ESD Measurements: A Case Study

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INTRODUCTION

A series of ESD measurements was performed in order to characterize a set of two ESD guns. Both guns were the products of one manufacturer and had been recently calibrated. The purpose of the study was to better understand the correlation possible between two testing sites and between targets with differing impedances as seen by the ESD gun. With the information gained from this series, a further set of measurements will be planned and performed that should give us greater detail and insight into ESD.

The inherent problem with ESD measurements is the speed and amplitude of the event. ESD discharges can be in the subnanosecond range. Because of this, there are few instruments that can capture the complete event. Previous attempts using an HP 1 GHz/sec sampling rate digital oscilloscope had shown that the sampling rate should be well above 1 GHz/sec in order to achieve at least a 500-MHz single-shot bandwidth. A LeCroy 9360 5 Gigasample/sec digital sampling oscilloscope was then obtained. This oscilloscope has a single-shot bandwidth of 600 MHz, with a resolution of 200 picoseconds. The LeCroy uses single-shot sampling, not repetitive sampling. This true, single-shot bandwidth of 600 MHz assures that the ESD event can be adequately characterized.

For the first set of measurements, two guns were compared, one from the HEDC test site and the other from the CTC test site. The guns, with and without a 10-foot extension cable, were compared. Comparisons were made of the gun discharge patterns into a coaxial calibration target with a bandwidth equal to 1 GHz, and through an automotive radio faceplate.

The type of discharge path affects the waveforms produced.

No essential difference was found between the two ESD guns when the discharge path was through a radio faceplate. However, when the discharge path was through the coaxial target, there was a significant difference between the guns when they were used with an extension cable. Close comparisons of the waveforms produced for the two discharge paths show that the faceplate attenuates some of the high frequency components of the ESD pulse, while most components pass through the coaxial target. In addition, the LeCroy scope allowed the observation of oscillations in the waveform after the initial discharge pulse. These post-discharge oscillations varied in amplitude and frequency from event to event. The CTC gun with extension was seen to have much higher secondary peaks than the HEDC gun. The HEDC gun, on the other hand, was seen to have a higher repetitive amplitude when discharging into the coaxial target. Comparison of the waveforms for the faceplate discharge showed conformity between the four configurations: HEDC with and without cable and CTC with and without cable.

A copper table is the workbench used for ESD testing. The variable attenuator is an HP with twelve 10-dB steps from 0 to 120 dB. The attenuator was measured through 500 MHz to determine if any frequency dependency existed. None was found and it was essentially flat to 500 MHz. Belden 9913 cable was used to connect the target to the attenuator. The copper plate on which the target was mounted was bonded to the copper table surface. The separation distance was determined empirically to be the minimum distance at which a single discharge occurred in a repeatable manner.

The faceplate ground was connected directly to the attenuator through a section of RG58. Again, the separation distance was determined empirically to be the minimum distance at which a single discharge occurred in a repeatable manner. Humidity in the room varied from 38 to 45%.

COAXIAL TARGET DISCHARGE

Figures 1,2,3 and 4 show the accumulated waveforms for 40 consecutive events triggered with the HEDC gun, with and without cable extension, and the ESD discharged into the coaxial target. Figures 1 and 3 show the initial discharge event and the subsequent secondary events. Figures 2 and 4 show the initial event. As these figures show, the ESD discharge is reasonably

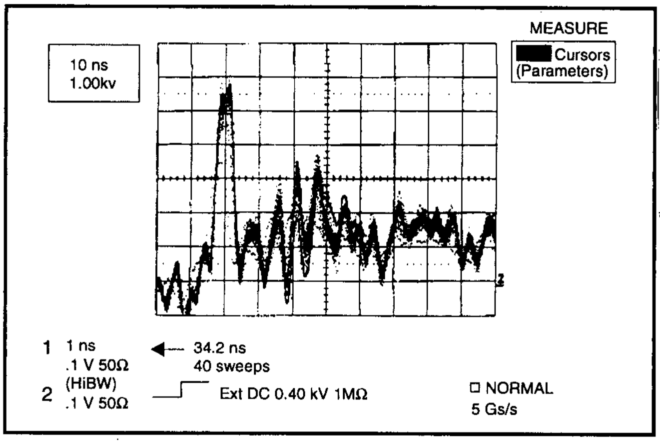

Figure 1. *HEDC without Cable Extension.*

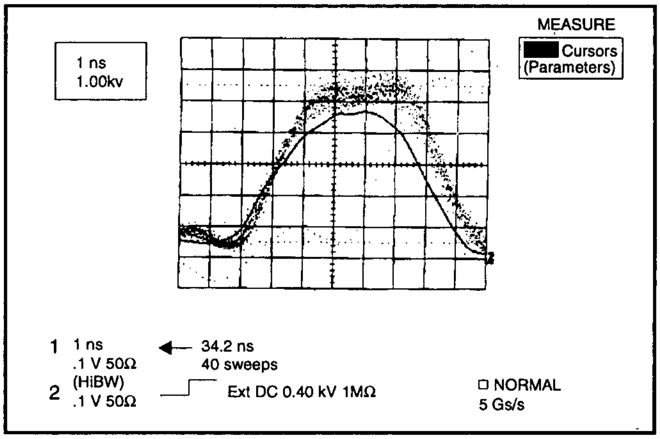

Figure 2. *Leading Edge of Event.*

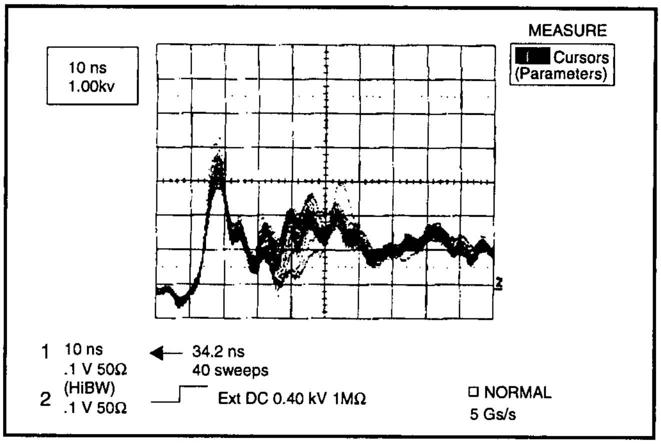

Figure 3. *HEDC with Cable Extension.*

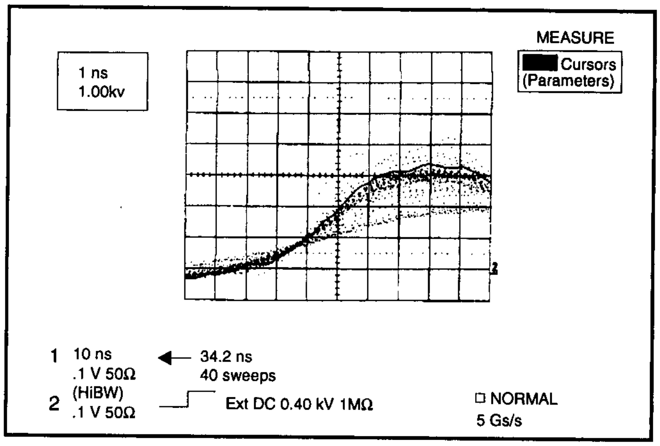

Figure 4. *Leading Edge with Extension.*

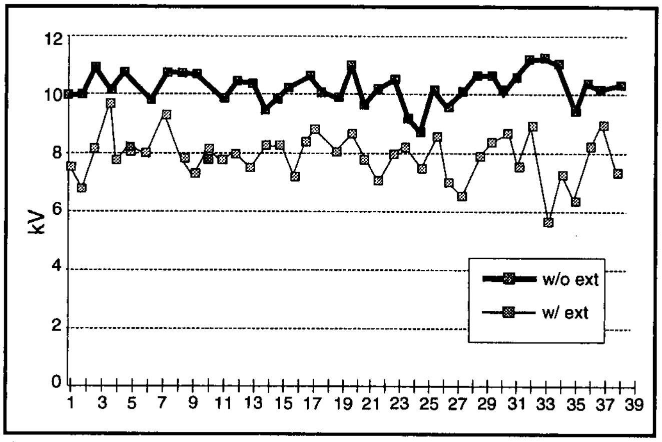

Figure 5. *HEDC Coaxial Target Amplitudes.*

	Variable 1	Variable 2	Variable 2
Mean	4.8545	3.7815	6.74675
Variance	0.118559	0.152557	0.334376
Observations	40	40	40
df	39	39	39
F	1.28676		
P(F<=f)one-tail	0.217339		
F Critical one-tail	1.51365		

Table 1. *Two-Sample F-Test for Variances.*

repeatable. The trigger level to the scope was held constant at 0.40 kV. The attenuator was set to 10 dB of attenuation. As Figure 3 shows, there are secondary high frequency components present, but they are reduced compared to those without the extension cable, as seen in Figure 1.

Figure 5 shows a comparison of the HEDC gun with and without cable extension. The gun readout was set to 10 kV. The coaxial target was determined to have a 70:1 attenuation ratio. Figure 5 shows the measured amplitudes in sequential order; Figures 6 and 7 show the distribution of the amplitudes.

A comparison of the two amplitude distributions revealed that the discharge pattern with the extension has an overall lower amplitude. However, when an F-test was run for significance, no significant difference was found (Table 1).

When the rise times of the event were compared, it was noted that the extension cable degrades the discharge time. Figure 8 shows a comparison.

The average discharge time for the gun without the cable extension is 2.9 nanoseconds, while the time for the gun with the cable is 4.0 nanoseconds. The manufacturer's data for calibration show dis-

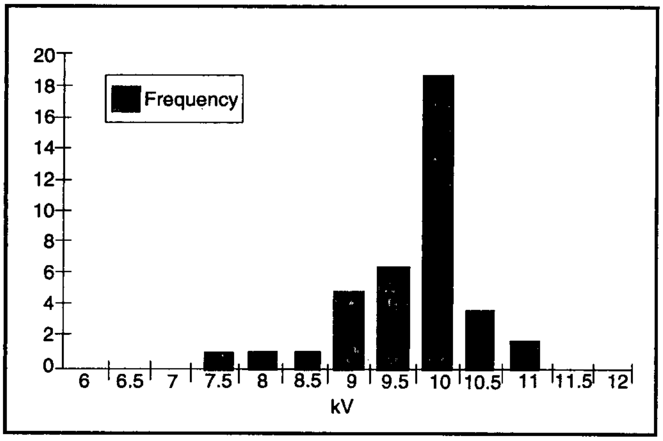

Figure 6. *HEDC Coaxial Target Amplitudes without Cable Extension.*

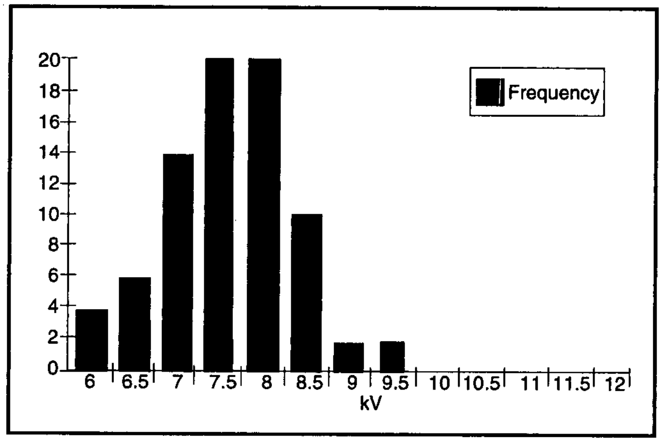

Figure 7. *HEDC Coaxial Target Amplitudes with Extension.*

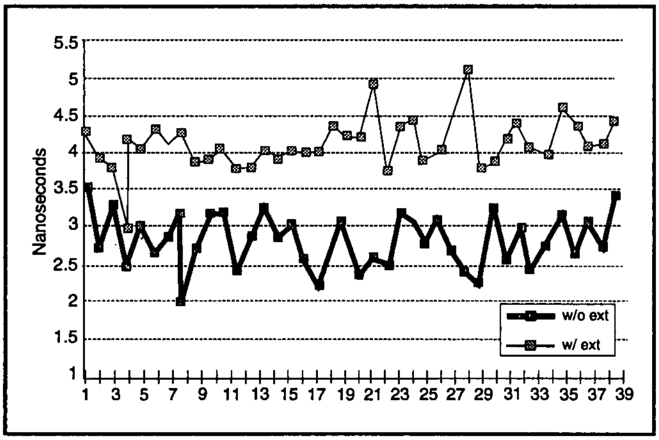

Figure 8. *HEDC Coaxial Target Rise Times.*

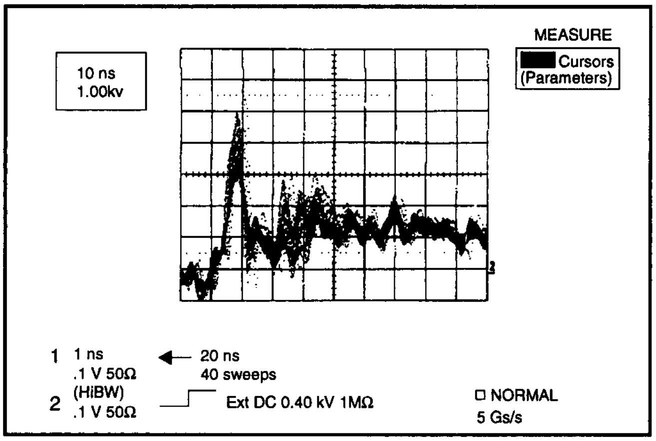

Figure 9. *CTC Gun without Cable Extension.*

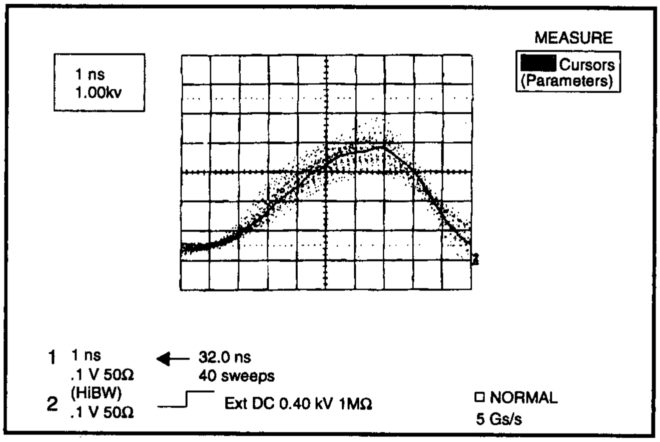

Figure 10. *CTC Gun without Cable Extension.*

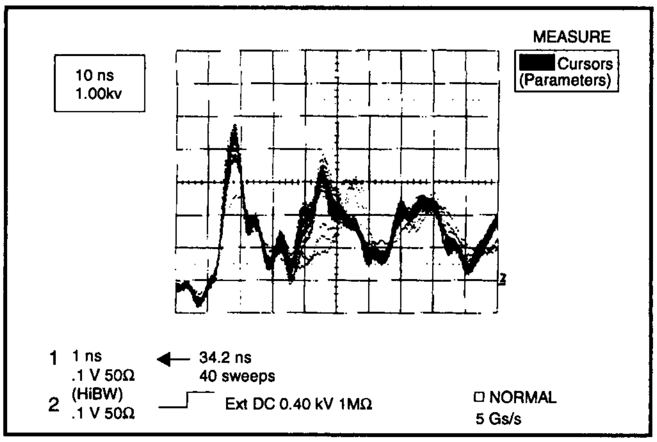

Figure 11. *CTC Gun with Cable Extension.*

charge times under 1 nanosecond. However, the discharge amplitude was 2 kV.

A comparison of the waveforms for the guns with and without the cable extension shows that the HEDC gun without the extension had a higher overall average amplitude and higher secondary peaks. Figures 9, 10, 11 and 12 show the waveforms for the CTC gun. A quick comparison shows that the CTC gun with the cable extension has significantly higher secondary peaks. Figure 13 shows a comparison of the amplitudes with and without the cable extension.

Figures 14 and 15 show the distributions. Note that the discharge amplitude is greater for the gun with the extension. Figure 16 shows a comparison of the rise times. There is not as much difference between the two configurations as there was for the HEDC gun. Figure 17 shows a comparison between

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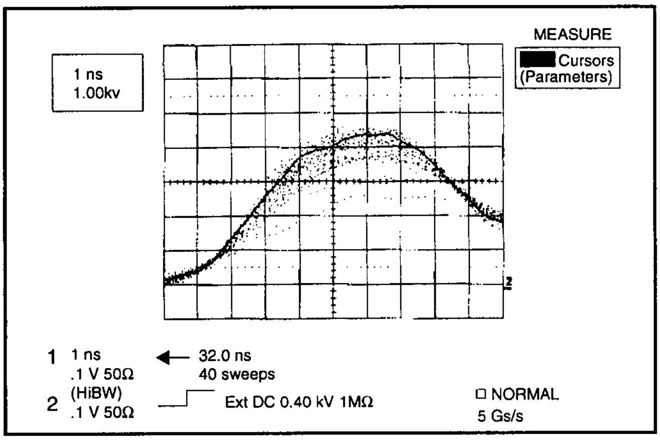

***Figure 12**. CTC Gun with Cable Extension.*

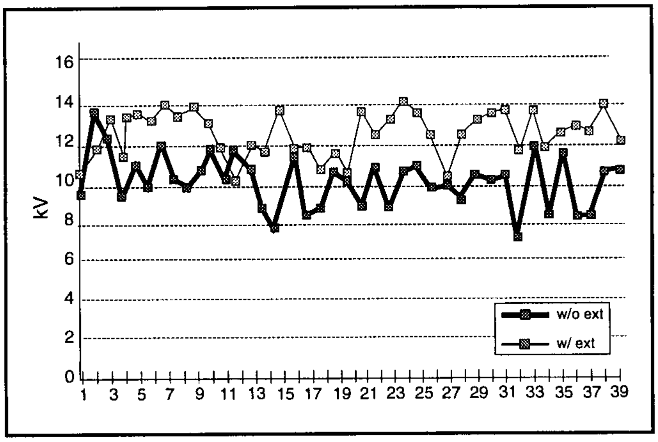

***Figure 13**. CTC Coaxial Target Amplitudes.*

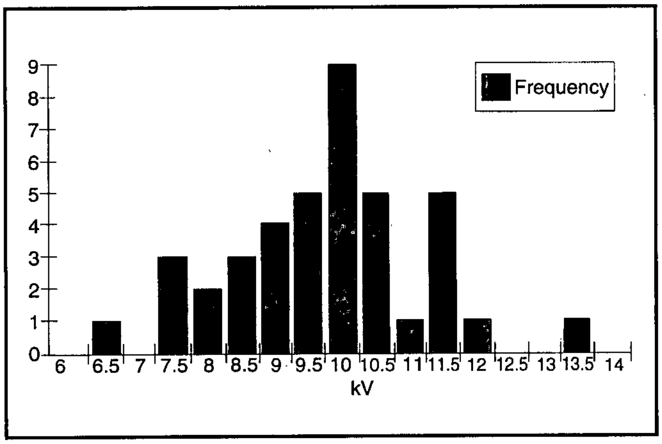

***Figure 14**. CTC Coaxial Target Amplitudes without Cable Extension.*

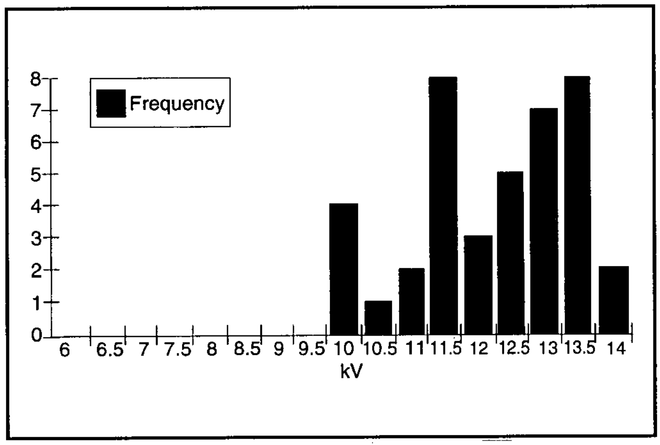

***Figure 15**. CTC Coaxial Target Amplitudes with Cable Extension.*

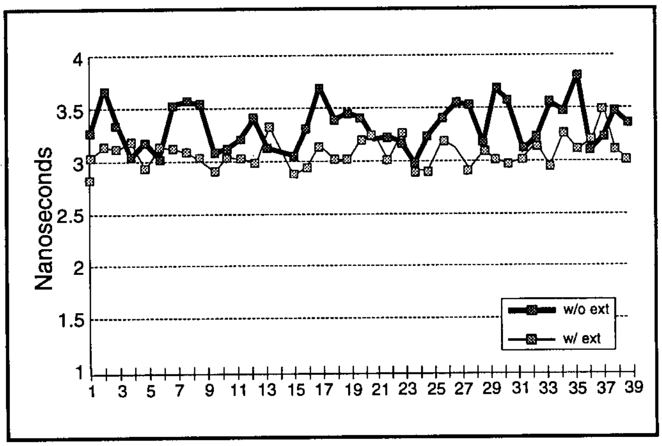

***Figure 16**. CTC Coaxial Target Rise Times.*

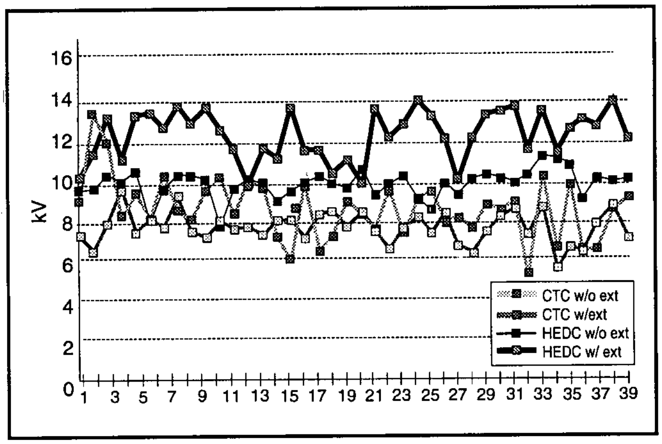

***Figure 17**. CTC/HEDC Amplitude Comparisons - Coaxial Target.*

the CTC and HEDC gun in the four configurations. If the data are removed for the two events without the cable extension, Figure 18 results.

The average for the CTC gun was 12.5 kV and the average for the HEDC gun was 7.8 kV, clearly a significant difference. Note also that the CTC gun varies more than the HEDC. The question that arises is, what caused the difference? Is it the gun itself, the power supply, the attachments or the cable? An ancillary question is whether further differences would be seen if a third gun were measured.

RADIO FACEPLATE DISCHARGE

For faceplate discharge, the gun read-out was set to 15 kV. The attenuator was set to 60 dB because the faceplate transfer was lower than the coaxial target. The scope trigger level was set to 2.0 kV.

Figures 19, 20, 21 and 22 show the discharge waveforms for the HEDC gun with and without the

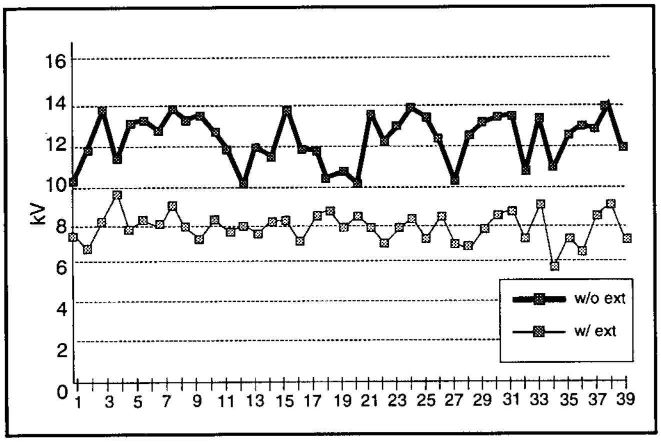

Figure 18. *CTC/HEDC Amplitude Comparisons - Coaxial Target.*

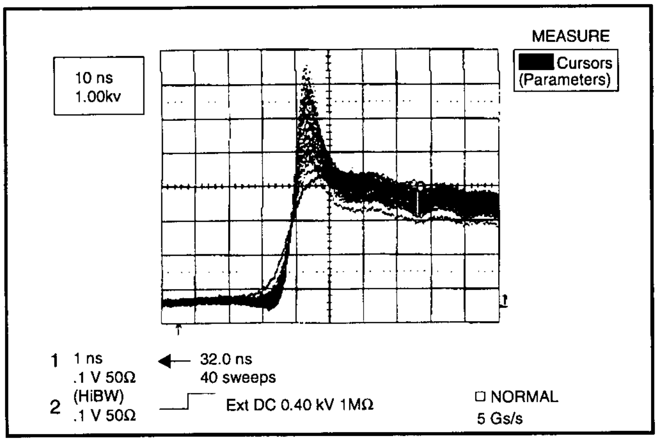

Figure 19. *HEDC Gun without Cable Discharge Waveforms.*

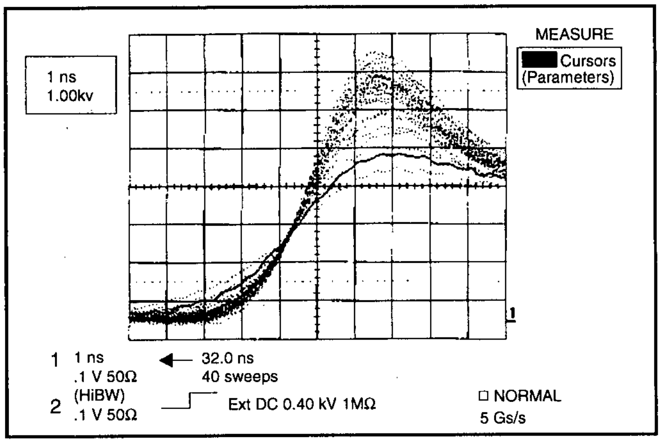

Figure 20. *HEDC Gun without Cable Extension.*

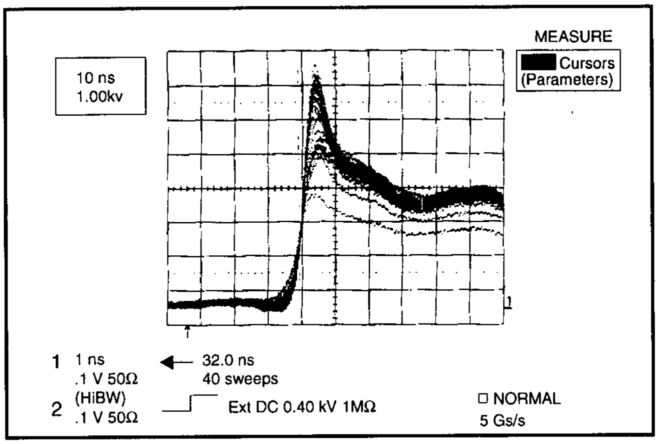

Figure 21. *HEDC Gun with Cable Discharge Waveforms Extension.*

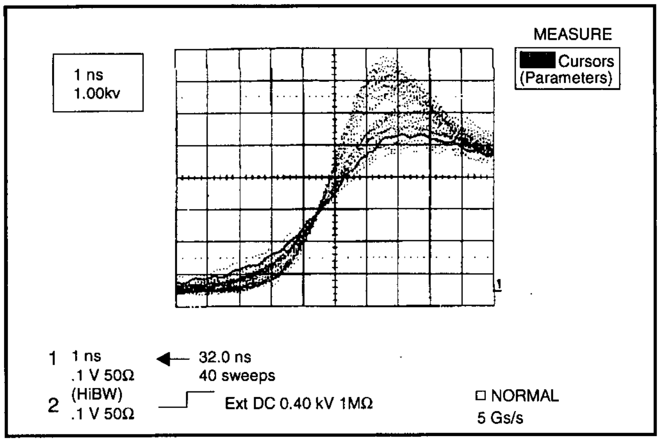

Figure 22. *HEDC Gun Discharge Waveforms with Cable Extension.*

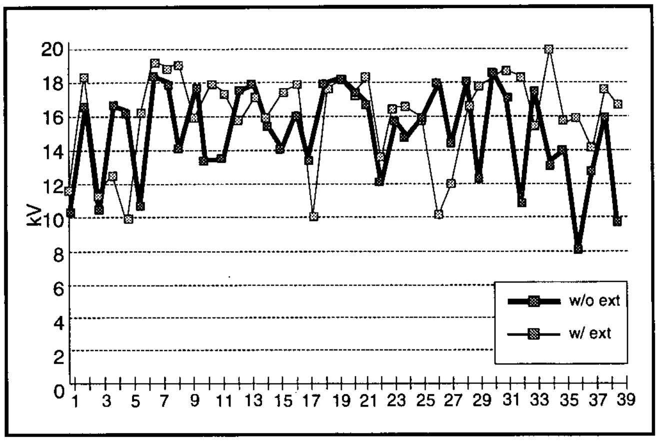

Figure 23. *HEDC Faceplate Discharge Amplitudes.*

extension into the radio faceplate. Comparisons of these discharge waveforms with those of the coaxial target show a marked difference. When the discharge path is through the faceplate, it would appear that the higher frequency components are attenuated. None of the secondary peaks that were so evident with discharge through the coaxial target are seen. Also, the variations from the guns with the cable extensions to those without the extensions are unlike those noted when the discharge path is through the coaxial target.

Figure 23 is a comparison of the amplitudes. Comparisons with the distributions for the coaxial target show that the discharge amplitudes through the faceplate are not as Gaussian as they were for the coaxial target.

Figure 24 shows the rise times. It can be seen that the rise times are significantly the same.

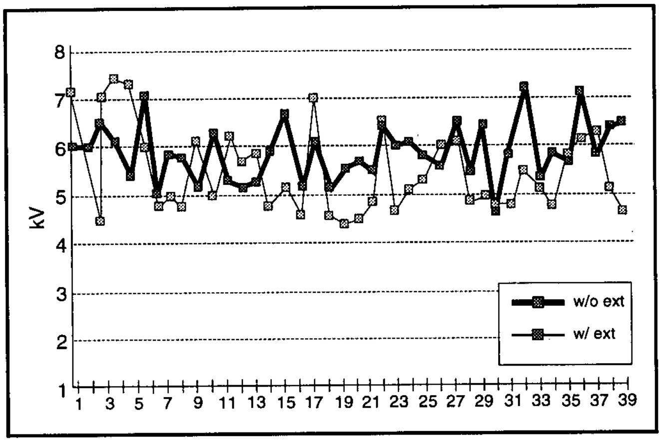

Figure 24. *HEDC Faceplate Discharge Rise Times.*

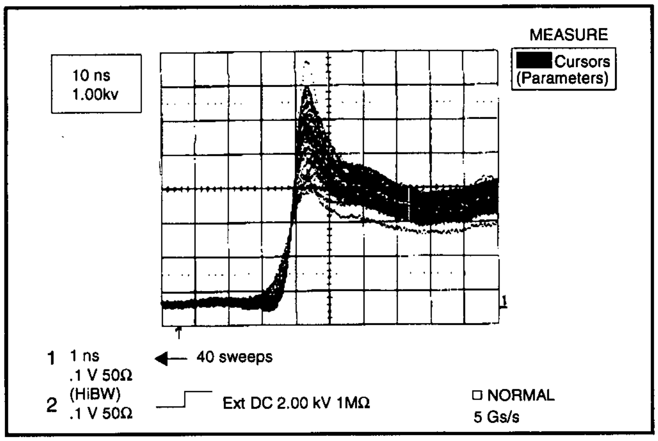

Figure 25. *CTC Gun Waveforms without Extension.*

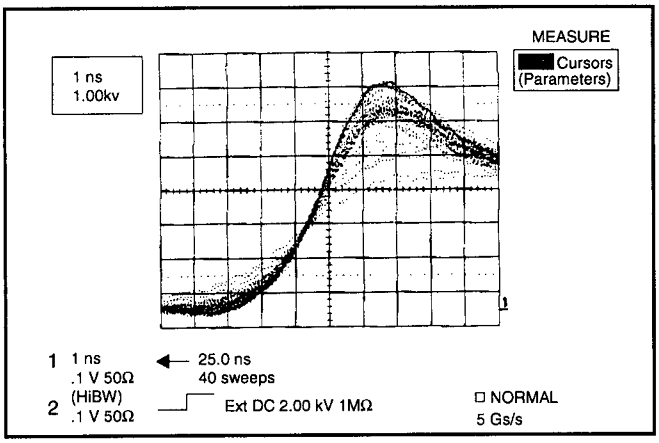

Figure 26. *CTC Gun Waveforms without Extension.*

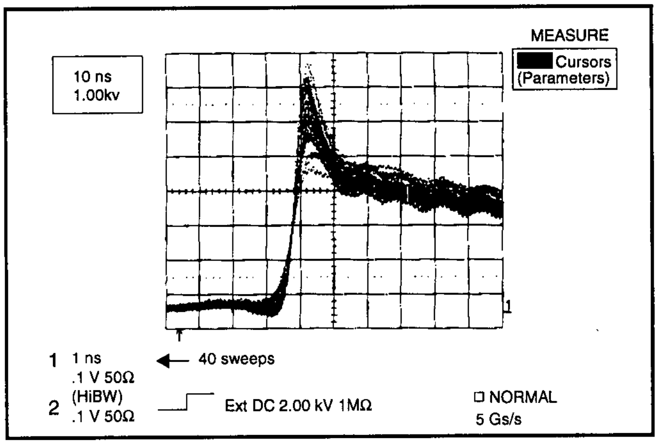

Figure 27. *CTC Gun Waveforms with Extension.*

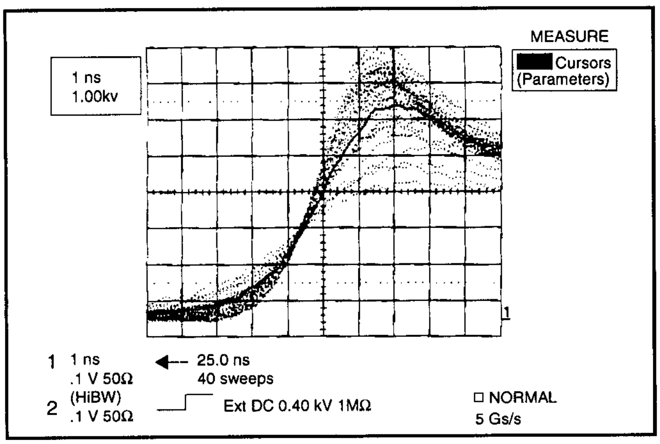

Figure 28. *CTC Gun Waveforms with Extension.*

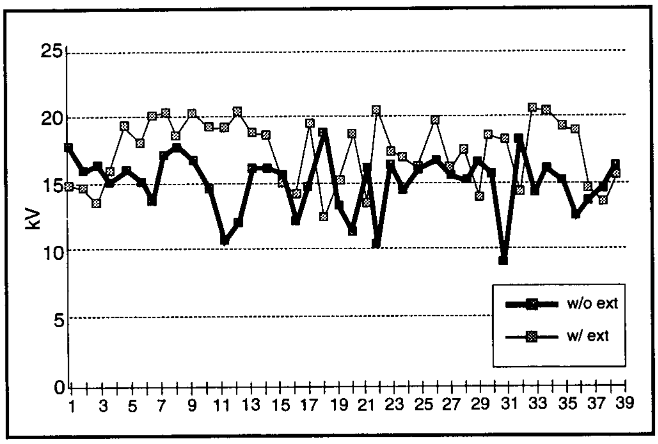

Figure 29. *CTC Gun Radio Faceplate Discharge Amplitudes.*

Figures 25, 26, 27 and 28 show the waveforms for the CTC gun. Again, comparison with the HEDC gun shows a marked similarity.

Figure 29 shows a comparison of the amplitudes for the case with an extension and without an extension. Good correlation can be seen with the HEDC gun.

Figure 30 shows the rise times. Figure 31 shows a comparison between the two guns for the single case with an extension cable. The two guns are in reasonable agreement, although the HEDC gun appears to have greater variation in extremes.

SUMMARY

These initial ESD measurements have shown that the type of discharge path has an effect upon the waveforms produced. Depending upon the discharge path, some higher frequency components of the ESD event may or may not be attenuated. The rise times of the events, as well as the ampli-

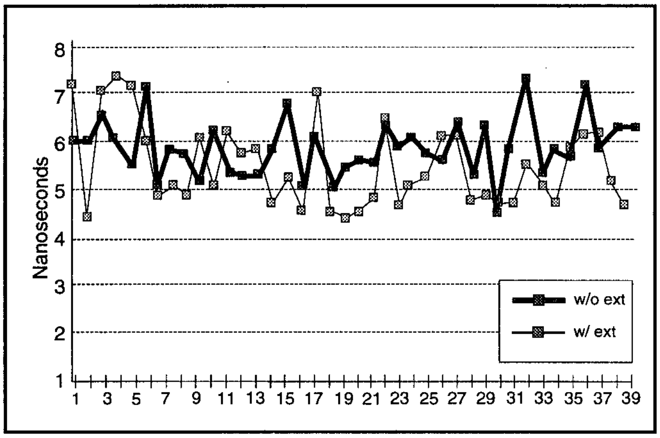

***Figure 30**. CTC Faceplate Discharge Rise Times.*

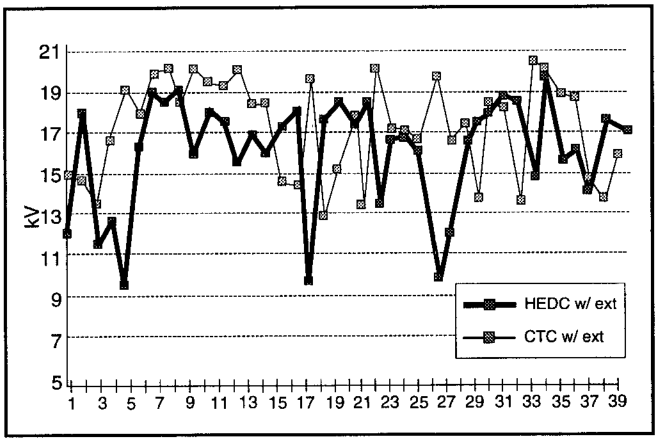

***Figure 31**. CTC/HEDC Amplitude Comparison - Faceplate Discharge.*

tudes, differ markedly. Comparison of the waveforms shows significant variations from event to event. We have also seen a difference between two guns, with and without extension cable, for the calibration target. This leads to questions concerning repeatability between testing sites. Indeed, it leads to questions concerning guns and their fixtures and their own inherent repeatability. In order to more fully ascertain the problem, another gun should be examined to obtain a third data point. Two data points (the two guns investigated here) do not fully reveal what the problems are or may be. A deeper understanding of the gun fixtures is required. In addition, differing types of discharge paths will have to be investigated. The scope has given us a fascinating window into the ESD event, allowing us to see details that we have not previously seen.

KEVIN SLATTERY *currently works in the field of automotive electronics as a consultant. He performs basic research into new methodologies; tests and measures products in development; and prepares seminar materials for presentation to various audiences of automotive engineers. Previously, Mr. Slattery worked for CKC Labs. Prior to that, he spent 14 years developing high-speed timing systems and particle beam transport systems at the Stanford Linear Accelerator Center in California. (205) 464-2864.*