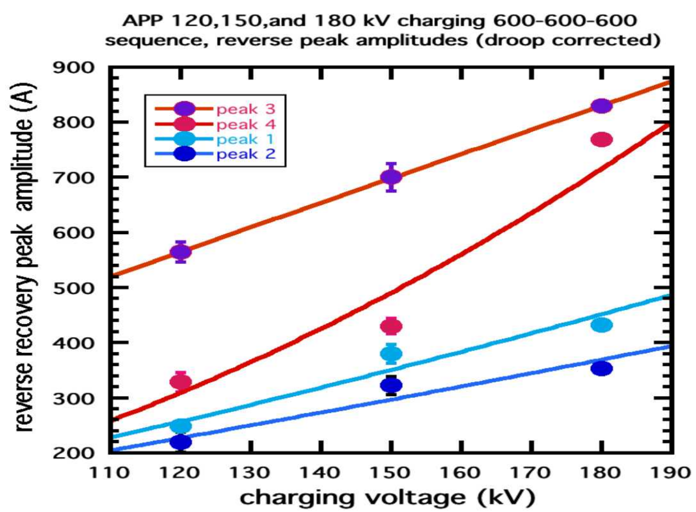
The reverse recovery pulse amplitude increases with the direct bias voltage of the diodes sequence (1234).



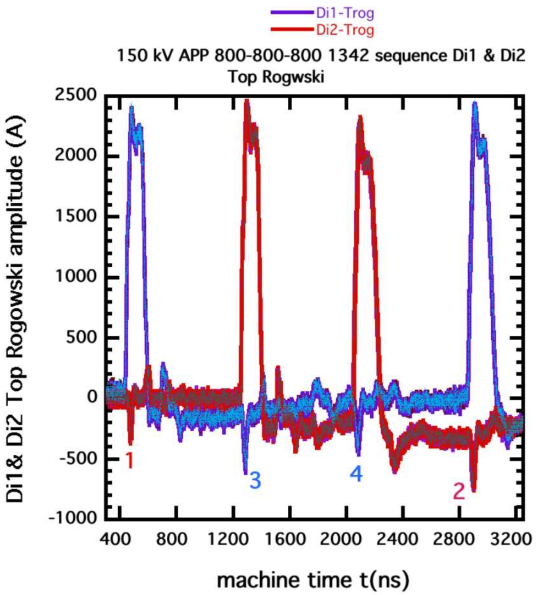


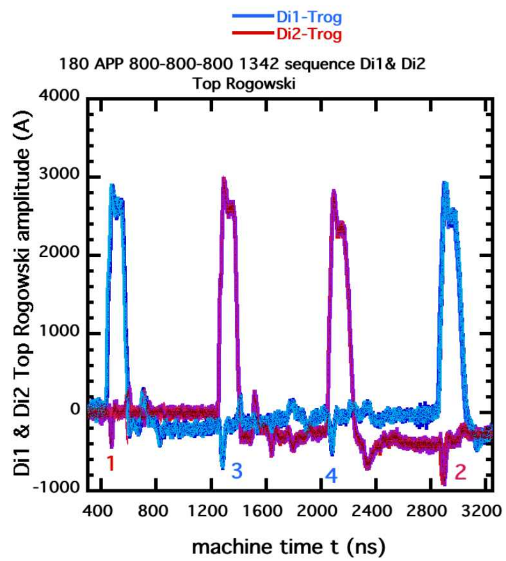


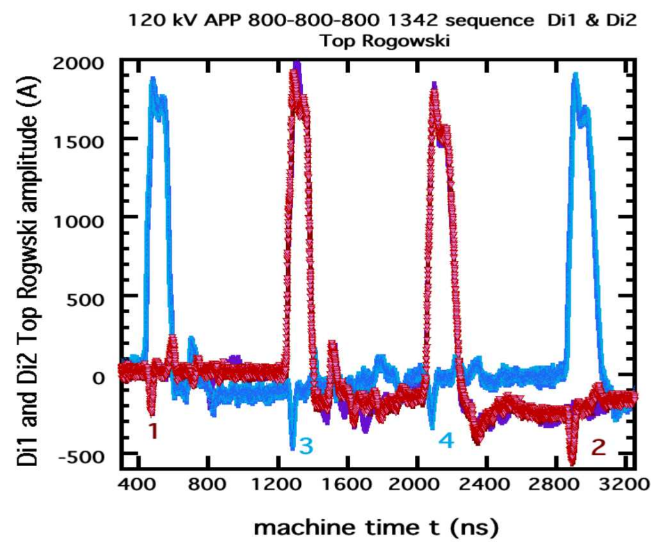
600-600-600 ns	Diode #1	Diode #1	Diode #1	Diode #1	Diode # 2	Diode # 2	Diode # 2	Diode # 2
	Peak # 3 (A)	Delta # 3 (A)	Peak # 4 (A)	Delta # 4 (A)	Peak # 1 (A)	Delta # 1 (A)	Peak # 2 (A)	Delta # 2 (A)
180 kV	829	-------	602 & 794	-----------	432	--------	353	--------
150 kV	700	± 25	430	± 14	380	± 17	322	±16
120 kV	564	±18	328	± 18	248	± 10	219	±18



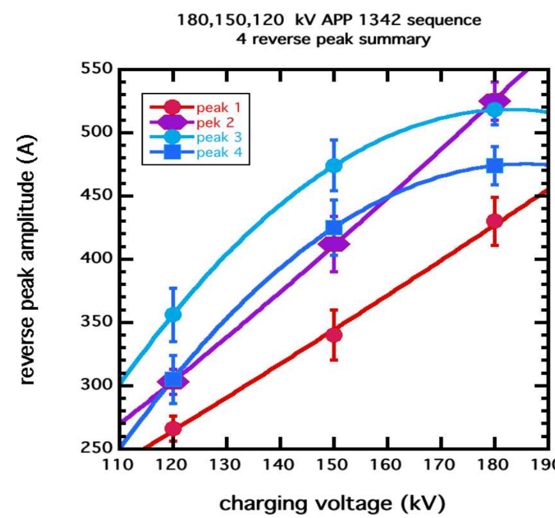
The reverse recovery pulse amplitude increases with the direct bias voltage of the diodes sequence (1342)



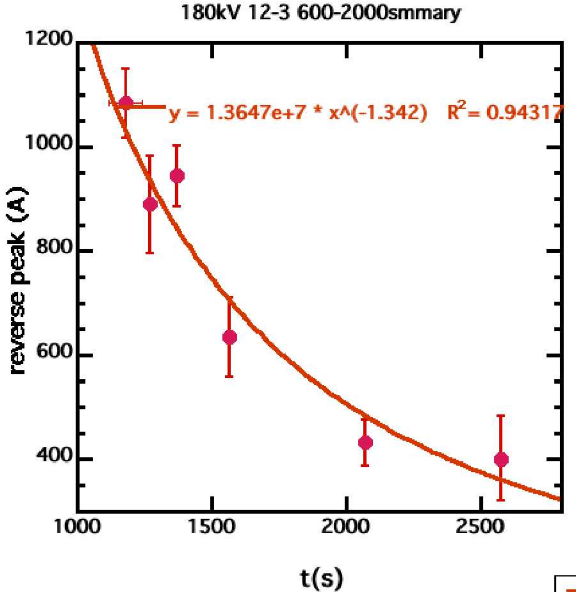


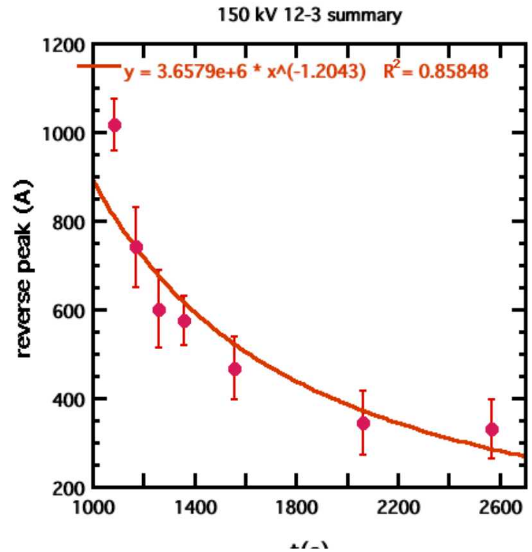


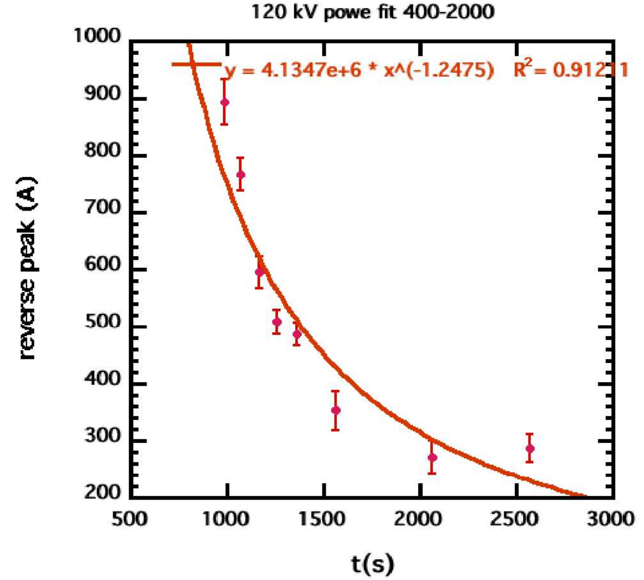
800-800-800 ns	Diode #1	Diode #1	Diode #1	Diode #1	Diode # 2	Diode # 2	Diode # 2	Diode # 2
	Peak # 3 (A)	Delta # 3 (A)	Peak # 4 (A)	Delta # 4 (A)	Peak # 1 (A)	Delta # 1 (A)	Peak # 2 (A)	Delta # 2 (A)
180 kV	518	±12	474	±15	430	± 19	525	±15
150 KV	474	± 20	425	± 21	340	± 20	412	±22
120 kV	356	±21	305	± 19	266	± 10	303	±10

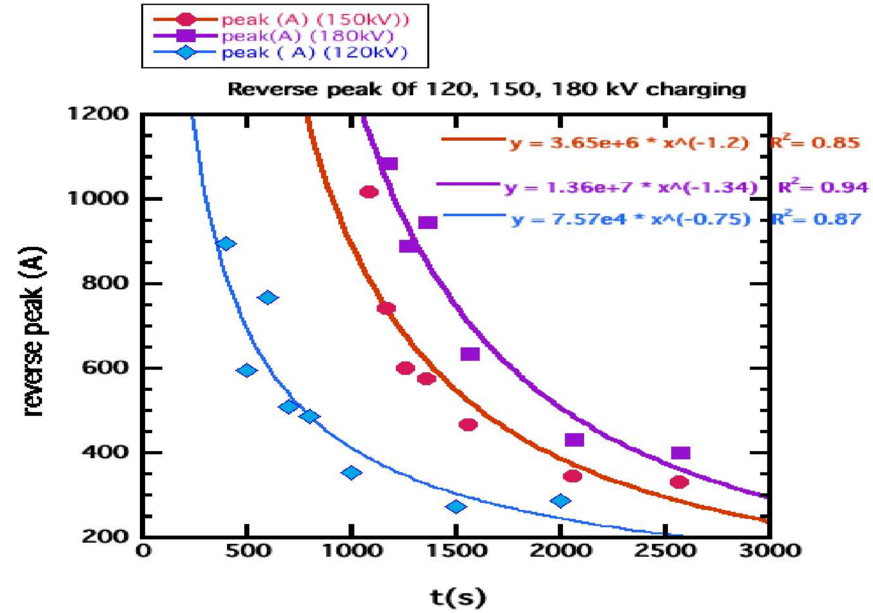


The reverse peak amplitude # 3 of APP diodes decreases exponentially with the increase of pulse separation between pulses # 2 and #3 but increases with the charging voltage

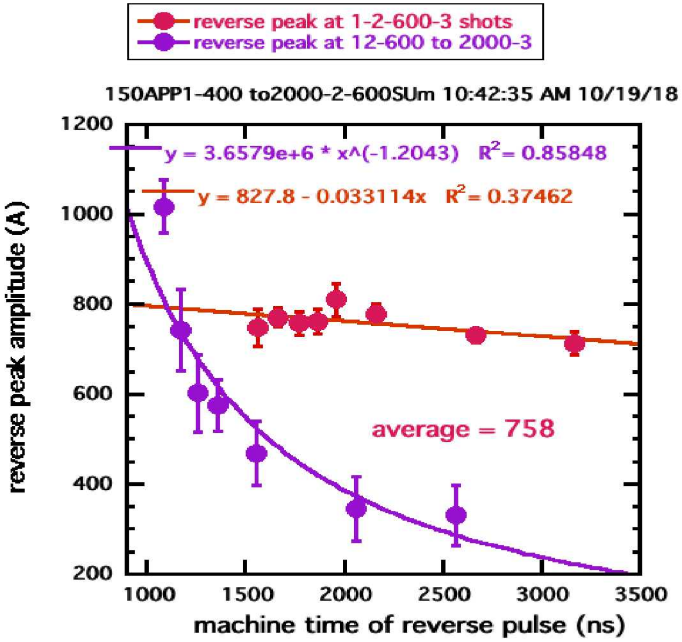


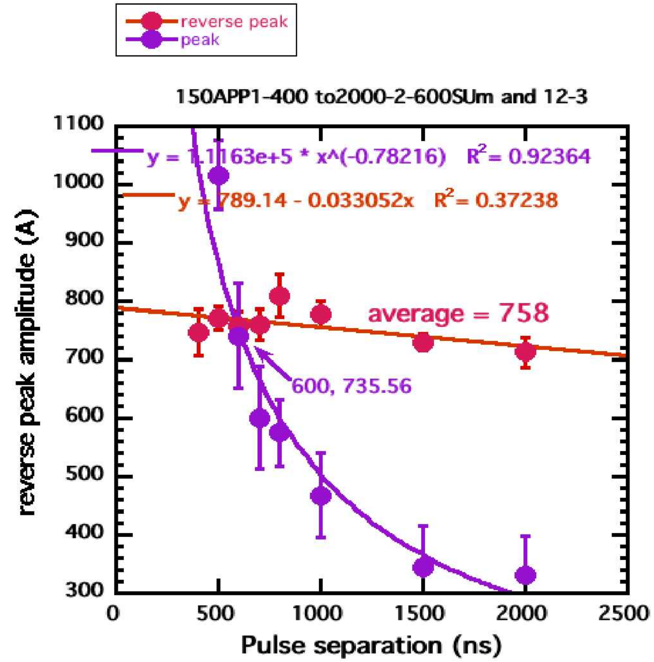






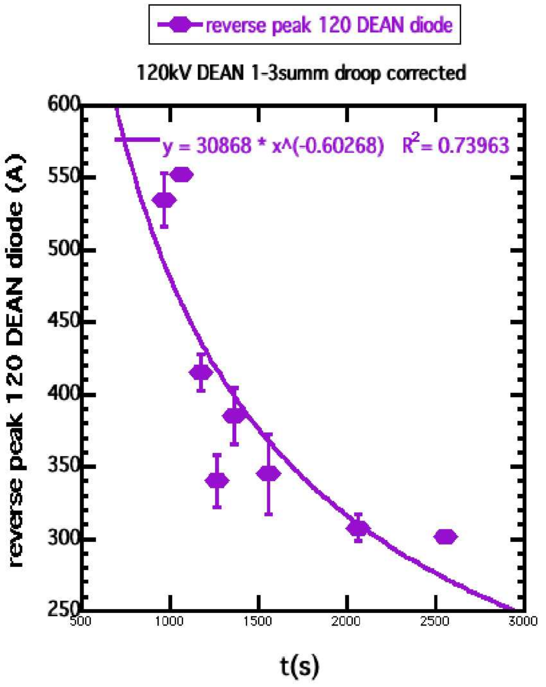
So, the reverse recovery current peak amplitude on diode #1 depends only on the pulse separation between pulses #2 and #3

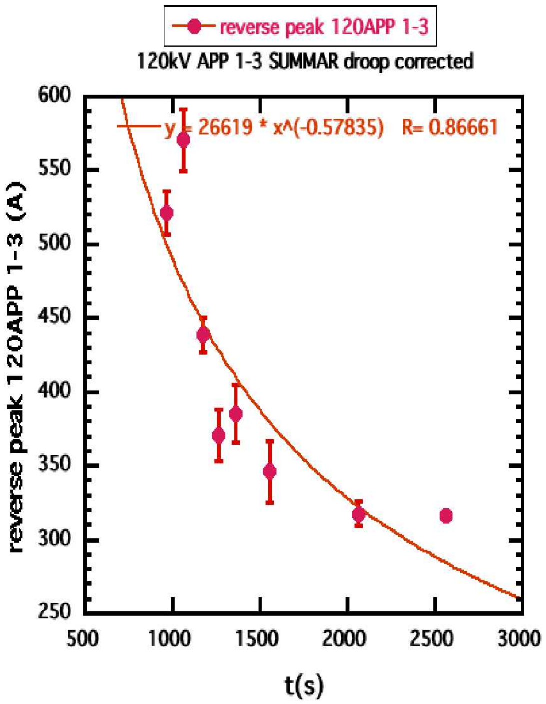


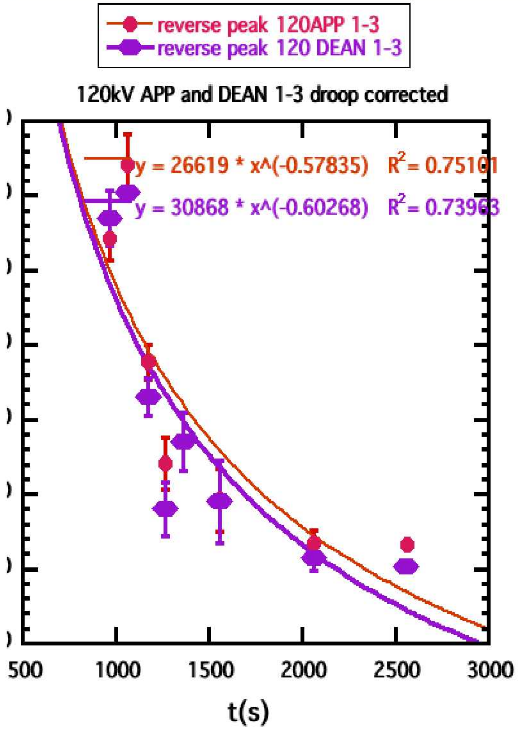


These graphs compare the reverse recovery peak # 3 (similar to # 3 of previous viewgraph 25) on diode one traces (Di1) for two type of sequences. It was suggested to check if there is a difference between the reverse recovery pulse observed when pulses #1 and #2 are adjacent (12-3 sequence) as compared with the sequence when the pulse separation of #1 and #2 varies. It is obvious that all the reverse pulse amplitudes of the sequence 1-2-600-3, where the #2-#3 pulse separation is fixed and equal to 600ns, are practically the same (**red trace**) and equal to the one 12- 600 -3 shot of the 12-3 sequence (**purple trace**).

The reverse recovery peak # 3, droop corrected, of the APP and DEAN diodes is practically the same.

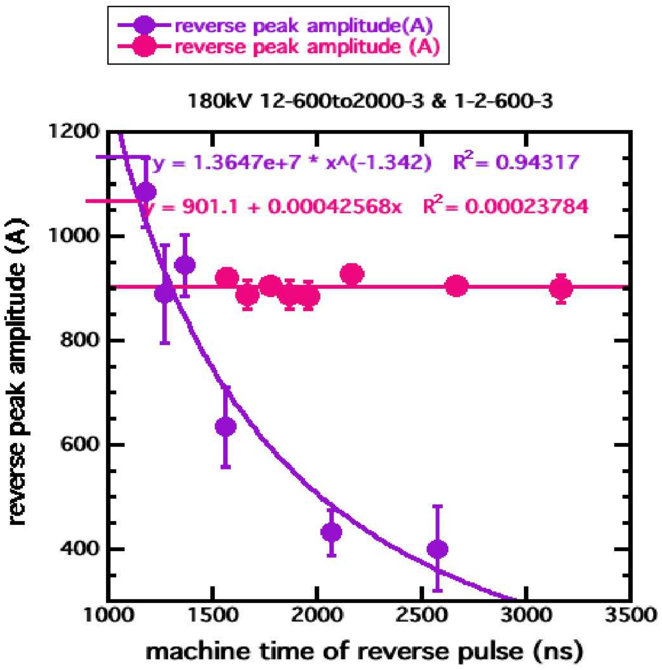


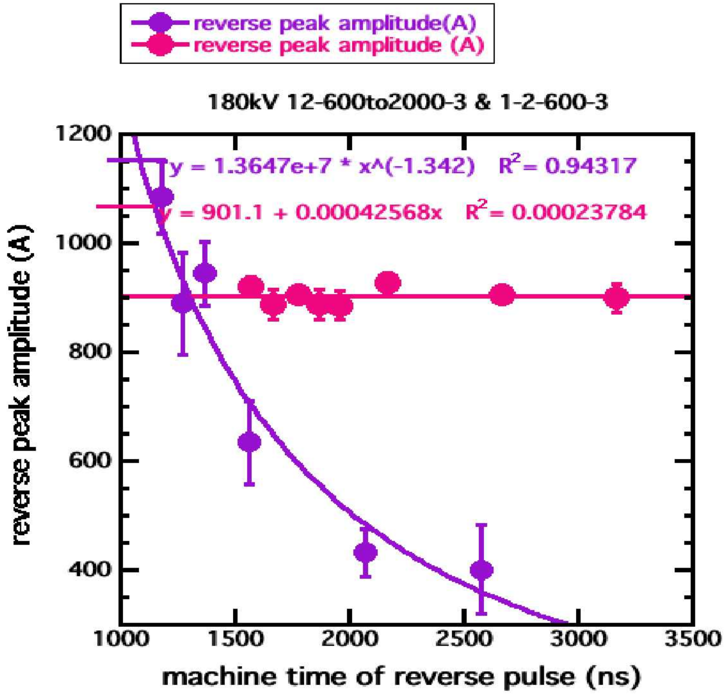




The charging voltage was 120 kV and the sequence was 1-3. Every point is the average of five shots.

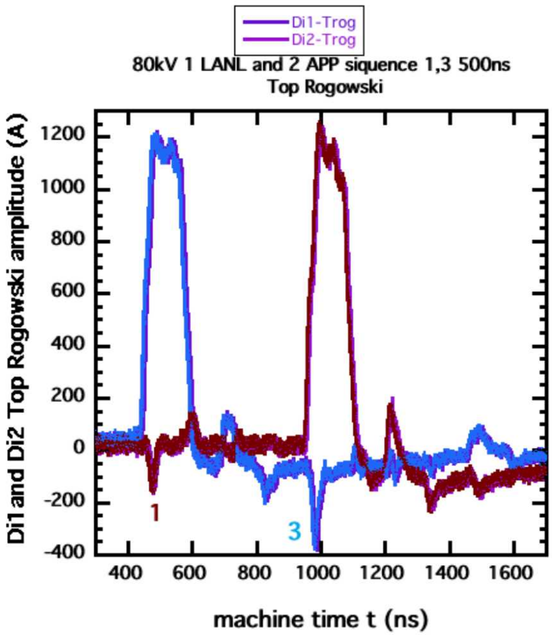
The reverse recovery current peak amplitude on diode #1 depends only on the pulse separation between pulses #2 and #3

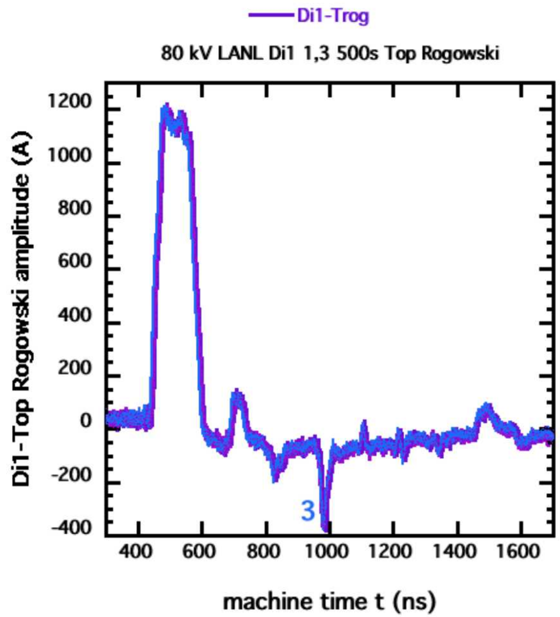


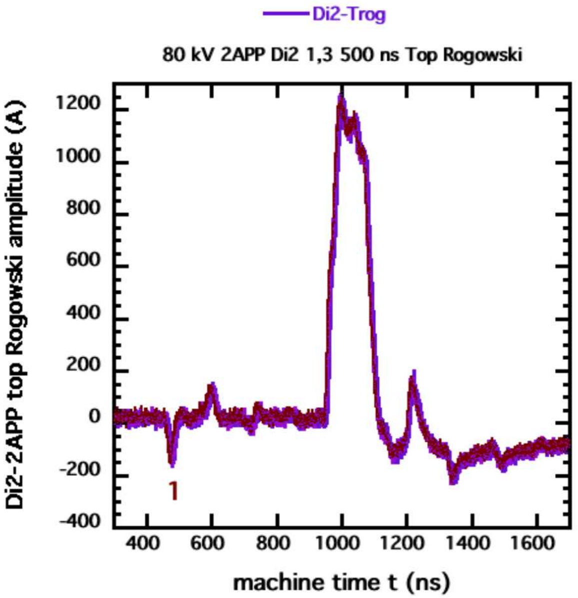


Similar results as previous viewgraph 26 butnow at 180kV charging

LANL diode in Branch A second branch B had an APP cartridge

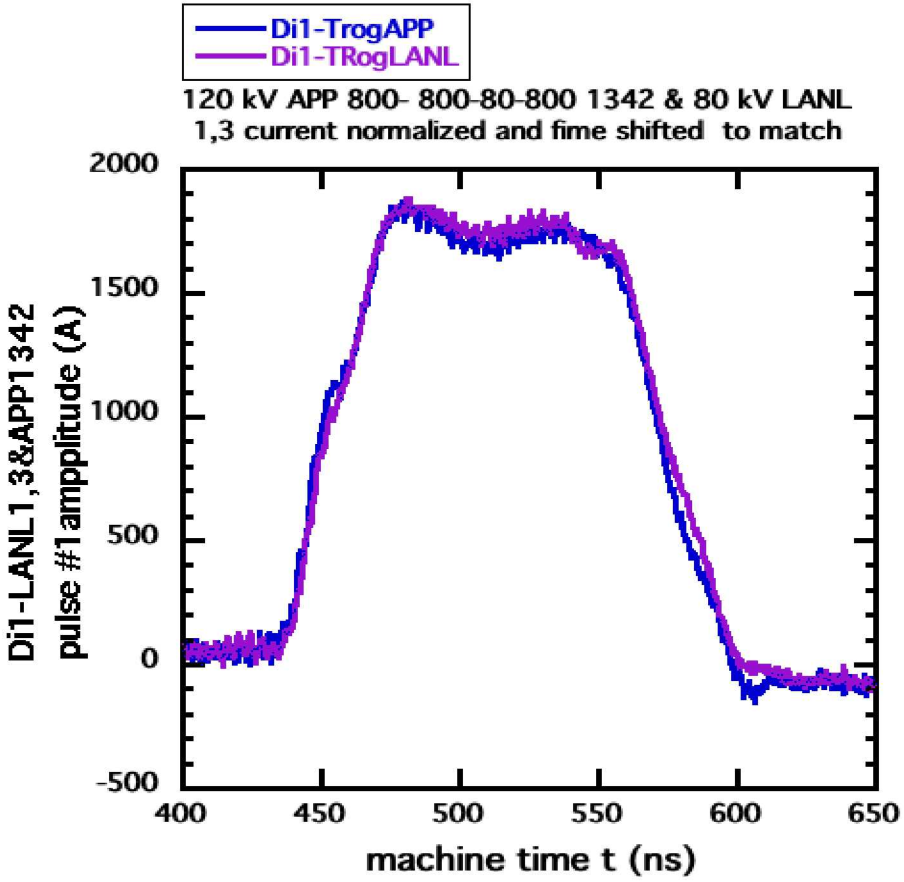






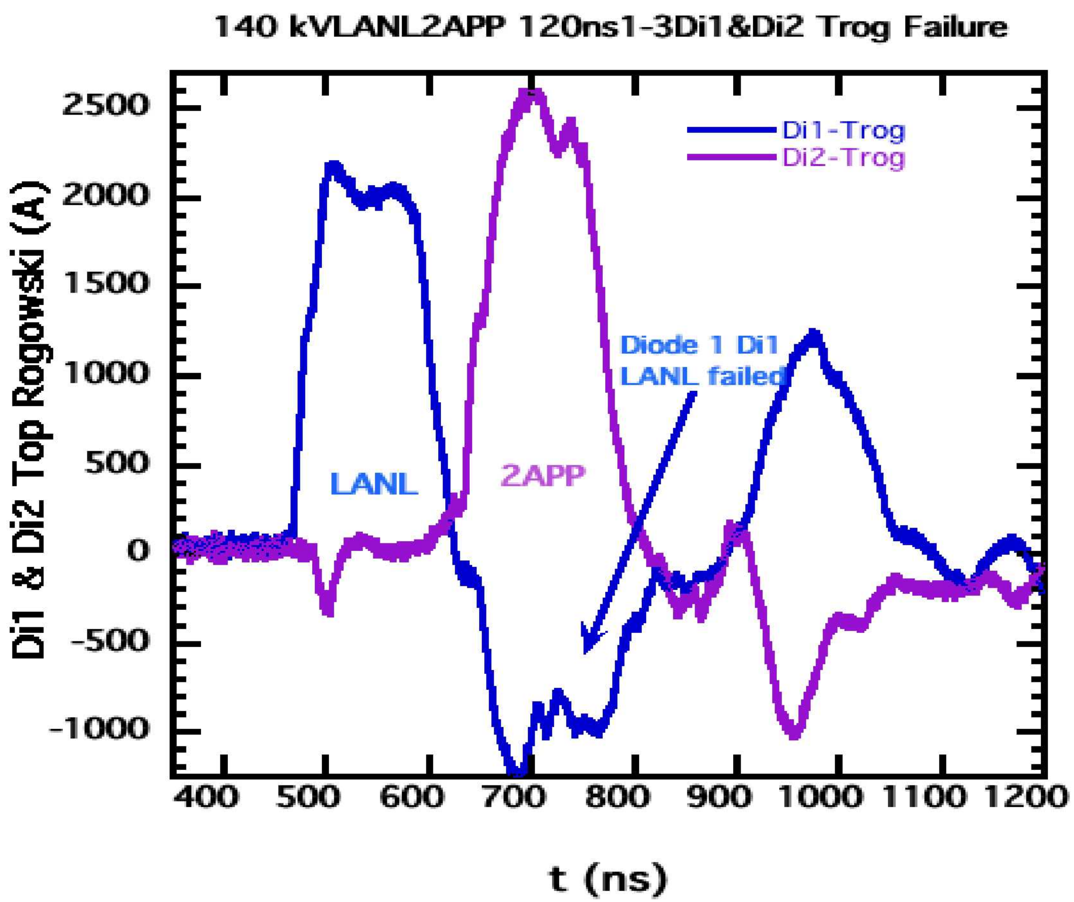
The charging was 80 kV, and the pulse separation was 500 ns in the sequence 1-3.

Overlay of LANL and APP Pulse # 1 traces



We compare here the first pulse #1 of LANL diode, 1-3 sequence with the first pulse #1 of the APP diode.
The LANL trace is normalized and time-shifted to match the APP pulse.
The agreement of the two pulses is impressive

The LANL failed because we over-voltaged it by ~ 10% above rating,



Summary

- All three diodes, APP, DEAN and LANL exhibited the same behavior.
- The reverse recovery times and current amplitudes were practically the the same and approximately 2000ns.
- The APP cartridge demonstrated longer life times for thousand shots.