CONDUCTION TIME/CURRENT LIMITATION ON THE DEFENSE SPECIAL WEAPONS AGENCY DECADE MODULE 1*

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INTRODUCTION

The Defense Special Weapons Agency's DECADE radiation effects simulator design consists of 16 separate pulsed power modules each driving individual bremsstrahlung diodes.[1,2] DECADE is required to produce a dose in a near field test plane of 20 krad (Si) with 2:1 uniformity over 10,000 cm^2, as well as meeting several other specifications. Each DECADE module utilizes a plasma opening switch (POS) in the final stage of pulse compression. DECADE Module-1 (DM1), the first full scale module tested, is capable of delivering up to 1.8 MA in 300 ns to the POS. Power delivery to the load is dependent on the POS and load coupling performance. During testing the DM1 performance level was found to be nearly a factor of two below that required to meet the DECADE dose specification. A DECADE Assessment Program was initiated to evaluate and assess the likelihood of achieving the original design specification based on the performance of a single module.[3,4,5] The Assessment Program, with emphasis on diagnostics, was coordinated by scientists from Maxwell Technologies, the Naval Research Laboratory, and Primex/Physics International and included involvement by other collaborators throughout the pulsed power community. This paper describes the results of a study addressing the observed degradation in dose with increased POS conduction current and/or conduction time.

DM1 POS-TO-LOAD CONFIGURATION AND DIAGNOSTICS

Figure 1 shows the baseline DM1 hardware configuration in the POS-to-load region and the primary diagnostics used to characterize the POS and e-beam diode load performance. Local anode B-dot current monitors are distributed azimuthally and axially between the POS and load. Located just downstream of the POS, the A-ring current monitor consists of six individually monitored B-dots, evenly distributed in azimuth. Monitor rings B through E consist of three B-dots each, also evenly distributed in azimuth. External to the DM1 hardware are two time-integrated x-ray pinhole cameras (side-on and end-on views), a calibrated silicon PIN diode (Jaycor PIN) used for making absolute radiation dose rate measurements, and a filtered PIN array, endpoint voltage monitor (EVM) used to determine the e-beam diode voltage time history.[6] The diode electron current is also calculated from the produced radiation using the Jaycor PIN and EVM signals.[7]

Typical load related waveforms are shown in Figure 2 for an e-beam diode shot on DM1. Shown are the measured radiation dose rate and the diode current based on the E-ring B-dot monitors. Overlaid are the calculated diode voltage based on the EVM and calculated diode current based on the produced radiation (the calculated values are truncated at the time when radiation signals become small). The calculated radiation-based diode current and the current measured by the E-ring B-dots generally show good agreement during the initial 20-30 ns of the radiation pulse but diverge at later times, typically near the time of peak dose rate, when there is either turn-on of ion current in the diode region or the B-dot monitors become shielded by plasma.

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14. ABSTRACT

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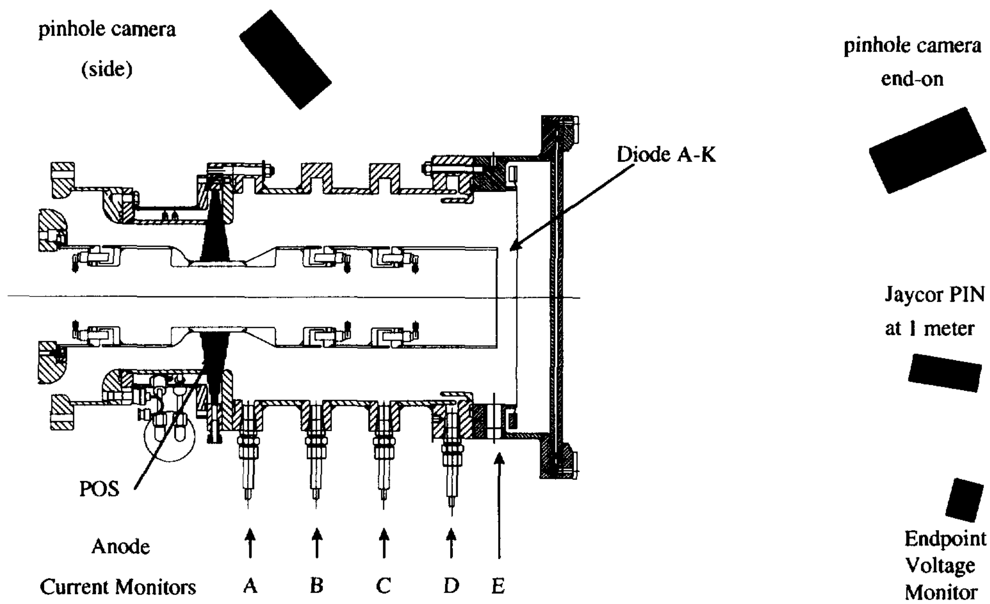


Figure 1. Baseline DM1 hardware and diagnostic configuration.

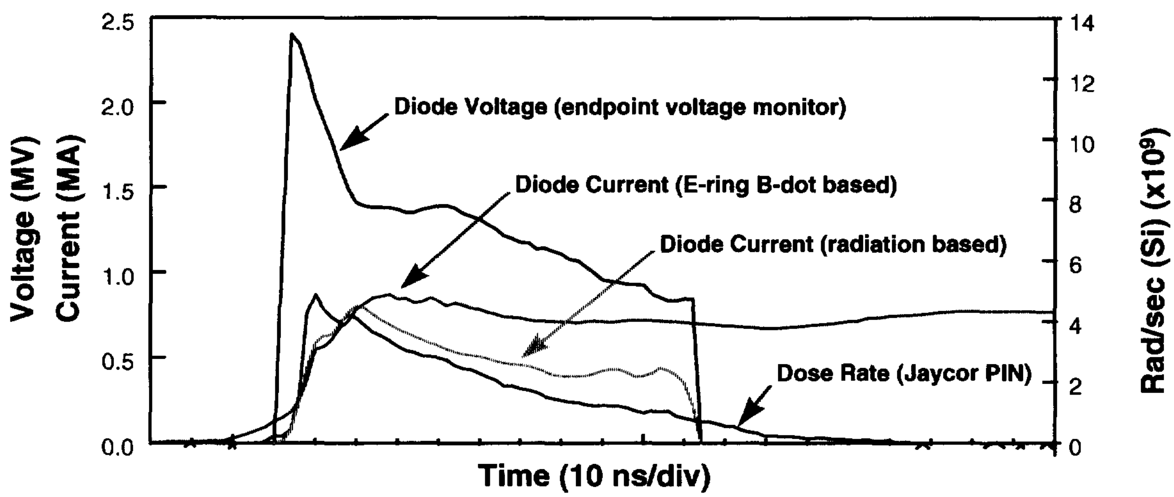


Figure 2. Typical load related waveforms.

Current losses near the load are estimated by taking the average difference between the D-ring current monitors and the radiation based current during the time interval when the E-ring B-dot and radiation-based currents typically agree. The losses are typically a fixed percentage of the D-ring current over that initial time interval.

GENERAL CHARACTERIZATION OF THE CONDUCTION TIME/CURRENT LIMIT

The conduction time/current limit observed on DM1 is a systematic reduction in the produced radiation dose as the POS conduction time is increased beyond about 240 ns as shown in Figure 3. Associated with this decrease in radiation dose is an increase in both radiation pattern asymmetry and current loss near the diode load. Figure 4 shows a series of time-integrated, end-on pinhole camera images for individual shots displaying these trends as the POS conduction time was increased from 183 to 295 ns. Indicated on each image is the radiation dose as measured by the Jaycor PIN and the estimated current loss downstream of the D-ring current monitors defined above.

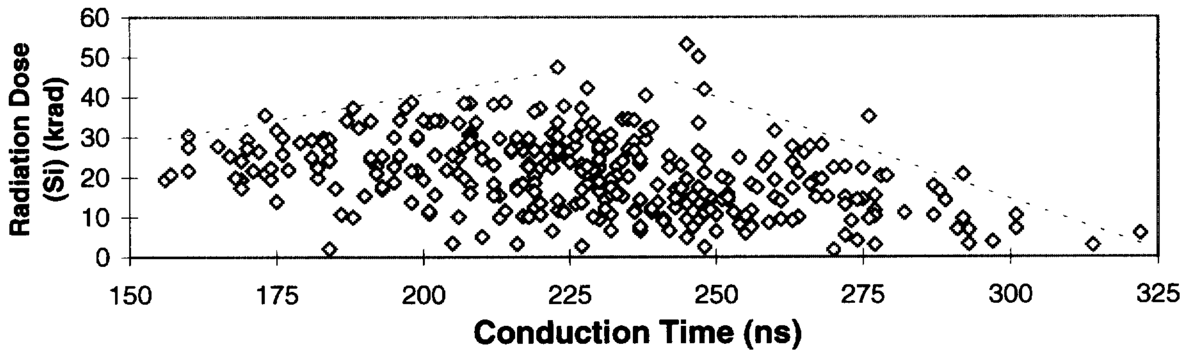


Figure 3. The statistical dependence of the radiation dose on the conduction time. The data shown is for a variety of POS-to-Load hardware variations.

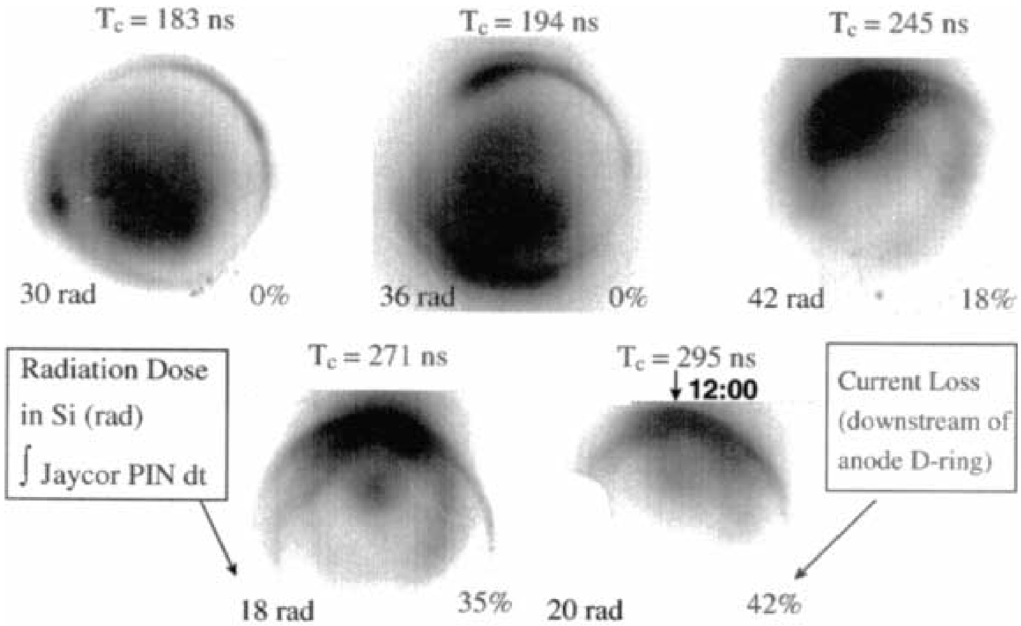


Figure 4. Radiation pattern, radiation dose, and current loss dependence on conduction time.

Current asymmetries are routinely observed at the same nominal azimuth as the radiation pattern asymmetries. Figure 5 shows data exhibiting a current asymmetry at the probes located nearest the 12:00 azimuth for the shot in Figure 4 with T_c = 295 ns, which had a radiation asymmetry near the 12:00 azimuth. The current asymmetry initially observed in the A-ring propagates axially to the load. Characteristic of the current asymmetries are the delayed current appearance and increased current magnitude propagating between the POS and the load.

The localization of losses near the diode are shown by both the current measurements and the side-on x-ray pinhole camera images. The side-on pinhole camera images in Figures 6a and b show the axial distribution of losses in relation to the location of the coaxial cathode and anode structure, and the POS and diode load. The azimuthal location of the losses observed near the diode are consistent with the azimuth of the radiation pattern asymmetry in the corresponding end-on pinhole camera image. Electron loss measurements along the anode between the POS and load using radiochromic film are well correlated with the observed axial x-ray distribution. Filament structure is often observed between the POS and load at the same azimuth as the asymmetries. Cathode ablation downstream of the POS extending to the load at the azimuth of the asymmetry suggests that plasma is involved in the formation and transport of the current channel associated with the asymmetry.

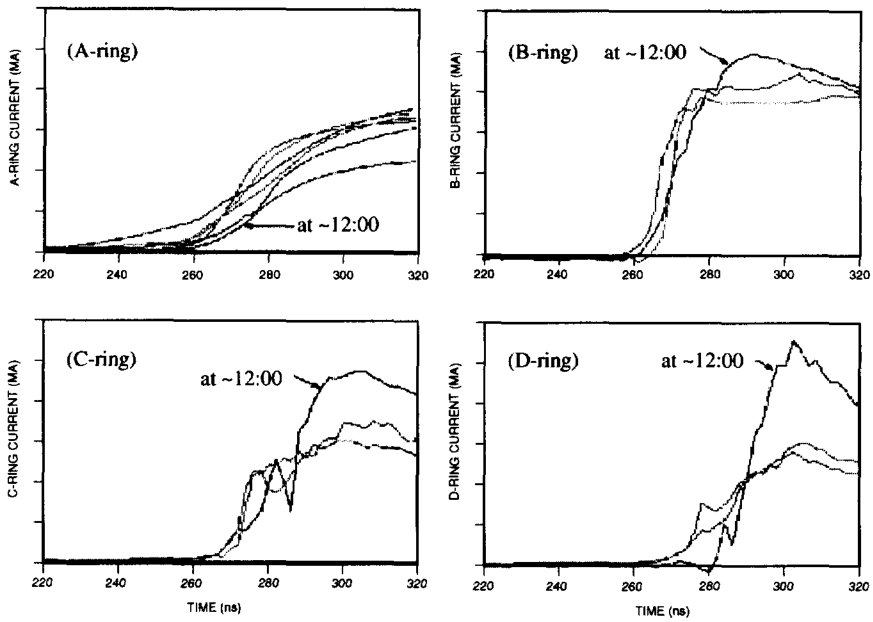
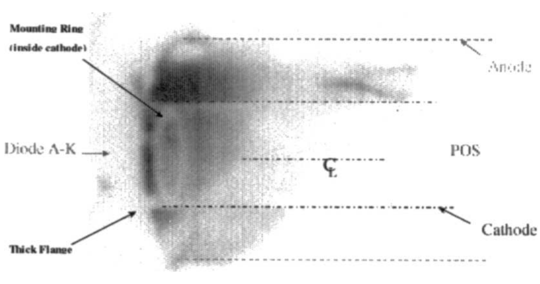
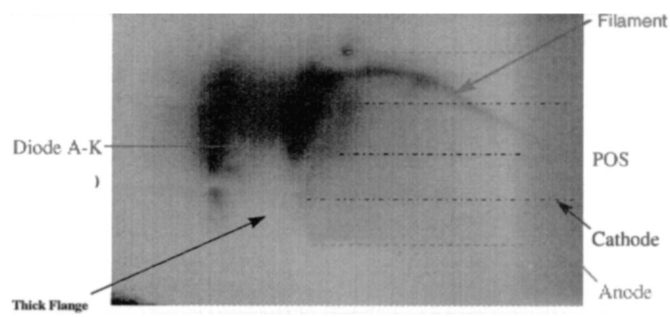


Figure 5. The current as measured at the different azimuths is shown for the A, B, C, and D-ring monitors for the Figure 4, T_c = 295 ns shot. The current asymmetry and radiation asymmetry are both observed at the nominal 12 o'clock azimuth.



6a. Backlit cathode structure



6b. Filament structure between POS and load

Figure 6. Typical side-on x-ray pinhole images for asymmetric shots showing the axial radiation distribution. The coaxial inner (cathode) and outer (anode) diameters are indicated by dashed lines. The e-beam diode A-K gap is shadowed by a thick flange at the left and the POS region is located at the right of each image. Energy loss is seen to be primarily near the e-beam diode. Localized, filamentary structures are seen leading from the POS region towards the e-beam diode at the azimuth of the radiation asymmetry.

In general the azimuth of the asymmetry appears random. An exception was early in the DECADE Assessment Program when it was observed that the radiation pattern asymmetry appeared to be systematically at azimuths in the upper half of the e-beam diode. Subsequently it was noted that the cable guns were not all uniformly worn or identically positioned. Replacement and realignment with new cable guns resulted in a noticeably increased azimuthal randomness as shown in Figure 7. The cable gun change may also have reduced the magnitude of the asymmetries, but did not eliminate them.

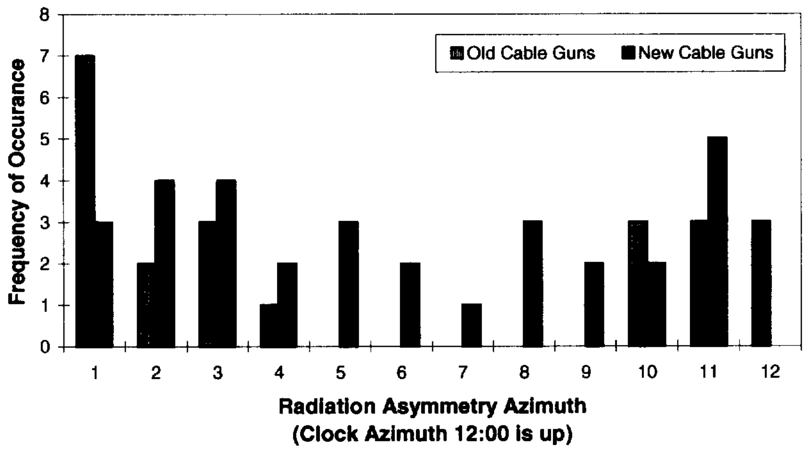
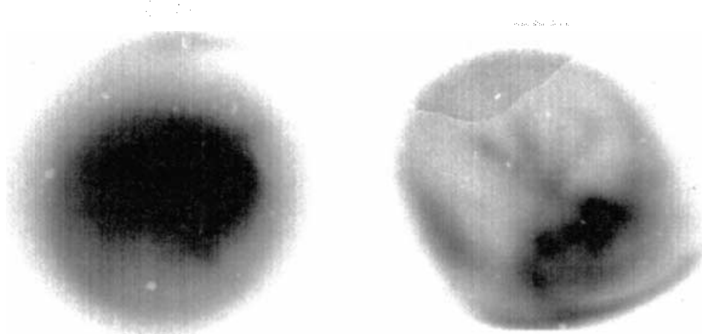


Figure 7. The effect of changing the POS plasma sources on DM1 radiation asymmetry.

T_c = 250 ns T_c = 261 ns



18 kRad DECADE Equivalent Dose   **10 kRad DECADE Equivalent Dose**

8a. Shot 2391   8b. Shot 2392

Figure 8. Reproducibility is observed to degrade for longer conduction time shots; (a) and (b) show the radiation pattern and dose for two "identical" DM1 shots.

Figure 8 shows an example of the lack of reproducibility in both radiation pattern asymmetry and produced radiation dose for long conduction time shots with identical initial shot settings. A similar trend is given by Figure 9 which shows the general trend of current loss near the diode with conduction time. Both the magnitude and the variability of current losses are seen to increase with conduction time. Figure 10 shows the correlation of radiation dose and current loss. The upper limit on the radiation dose falls with increased current loss, suggesting a strong correlation of limited dose with the observed current losses. The lower bound in the dose scatter includes effects due to other variables such as reduced conduction times and narrower radiation pulse widths.

SUMMARY AND CONCLUSIONS

The conduction time/current limitation on DM1 has been characterized and appears to be related to current asymmetries originating in the POS region. The azimuth of the radiation pattern asymmetry and current losses near the load can be identified with current asymmetries observed during the final phase of POS conduction. Cathode damage patterns and current probe signals suggest the transport of the asymmetry originating in the POS region to the load. This is evidence of a moving plasma column which could be introducing plasma in the load, thereby affecting diode operation. The observed asymmetries increase with conduction time and current resulting in both reduced and irreproducible dose at longer conduction times due primarily to current losses near the e-beam diode.

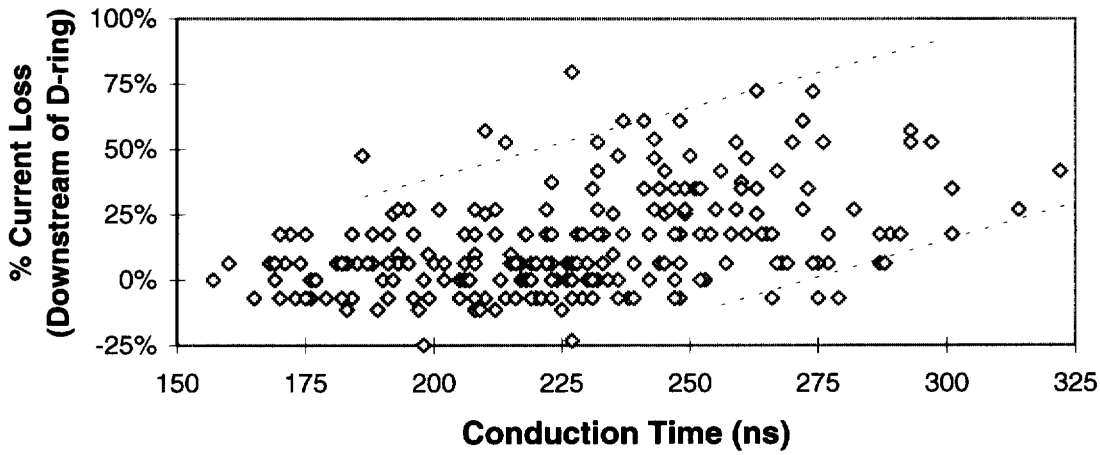


Figure 9. The statistical dependence of current losses near the load on the conduction time. Both the magnitude and the variability of the current losses are seen to increase with conduction time.

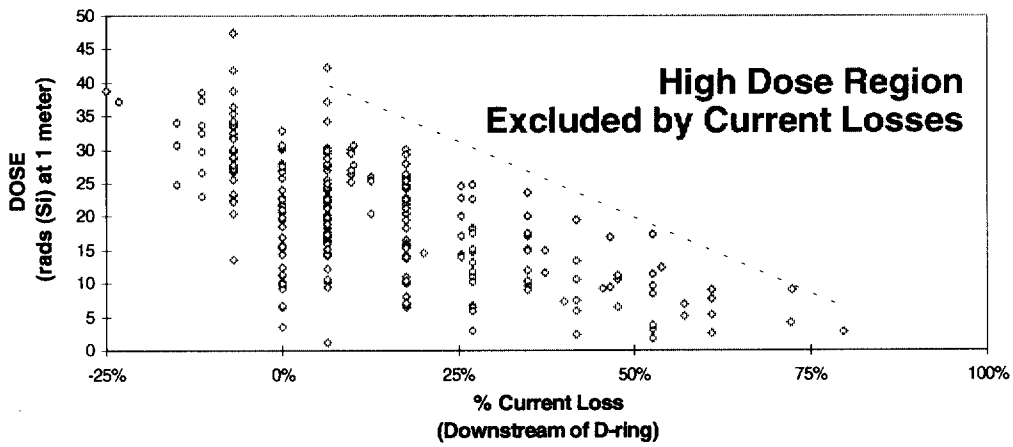


Figure 10. Correlation of radiation dose with current loss near diode.

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