1982

IEEE International Symposium

on

Electromagnetic Compatibility

September 8—10, 1982

Radiating Technology from Silicon Valley

Library of Congress Catalog
No. 81-86699

IEEE Catalog
82CH1718-6

PERSONNEL ELECTROSTATIC DISCHARGE: IMPULSE WAVEFORMS RESULTING FROM ESD OF HUMANS THROUGH METALLIC-MOBILE FURNISHINGS INTERVENING IN THE DISCHARGE PATH

W. Michael King
Electromagnetic Compatibility Advisor
Costa Mesa, California 92626
(714) 545-2519

David Reynolds
Electromagnetic Compatibility Engineer
Digital Equipment Corporation
301 Rockrimmon Blvd. South
Colorado Springs, Colorado 80919

Abstract

This study represents an extension of an effort that was originated by King and Reynolds in 1980, and presented to the 1981 IEEE EMC Symposium (1) held at Boulder, CO. In the 1981 presentation, ESD impulse waveforms were reported as measured from two conditions: Human-direct; and, human through small hand-held metallic objects that were intervening in the discharge path. Using a compatible measurement approach, this effort expands the study to be inclusive of metallic-mobile furnishings found typically in the office and/or data processing environment, such as desk chairs and push-carts. Cursory sample measurements were additionally taken to illustrate impulse waveform variability at selected amplitudes, describing different effects due to different Electrostatic Discharge locations on the surfaces of a desk chair. Other sample measurements provide indication of other impulse results if the desk chair were to be replaced by a stool-type "lab chair". As in the previous publication, the conceptual goal of this effort was to develop information derived from actual ESD events that would facilitate the design of an ESD test generator which could produce impulse waveforms in reasonable but realistic simulation of actual ESD events for these ESD "furnishings" event conditions.

Retrospective Overview

As reported in the 1981 publication, the impulse characteristics of ESD dynamically varied as the initializing (charge) amplitude was varied. The dramatic alterations encountered in the waveshapes as the initializing level was incrementally increased confirmed the hypothesis that waveform measurements derived from incrementally varied amplitudes were required to fully characterize the ESD event continuum. Generally, it was found that the impulse waveforms derived from lower-level initial amplitudes exhibited ultra-fast risetimes between 200 picoseconds (the limit of the measurement capability) and 500 picoseconds, while the impulse waveforms derived from higher static levels exhibited risetimes in the approximate range between one nanosecond and several tens of nanoseconds. The waveform components providing the ultra-fast risetimes were also found to be confined to exceptionally small pulse widths, typically in the area of a few hundred picoseconds, developing intense currents between the general range of a few tens of Amperes to over 100 Amperes. The more-conventional ionization-based impulses developing risetimes of one nanosecond (or more) exhibited peak currents up to a few tens of Amperes with base widths up to approximately 500 nanoseconds, although typical values were usually less than 200 nanoseconds. The development of multiple impulses within the framework of what was considered a 'single' ESD event was investigated in the previous effort, as was the duty cycle (or, periodicity) among events within the time envelope of 'one' event. Although the suggestion that ESD events were encountered with risetimes as fast as 200 picoseconds was recognized as unconventional (if not controversial) by the authors at the time of publication, another presentation by Carruth, et al, (2) at the same symposium hypothesized that dielectric discharges may exhibit risetimes faster than 100 picoseconds, based on statements made by Leung, the presentor. Given the background of the study effort provided above, measurements were taken on the ESD dynamic characteristics of impulses developed from human interaction with mobile-metallic furnishings, based on the measurement techniques previously used, and with the ESD initializing amplitude incrementally ascending to determine the impulse waveform alterations attendant to the amplitudes.

Measurement Approach

As in the previous study, the conceptual measurement goal was to determine the ESD waveforms and waveform characteristics for the 'source' ESD events in as low an impedance measurement system as was considered practical. The foundation for this approach is that if the 'source' characteristics were known, and adequately simulated in an identical measurement-evaluation condition, then an eventual 'system-in-test' would respond to the simulated impulses in an equal manner compared against the 'actual' ESD occurrence (through furnishings).

Reference is made to the 1981 publication (1) for the details of the development of the measurement system and approach, to enhance brevity here, although the following is provided to aid understanding of this effort. The essential components of the measurement method consisted of: a) A discharge 'load', of known impedance characertistics; b) An exceptionally wide bandwidth oscilloscope system; and, c) A reference plane arrangement to 'capture' the distributive impedances from the human and furnishing under evaluation. The impedance characteristic of the 'load' was designed to partially compensate for higher frequency roll-off in the oscilloscope system, resulting in an enhanced-bandwidth measuring system.

Measurement 'Discharge' Load:

The discharge 'load' consisted of a circular array of nine, 1.8 Ohm carbon-composition resistors, providing an initial impedance of 0.2 Ohms. The array was matched to the 50 Ohm input of the oscilloscope, through which a coupling loss of 6dB was experienced. With the 6dB loss, the load yielded an equivalent response of 1.0 Ampere per 0.1 Volt indicated on the oscilloscope. An insertion loss profile of the load indicated a 'flat' response within 4dB from 0 - 1.0GHz, elevating in impedance by approximately 8dB between 1.0GHz and 1.5GHz. This impedance increase compensated for the 'scope roll-off, approximately. Figure A-1 of Appendix I illustrates the insertion loss profile of the load.

Oscilloscope System:

The Oscilloscope System consisted of a Tektronix 7104 main frame with a Type 7A29 Vertical Amplifier and a Type 7B15 (or Type 7B10) Time Base. The system provided an instantaneous analogue bandwidth of 1.0GHz, a write speed of 200 picoseconds in the amplitude ranges used, with the bandwidth rolling-off by 8dB at 1.5GHz. The amplitude response of the oscilloscope actually used for this effort is provided by Figure A-2 of Appendix I. The frequency response deviation curve for the measurement system as utilized may be gained by combining the load response curve and the response curve of the oscilloscope system, as provided in the Appendix. The approximate net system response deviation is provided By Figure 1.

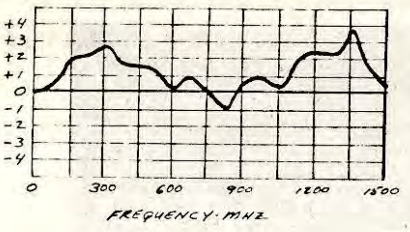


Figure 1. Approximate Net Response Deviation of Measurement System.

Measurement Planes & General Arrangement:

Figure A-3 of the Appendix illustrates the general arrangement of the measurement approach. Although initial measurement efforts were attempted utilizing the reference measurement planes described in the 1981 publication, susceptibility problems with the oscilloscope system were encountered due to radiated impulse fields from the furnishings/human under evaluation. In order to circumvent these susceptibility effects, the test arrangement was re-built, incorporating the use of a standard metal-cell shielded enclosure. The walls and floor of this shielded enclosure then substantially formed the actual reference planes needed in the test arrangement. The coaxial cable (RG 223/u) between the ESD 'load' and the oscilloscope was terminated to a bulkhead connector mounted in the shielded enclosure wall (to terminate the coaxial shield to the wall). The outside portion of the bulkhead connector was terminated to the oscilloscope system through (RG 223/u) coaxial cable. The segment of the coaxial cable within the shielded enclosure was 'over-shielded' with a tinned-copper braid, in an attempt to minimize stray field coupling into the coaxial cable. The incorporation of the metal-cell shielded enclosure into the test arrangement, resolved the susceptibility problems with the oscilloscope.

D.C. Power Supply

A D.C. Power Supply was utilized to 'charge' the human-furnishing under evaluation to the desired initializing level. The accuracy of the supply was ±10%. The supply provided an output impedance of approximately 200 megohms, to minimize shock hazard to test personnel. As a further precaution, test personnel were equipped with rubber-soled shoes. The rubber-soled shoes also minimized the dissipation of the initialized 'charge' prior to executing the desired impulse. Cursory checks were performed to assure that no significant reduction in the charge level occurred between the time points of disconnecting the D.C. Supply and actually applying the ESD to the measurement load.

Measurement Environment

All measurements were performed under the environment of 40% relative humidity and 70° F. These values were held within a tolerance of 5% (envelope).

Discharge Motion & Velocity:

The human/furnishing under measurement evaluation was charged to the desired D.C. (static) level. The human then 'pushed' the furnishing into the ESD 'load' to cause the impulse to occur. Every attempt was made to have the motion and velocity of the furnishing develop as would be anticipated in an actual office environment, including variabilities.

Multiple Impulses and Periodicity:

Although multiple ESD impulses are known to be developed under these 'furnishings' conditions in the manner reported in the 1981 publication, available time did not permit sequence and periodicity measurements during this investigation. Accordingly, all measurements noted here are based on the primary 'first-pulse' event which was guaranteed during the measurement process by adjusting the oscilloscope system to the 'single-trace' mode, which inhibits trace triggers of follow-on impulses. Reference is made to the 1981 publication for a description of the multiple-impulse phenomenon.

Incremental Initialization Amplitude Approach

As previously described, a full characterization of the ESD event continuum requires (based on empirical data) incrementing the initialization (charge) level in steps previously found necessary to describe the impulse alterations that occur attendant to the changes in level. The measurement results provided in this study were taken in increment levels found to be appropriate for the specific measurment conditions of the human/furnishing interaction.

Measured Furnishings & Data Organization:

The impulse results provided in this effort are based primarily on personnel ESD events with humans in conjunction with two furnishings: a) An arm-rest equipped desk chair; and b) A lab-type, two-tier push cart. Cursory 'sample' measurements were additionally taken at a few test levels on a lab (stool) chair. The following describes the furnishings and human interface to the furnishings.

Desk Chair: A general description of the desk chair is provided by Figure A-4 of the Appendix. The tests were performed with a human seated in the desk chair, and holding the metal framework of the two arm-rest members, one in each hand. The position, grasp, and motion causing the ESD event was intended to simulate that of a person being seated in the chair, then adjusting the position of the human/chair combination at a desk, or, in front of a data terminal. Conceptually, as this adjustment was being executed, the ESD would occur from the outside end of a radial frame member of the base of the desk chair. Cursory 'sample' measurements were also taken at selected levels with the ESD event struck from the arm-rest frame of the chair, for purposes of comparison.

Push-Cart: A general description of the push-cart is provided by Figure A-5 of the Appendix. The person held the handlebar at the end of the cart with two-hand contact, in a standing position. The opposite end of the cart was then impacted into the ESD 'load' to cause the impulse occurrence. The intent of this motion was to simulate the inadvertent contact of the cart into a product as the result of forward movement.

Lab Chair: A general description of the lab chair is provided by Figure A-6 of the Appendix. The person that was moving the chair held the cushion only, and did not make electrical contact to the frame members. The ESD was struck to the measurement load only from the 'leg' immediately above the caster. These tests were performed for comparative purposes only.

Data Organization:

The data presentation that follows is organized by the ascending sequence of the initialization levels. At each level, all measurement results are provided to aid in comparisons among the furnishing conditions.

Impulse Waveform Components: Within the data organization, every attempt was made to photographically display all waveforms and waveform components found significant during the study. Each photograph is of a different ESD event however, indicating that the levels of each component may not precisely match to an adjacent display.

Incremental Level Measurements
Personnel ESD Through Mobile Furnishings

In reviewing all data to follow, it should be noted that external coaxial attenuators were occasionally utilized in the test arrangement, changing the actual scale that is otherwise annotated by the oscilloscope legends.

500 Volts Initialization Level

Condition 1 - Human Seated in Desk Chair, ESD from Chair Base.

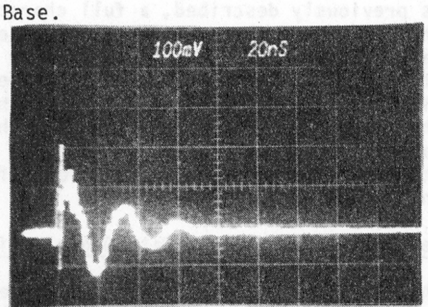


Figure 2
Vert: 10 Amp/Div.
Time: 20 nSec/Div.

Displayed:
Ip: 42 Amps Spike
20 Amps Surge

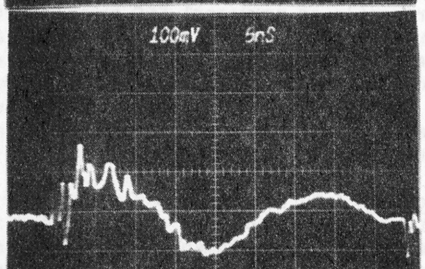


Figure 3
Vert: 10 Amp/Div.
Time: 5 nSec/Div.

Displayed:
Ip: 35 Amps Spike
19 Amps Surge

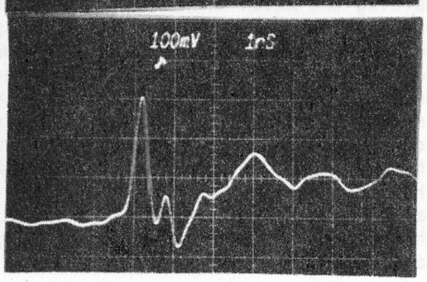


Figure 4
Vert: 10 Amps/Div.
Time: 1 nSec/Div.

Displayed:
Ip: 32 Amps Spike
Tr: 300 pSec
Width: 450 pSec
Approx.

Condition 2 - Human Seated In Desk Chair, ESD From Arm Rest Frame

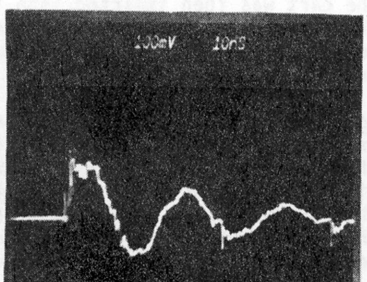


Figure 5
Vert: 10 Amp/Div.
Time: 10 nSec/Div.

Displayed:
Ip: 44 Amp Spike
18 Amp Surge

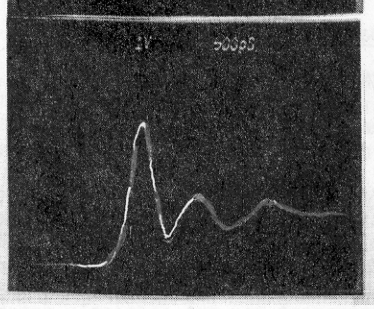


Figure 6
Vert: 10 Amps/Div.
Time: 500 pSec/Div

Displayed:
Ip: 41 Amp Spike
Tr: 400 pSec

Condition 3 - Human Moving Push Cart

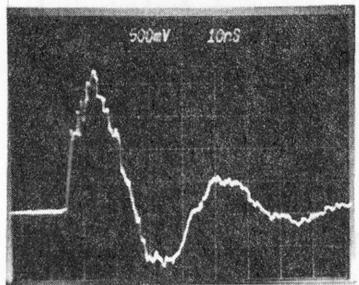


Figure 7
Vert: 5 Amps/Div.
Time: 10 nSec/Div.

Displayed:
Ip: 14 Amps Spike
22 Amps Surge

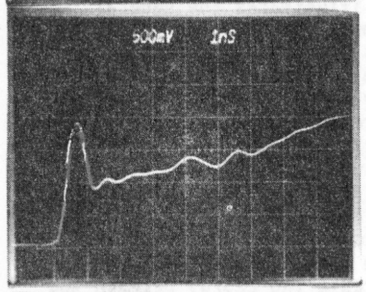


Figure 8
Vert: 5 Amps/Div.
Time: 1 nSec/Div.

Displayed:
Ip: 19 Amps Spike
21 Amps Surge

Tr: 450 pSec

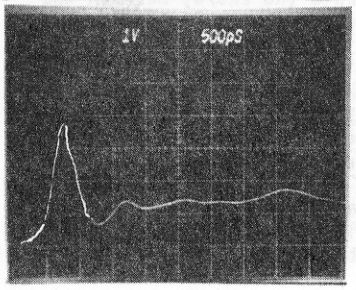


Figure 9
Vert: 10 Amps/Div.
Time: 500 pSec/Div.

Displayed:
Ip: 37 Amps spike
17 Amps Surge

Tr: 400 pSec.

From the 500 Volt level results above, all furnishings tend to exhibit an early component (spike) current of approximately 30 to 40 Amps, and a first-cycle surge of between 18 and 22 Amps. The early-component risetime indications typically fall between 300 and 500 pico-Seconds. The first-cycle surge widths appear to fall between 10 nanoseconds and 20 nanoseconds.

1,000 Volts Initialization Level

Condition 1 - Human Seated in Desk Chair, ESD From Chair Base

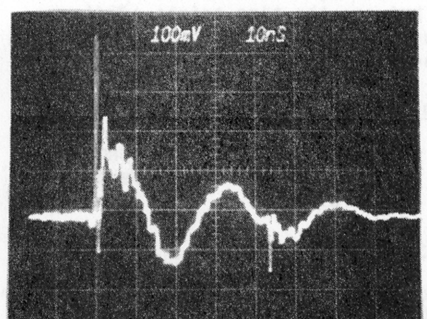


Figure 10
Vert: 10 Amps/Div.
Time: 10 nSec/Div.

Displayed:
Ip: 45 Amps Spike
25 Amps Surge

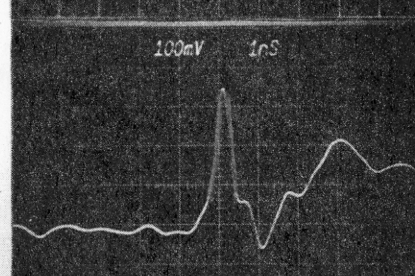


Figure 11
Vert: 10 Amps/Div.
Time: 1 nSec/Div.

Displayed:
Ip: 36 Amps Spike

Tr: 450 pSec

(1,000 Volts, Continued)

Condition 3 - Human Moving Push Cart (Condition 2 Not Evaluated)

Figure 12
Vert: 10 Amps/Div.
Time: 10 nSec/Div.

Displayed:
Ip: 55 Amp Spike
35 Amp Surge

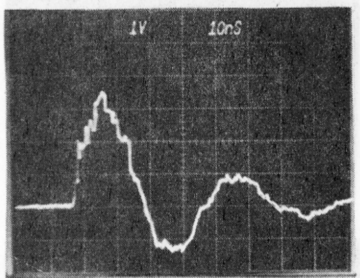


Figure 13
Vert: 10 Amps/Div.
Time: 10 nSec/Div.

Displayed:
Ip: 33 Amp Spike
32 Amp Surge

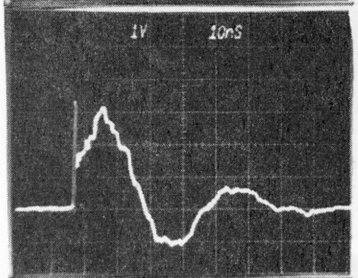
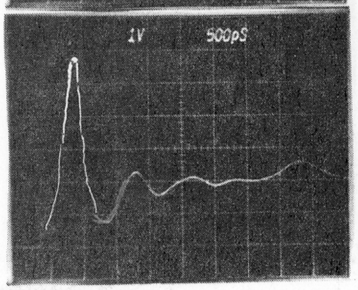


Figure 14
Vert: 10 Amps/Div.
Time: 500 pSec/Div.

Displayed:
Ip: 58 Amps Spike

Tr: 350 pSec.



2,500 Volts Initialization Level

Condition 1 - Human Seated In Desk Chair, ESD From Chair Base

Figure 15
Vert: 10 Amps/Div.
Time: 20 nSec/Div.

Displayed:
Ip: 40 Amp Spike
32 Amp Surge

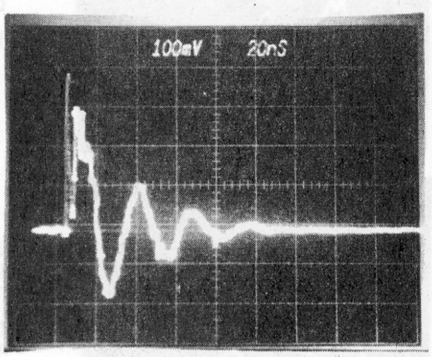
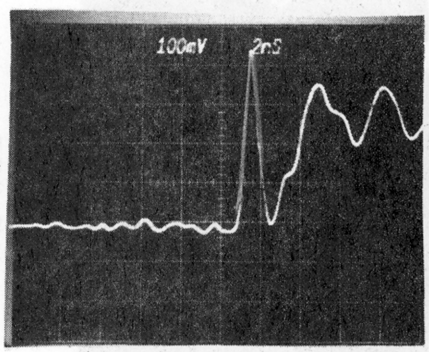


Figure 16
Vert: 10 Amps/Div.
Time: 2 nSec/Div.

Displayed:
Ip: 45 Amps Spike



(2,500 Volts, Continued)

Condition 2 - Human Seated In Desk Chair, ESD From Arm Rest Frame

Figure 17
Vert: 10 Amps/Div.
Time: 10 nSec/Div.

Displayed:
Ip: 42 Amps Spike
42 Amps Surge

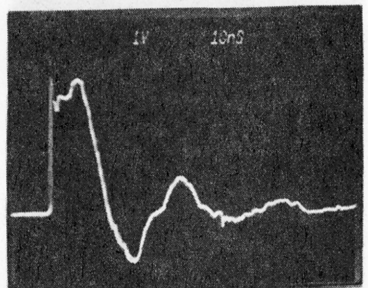
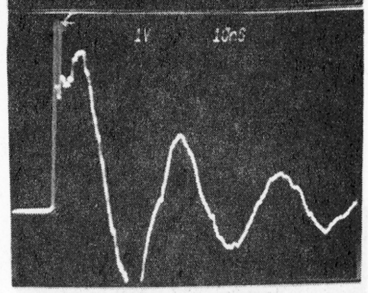


Figure 18
Vert: 10 Amps/Div.
Time: 10 nSec/Div.

Displayed:
Ip: 58 Amps Spike
50 Amps Surge



Condition 2A - Sample Test - ESD From Lab Chair Leg

Figure 19
Vert: 10 Amps/Div.
Time: 20 nSec/Div

Displayed:
Ip: 50 Amp Spike
(Contrast poor)
37 Amp Surge

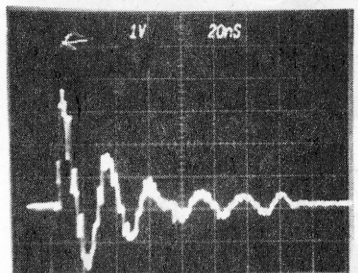
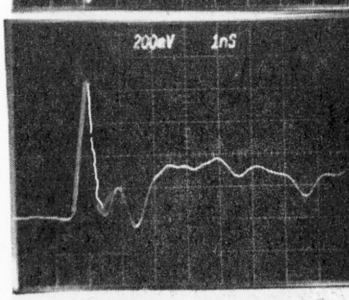


Figure 20
Vert: 20 Amps/Div.
Time: 1 nSec/Div.

Displayed:
Ip: 84 Amps Spike

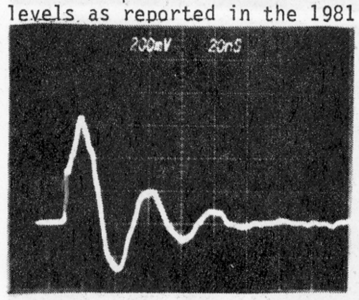


Condition 3 - Human Moving Push Cart

Note: The following impulse sequence illustrates the transistion between high level 'early' components, termed 'spikes', and the predominance of ionization-based 'surges'. The 2,500 Volt initialization level appears to represent this transistion point for the furnishings derived impulses. Personnel exhibited other transistion levels as reported in the 1981 publication.

Figure 21
Vert: 20 Amps/Div.
Time: 20 nSec/Div.

Displayed:
Ip: 64 Amps
Note 30 Amp early component.



(2,500 Volts, Condition 3, Continued)

Figure 22
Vert: 20 Amps/Div.
Time: 10 nSec/Div.

Displayed:
Ip: 64 Amps Surge

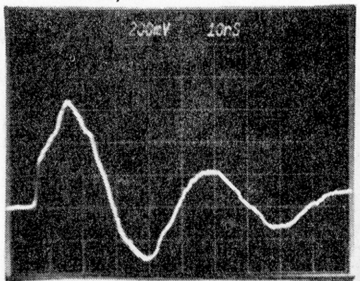


Figure 23
Vert: 20 Amps/Div.
Time: 10 nSec/Div.

Displayed:
Ip: 62 Amps Surge
48 Amps Spike

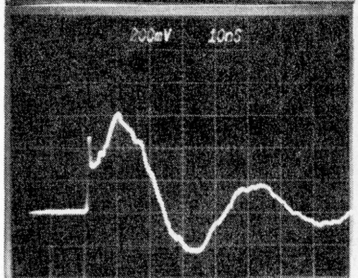
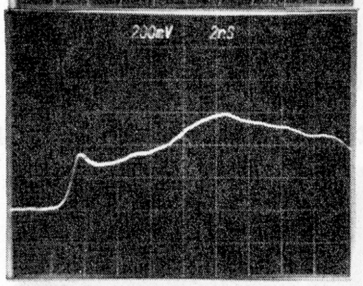


Figure 24
Vert: 20 Amps/Div.
Time 2 nSec/Div.

Displayed:
Ip: 60 Amps Surge
35 Amps Spike



5,000 Volts Initialization Level

Condition 1 - Human Seated in Desk Chair, ESD From Chair Base

Figure 25
Vert: 10 Amps/Div.
Time: 10 nSec/Div.

Displayed:
Ip: 35 Amps

Tr: 7 nSec

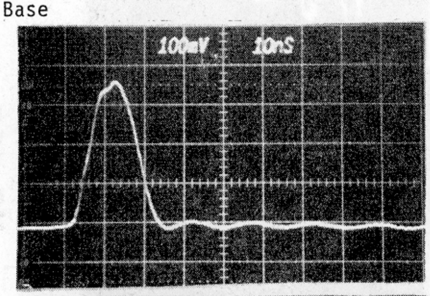


Figure 26
Vert: 10 Amps/Div.
Time: 10 nSec/Div.

Displayed:
Ip: 42 Amps
Tr: 8 nSec

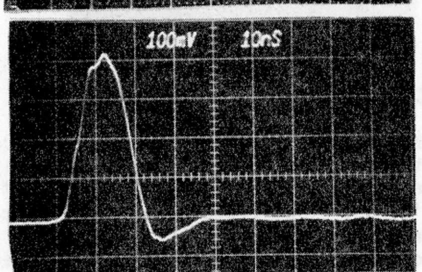
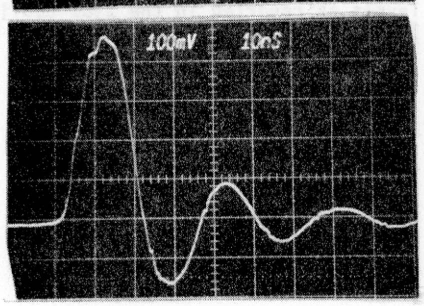


Figure 27
Vert: 10 Amps/Div.
Time: 10 nSec/Div.

Displayed:
Ip: 46 Amps
Tr: 6nSec



(5,000 Volts, Condition 1, Continued)

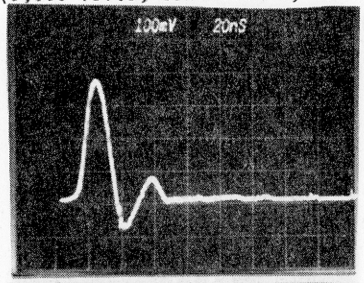


Figure 28
Vert: 10 Amps/Div.
Time: 20 nSec/Div.

Displayed:
Ip: 38 Amps

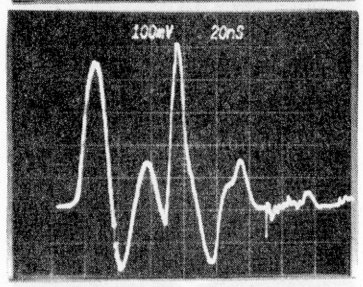


Figure 29
Vert: 10 Amps/Div.
Time: 20 nSec/Div.

Displayed:
Ip: 45 Amps, 1st component,
52 Amps, 2nd component

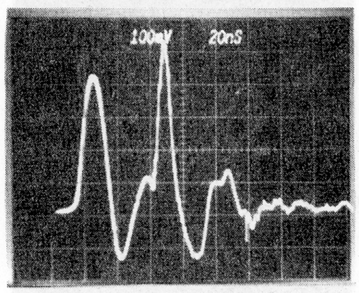


Figure 30
Vert: 10 Amps/Div.
Time: 20 nSec/Div.

Displayed:
Ip: 43 Amps, 1st component,
54 Amps, 2nd component

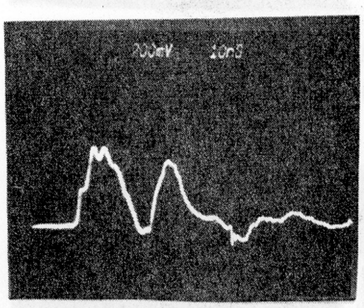


Figure 31
Vert: 20 Amps/Div.
Time: 10 nSec/Div.

Displayed:

Ip: 50 Amps

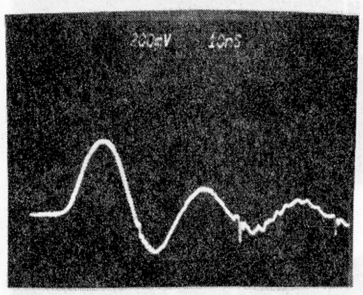


Figure 32
Vert: 20 Amps/Div.
Time: 10 nSec/Div.

Displayed:
Ip: 50 Amps

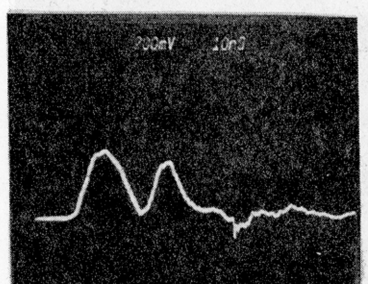


Figure 33
Vert: 20 Amps/Div.
Time: 10 nSec/Div.

Displayed:
Ip: 44 Amps

The results illustrated by Figures 25 through 33 above provide indication of the variability in waveforms that can be experienced due to small changes in the mechanical attitude and motion toward the ESD load point. If the approach velocity and attitude are held relatively uniform from impact-to-impact, then relatively similar waveshapes will be developed, as is the example established between Figures 25 through 28.

Condition 2 - Human Seated in Desk Chair, ESD From Arm Rest Frame. (5,000 Volts, Cont.)

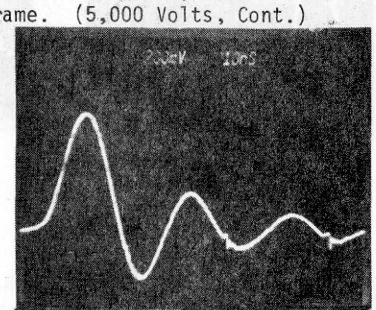


Figure 34
Vert: 20 Amps/Div.
Time: 10 nSec/Div.

Displayed:
Ip: 75 Amps

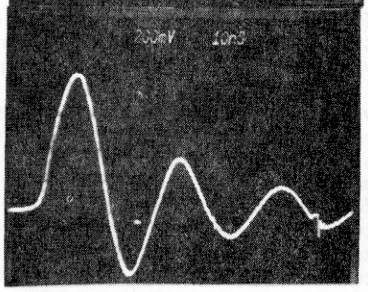


Figure 35
Vert: 20 Amps/Div.
Time: 10 nSec/ Div,

Displayed:
Ip: 85 Amps

Condition 2A - Sample Test - ESD From Lab Chair Leg

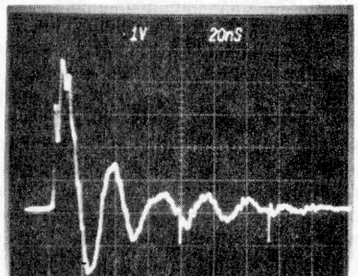


Figure 36
Vert: 10 Amps/Div.
Time: 20 nSec/Div.

Displayed:
Ip: 46 Amps
Note early component formation.

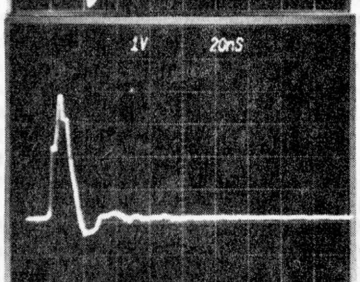


Figure 37
Vert: 10 Amps/Div.
Time: 20 nSec/Div.

Displayed:
Ip: 37 Amps

Condition 3 - Human Moving Push Cart (5,000 Volts, Cont.)

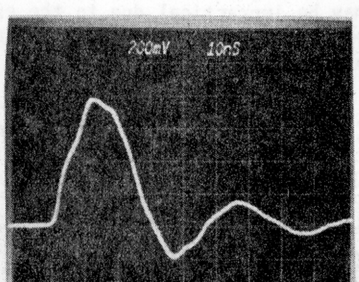


Figure 38
Vert: 20 Amps/Div.
Time: 10 nSec/Div.

Displayed:
Ip: 79 Amps

(5,000 Volts, Continued, Condition 3)

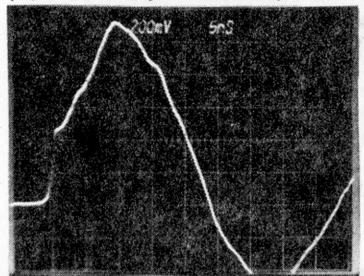


Figure 39
Vert: 20 Amps/Div.
Time: 5 nSec/Div.

Displayed:
Ip: 110 Amps

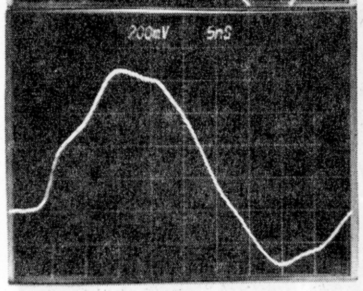


Figure 40
Vert: 20 Amps/Div.
Time: 5 nSec/Div.

Displayed:
Ip: 88 Amps

7,500 Volts Initialization Level

Condition 1 - Human Seated In Desk Chair, ESD From Chair Base.

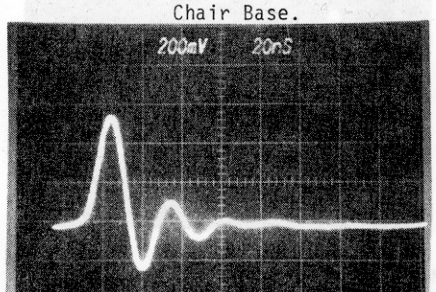


Figure 41
Vert: 20 Amps/Div.
Time: 20 nSec/Div.

Displayed:
Ip: 56 Amps

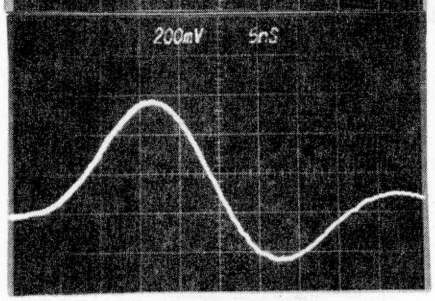
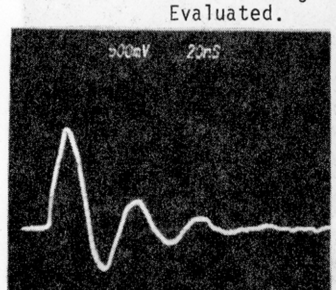


Figure 42
Vert: 20 Amps/Div.
Time: 5 nSec/Div.

Displayed:
Ip: 56 Amps

Condition 3 - Human Moving Push Cart (Condition 2 Not Evaluated.



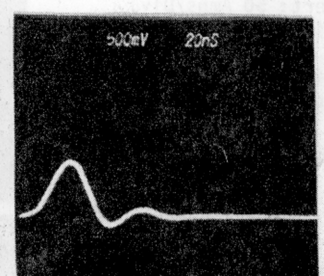


Figure 43
Vert: 50 Amps/Div.
Time: 20 nSec/Div.

Displayed:

Ip: 155 Amps

Figure 44
Vert: 50 Amps/Div.
Time: 20 nSec/Div.

Displayed:

Ip: 90 Amps

(Figures 43 to 44 illustrates pulse-to-pulse variations).

At the level of 7,500 Volts, an occasional double-pulse was observed while recording the results of Figures 41 and 42 (Desk Chair Condition). Although this double pulse did not occur consistantly enough to photograph, the observed spacing between the pulses was usually between 60 and 100 nSec. A similar double-pulse effect is found in the 10kV data below.

10,000 Volts Initialization Level

Condition 1 - Human Seated In Desk Chair, ESD From Chair Base

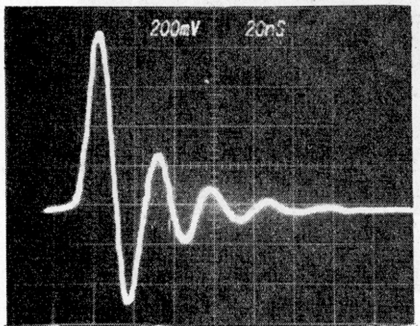


Figure 45
Vert: 20 Amps/Div.
Time: 20 nSec/Div.

Displayed:

Ip: 90 Amps
Tr: 9 nSec

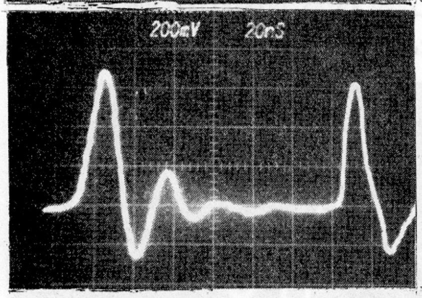


Figure 46
Vert: 20 Amps/Div.
Time: 20 nSec/Div.

Displayed:

Ip: 70 Amps

Spacing: 130 nSec

Condition 3 - Human Moving Push Cart (Condition 2 Not Evaluated)

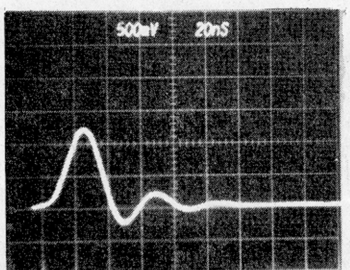


Figure 47
Vert: 50 Amps/Div.
Time: 20 nSec/Div.

Displayed:
Ip: 125 Amps

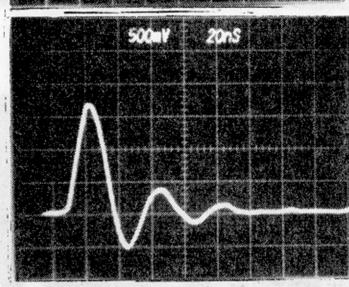


Figure 48
Vert: 50 Amps/Div.
Time: 20 nSec/Div.

Displayed:
Ip: 170 Amps

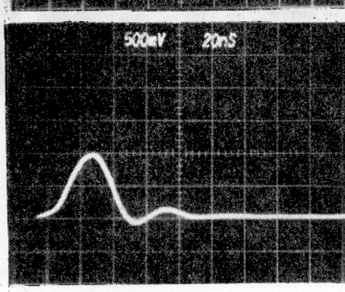


Figure 49
Vert: 50 Amps/Div.
Time: 20 nSec/Div.

Displayed:
Ip: 100 Amps

15,000 Volts Initialization Level

Condition 3 - Human Moving Push Cart (Conditions 1 & 2 Not Evaluated)

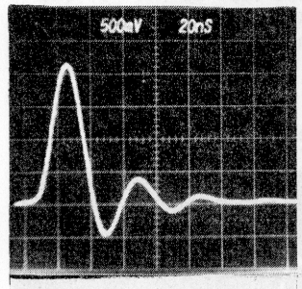


Figure 50
Vert: 50 Amps/Div.
Time: 20 nSec/Div.
Displayed: Ip= 220 Amps

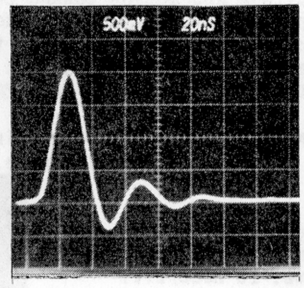


Figure 51
Vert: 50 Amps/Div.
Time: 20 nSec/Div.
Displayed: Ip= 200 Amp

Conclusions

The results of this effort provided photographically, tend to indicate that the conceptual circuit model that was advanced in the 1981 publication (1) for human events is also operative for the human-furnishings conditions with some parametric changes. Although the 'early' components may be recognized in both publications, the point of transition from ultra-fast risetimes to ionization-based risetimes is significantly lower in static level for the 'furnishings' conditions, by a factor of at least two. Additionally, the 'early' conponents do not appear to achieve as much impulse current for the 'furnishings' conditions, as in the 'human-with-small-object' condition by an approximate factor of two or three against the data previously published. The longer-risetime ionization based segment currents, are significantly greater than those encountered in the 'human conditions'. (The maximum human-derived ionization-based currents were less than 40 Amperes, peak, even at levels up to 20kV). It should also be considered that the spectral energy distribution for the 'furnishings' events appear to vary greatly from furnishing condition-to-condition, as well as from furnishing to human conditions. These variations among furnishings suggest that a thorough replication of the furnishings conditions through a test simulator is probably not reasonable (although replication was essentially achieved for human conditions) due to the unique properties of each possible furnishing. Despite that conclusion, however, the magnitude of the currents produced through furnishings suggested by these results implies that specific system/product areas that could be subjected to furnishings impacts should probably be subjected to simulation of furnishings-derived ESD impulses to determine susceptibility performance. As a suggestion, based on these results, such a simulation could provide an early component, measured at 1,000 Volts, of between 40 and 50 Amperes with a waveshape similar to those of Figures 11 or 14, extending to an ionization-based component, measured at 5,000 Volts, of between 40 and 50 Amperes, exhibiting a waveshape similar to those of Figures 25 through 28. It is suggested that simulation of the higher currents associated with larger furnishings may be impractical due to the excessively low impedances required both of the test simulator and of the test arrangement.

References

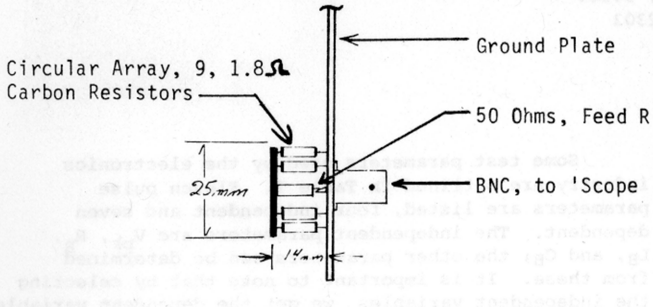
(1) King, W. & Reynolds, D. "Personnel Electrostatic Discharge: Impulse Waveforms Resulting From ESD of Humans Directly and through Small Hand-Held Metallic Objects Intervening in the Discharge Path", Proceedings 1981 IEEE Int'l EMC Symposium, Pgs 577-590.

(2) Carruth, B., Farhoomand, J., Garrett, H., Leung, P., Robinson, P., & Whittlesey, A. "r.f. Characterization of

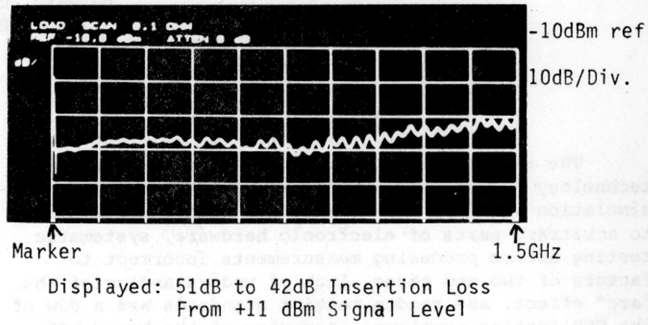
(References, Continued)

Dielectric Discharges", Proceedings 1981 IEEE Int'l EMC Symposium, Pgs 576, also, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, Calif.

APPENDIX



A-1a
Load Arrangement



A-1b
Insertion Loss

Figure A-1
Load

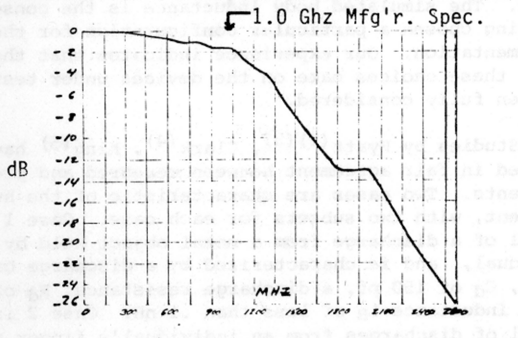


Figure A-2
Oscilloscope Response

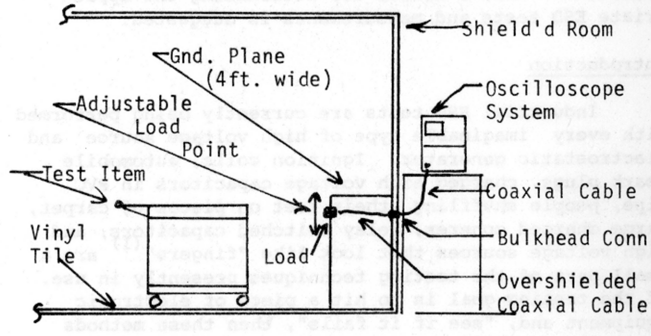


Figure A-3
General Test Arrangement

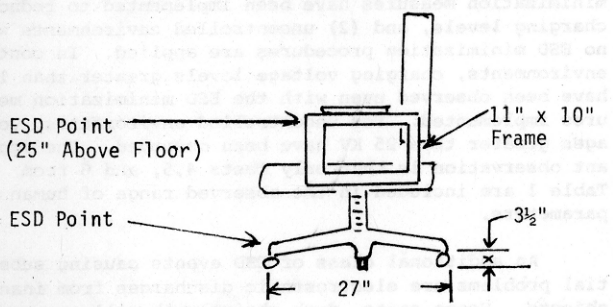


Figure A-4
Desk Chair

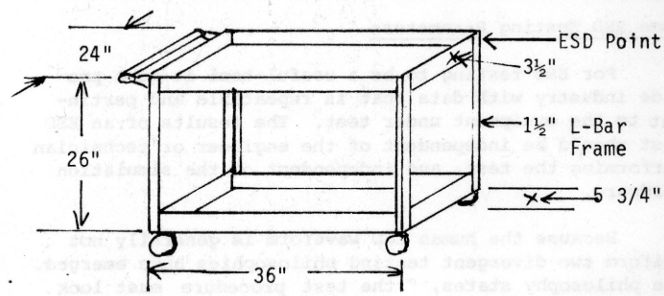
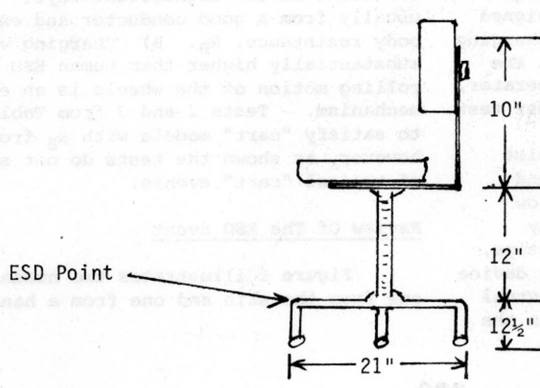


Figure A-5
Push Cart



Note: Drawings Are
Not To Scale

Figure A-6
Lab Chair