Instrument for Calibrating Antenna-based ESD Detectors

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It is now common to monitor electrostatic events in electronic assembly and test factories, using electromagnetic antennas of various kinds [1,2]. But we have just begun to make the link between the antenna data in the factory and its correspondence to some kind of component ESD test data, e.g. for the Charged Device Model [1]. What has been needed is a generator of a measured ESD event *in situ*, at the very same site in the factory equipment where a charged component would discharge. This will allow the antenna-based detectors to be understood, calibrated, and for the strength of the event to be assessed in terms of component ESD tests.

Figure 1 shows the schematic diagram of an instrument designed to produce a measured ESD event in a chosen location. The charged plate is the bottom board layer on a 32 mm disk (Figure 2), and faces the grounded metal surfaces to which the components will discharge. A power supply charges the plate through a 1 Megohm resistor, and when the feedthrough peg (Figure 3) discharges the plate, the current goes through 25 ohms (SMA coaxial launcher to 50 ohm scope input, in parallel with a 50 ohm matching resistor) to ground. At that point, the charge packet (Ch. 1, Figure 4) associated with the discharge is seen at the oscilloscope, while the EMI antenna (Ch. 2, Fig. 4) picks up the radiation. Thus the antenna signal can be related to the size of the charge packet for the particular discharge configuration, as described in [1].

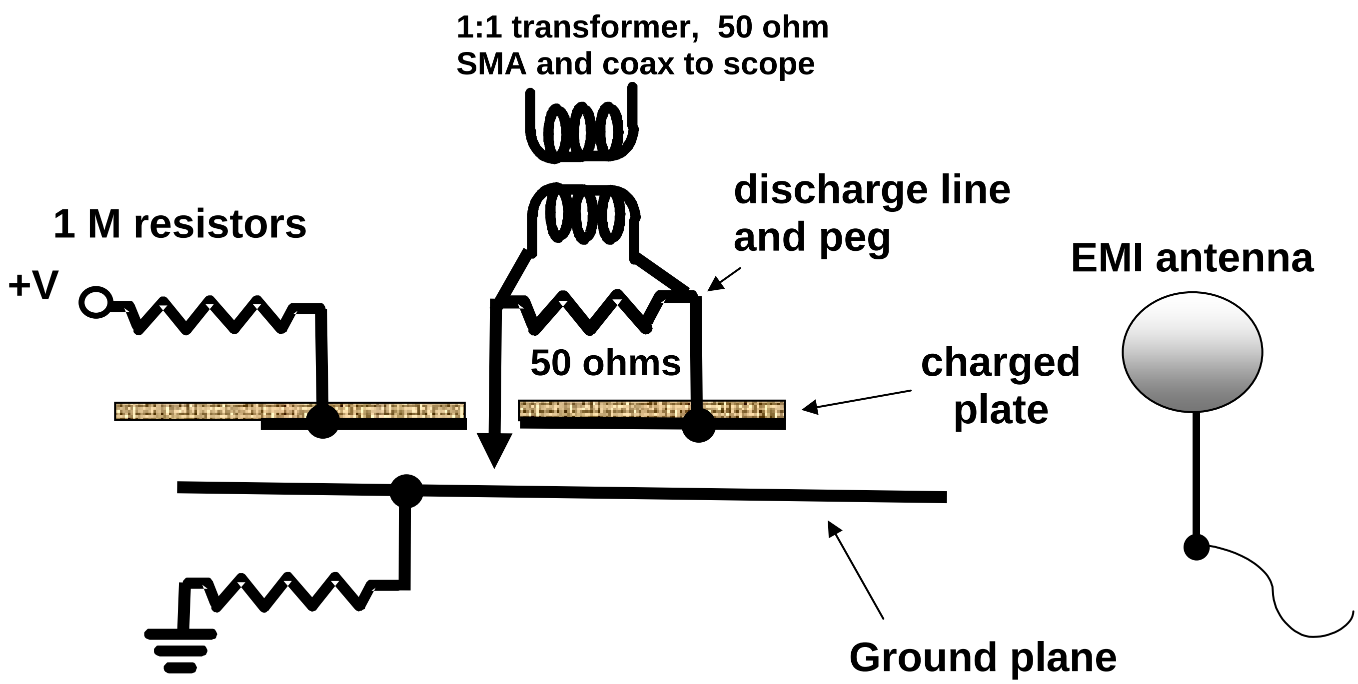

Figure 1. Schematic diagram of discharge instrument, plus EMI antenna.

In the example shown in Fig. 4, we have a charge packet of 384 pC and radiation efficiency of 568 mV/nC at 30 cm from the discharge. The radiation efficiency can vary over a factor of 2 or 3 at a given antenna distance, but is fairly stable given a particular configuration of ground metal and antenna position. This is ideal for calibrating antenna readings on a particular piece of factory equipment.

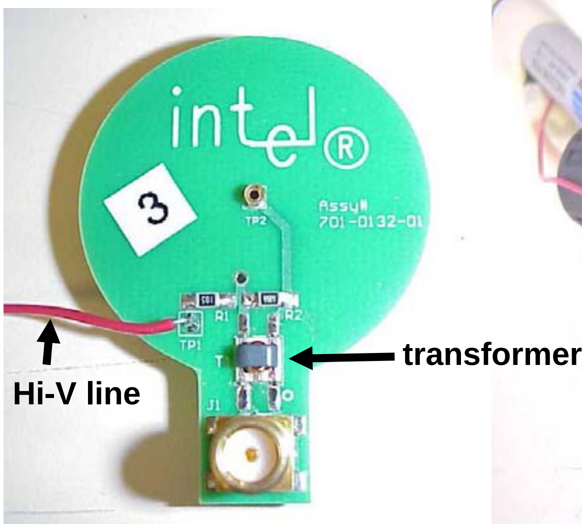

Figure 2. Top view of board.

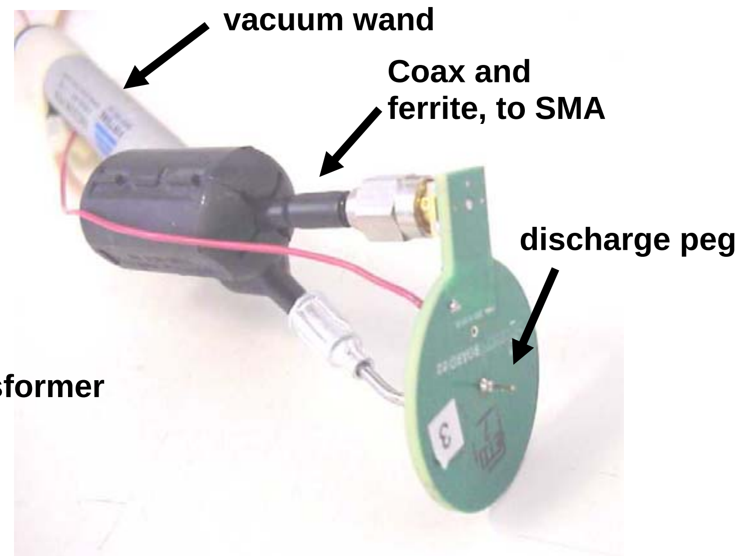

Figure 3. Instrument from side with discharge peg.

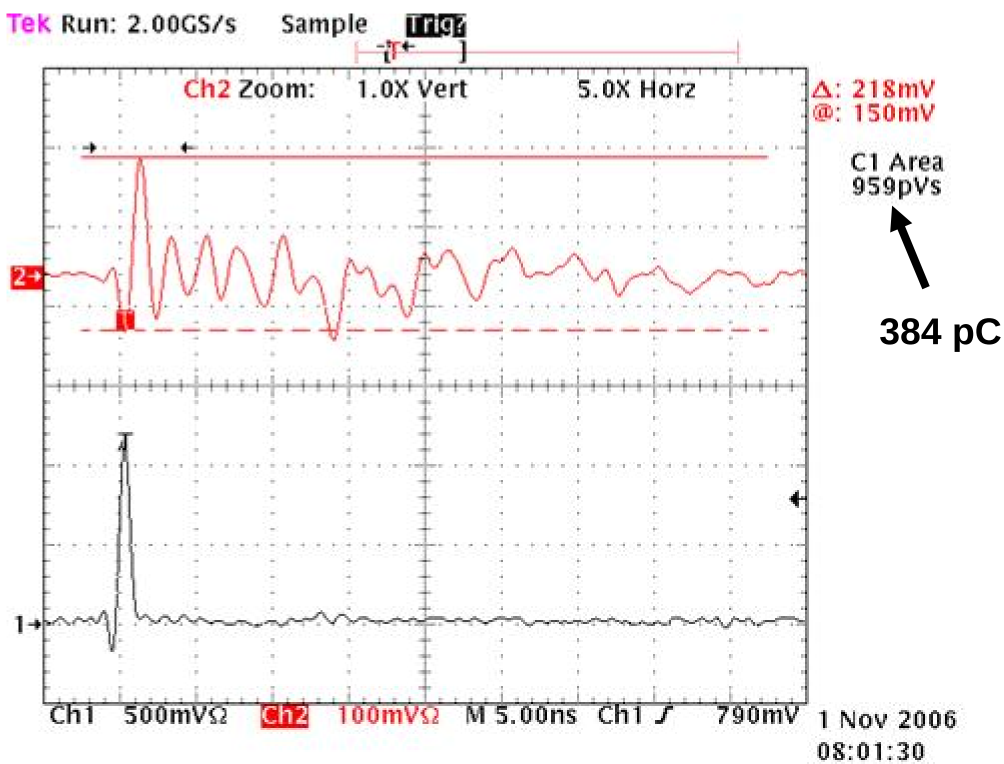

Figure 4. Scope traces; Ch. 1 discharge from board at 100V, Ch. 2 from antenna.

1. Julian A. Montoya and Timothy J. Maloney, “Unifying Factory ESD Measurements and Component ESD Stress Testing”, 2005 EOS/ESD Symposium Proceedings, pp. 229-237.
2. See, for example, products from Credence Techologies, Inc. (http://www.credencetech.com/)

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TIMOTHY J. MALONEY

Timothy J. Maloney received an S.B. degree in physics from the Massachusetts Institute of Technology in 1971, an M.S. in physics from Cornell University in 1973, and a Ph.D. in electrical engineering from Cornell in 1976, where he was a National Science Foundation Fellow. He was a Postdoctoral Associate at Cornell until 1977, when he joined the Central Research Laboratory of Varian Associates, Palo Alto, CA. At Varian until 1984, he worked on III-V semiconductor photocathodes, solar cells and microwave devices, as well as silicon molecular beam epitaxy and MOS process technology. Since 1984 he has been with Intel Corp., Santa Clara, CA, where he has been concerned with integrated circuit ESD protection, CMOS latchup testing, fab process reliability, signal integrity, and design and testing of standard IC layouts. He is now a Senior Principal Engineer at Intel. He has received the Intel Achievement Award for his patented ESD protection devices, which have achieved breakthrough ESD performance enhancements for a wide variety of Intel products. He now holds twenty-six patents, with several more pending.

Dr. Maloney received Best Paper Awards for his contributions to the EOS/ESD Symposium in 1986 and 1990, was General Chairman for the 1992 EOS/ESD Symposium, and received the ESD Association's Outstanding Contributions Award in 1995. He has taught short courses at UCLA, University of Wisconsin, and UC Berkeley. He is co-author of a book, "Basic ESD and I/O Design" (Wiley, 1998), and is a Senior Member of the IEEE.

Abstract

A new instrument allows antenna measurements of electrostatic discharge (ESD)-generated radiation to be associated with a concurrent, precisely-measured charged device model (CDM) event, in terms of the CDM charge packet. A charged plate equipped with an on-board transformer is designed so that the required measurements can be made. CDM events on factory handling equipment can thereby be monitored with antennas, and the resulting ESD stresses related back to CDM product testing. This is a new capability and gives us much-needed feedback on factory conditions.

Purpose

- Introduce new ESD antenna calibration instrument
  - Motivation (from 2005 EOS/ESD paper)
- Describe design and show function
- Show field results and applications
- Relate to 2005 stochastic model for risk assessment

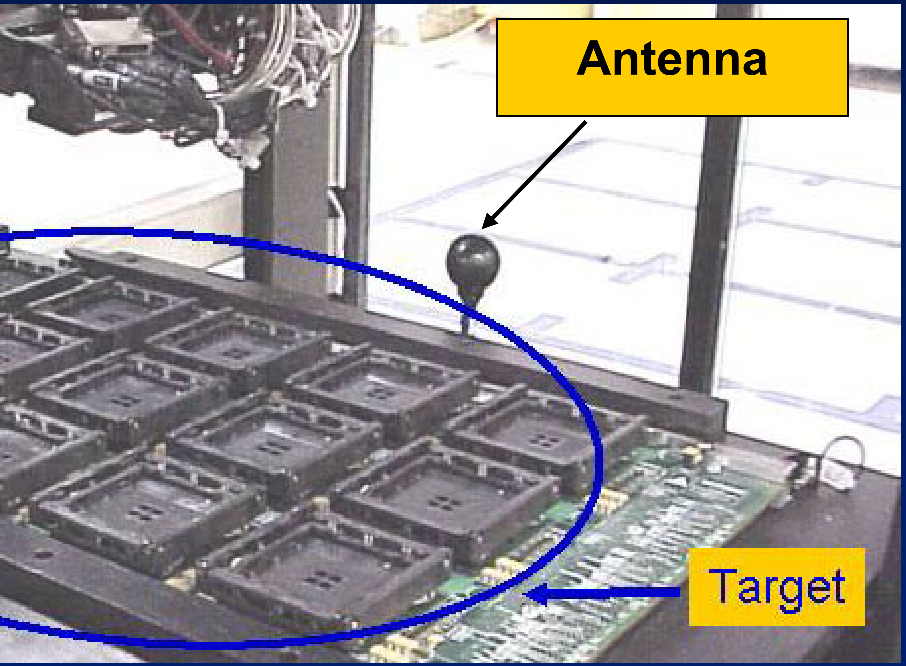
Outline

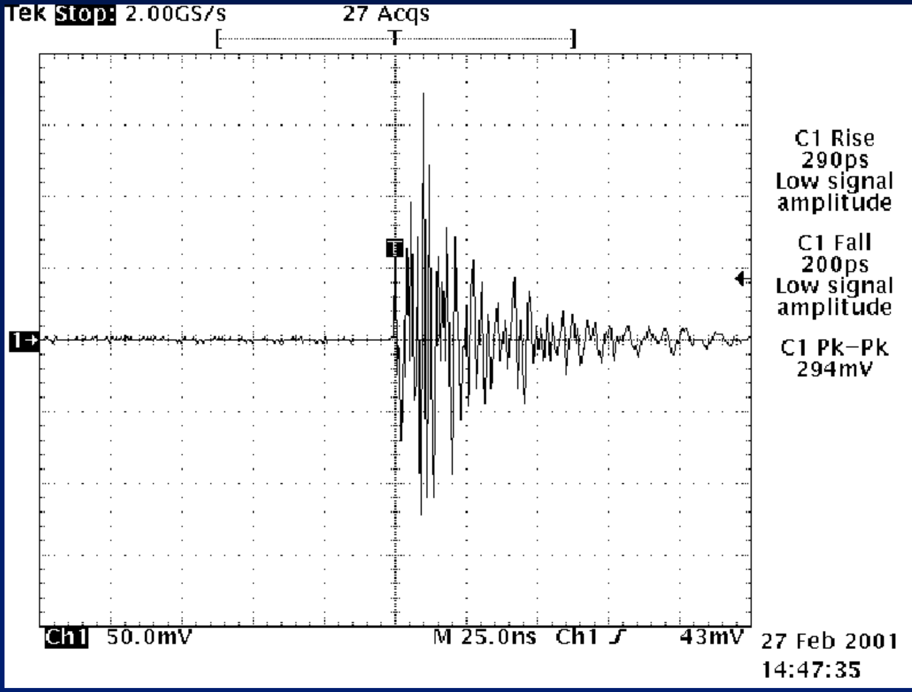
- Began with 2005 EOS/ESD paper
  - mV/nC measure of radiation efficiency η discovered
  - Result: need a component-like object delivering measured quantity of charge
    - Plan to characterize each machine or subprocess
- Instrument design, photos, principles of operation
- Field trials, scope data, statistics
- Examples of relating antenna data directly to component CDM test data (!)
- Apply to stochastic model, as in 2005 paper

Antenna Oscope Method for ESD Detection

Antenna Placed To Identify ESD

Typical ESD Event Signature, 25-75 nsec

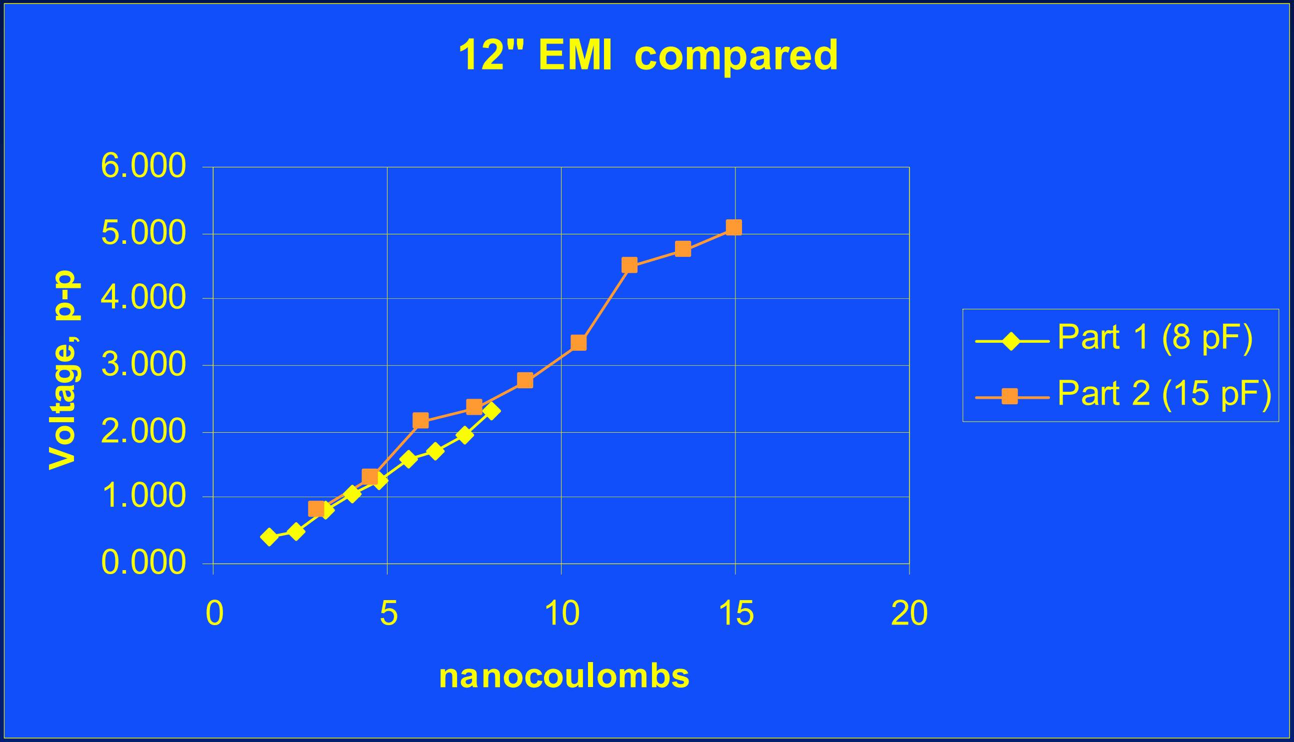




From Montoya and Maloney, 2005 EOS/ESD Symposium

EMI Vs. Charge Packet Size

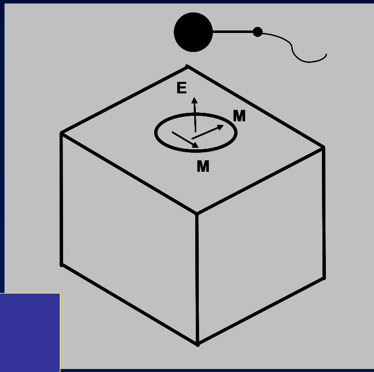
Results showing EMI is a function of charge packet size



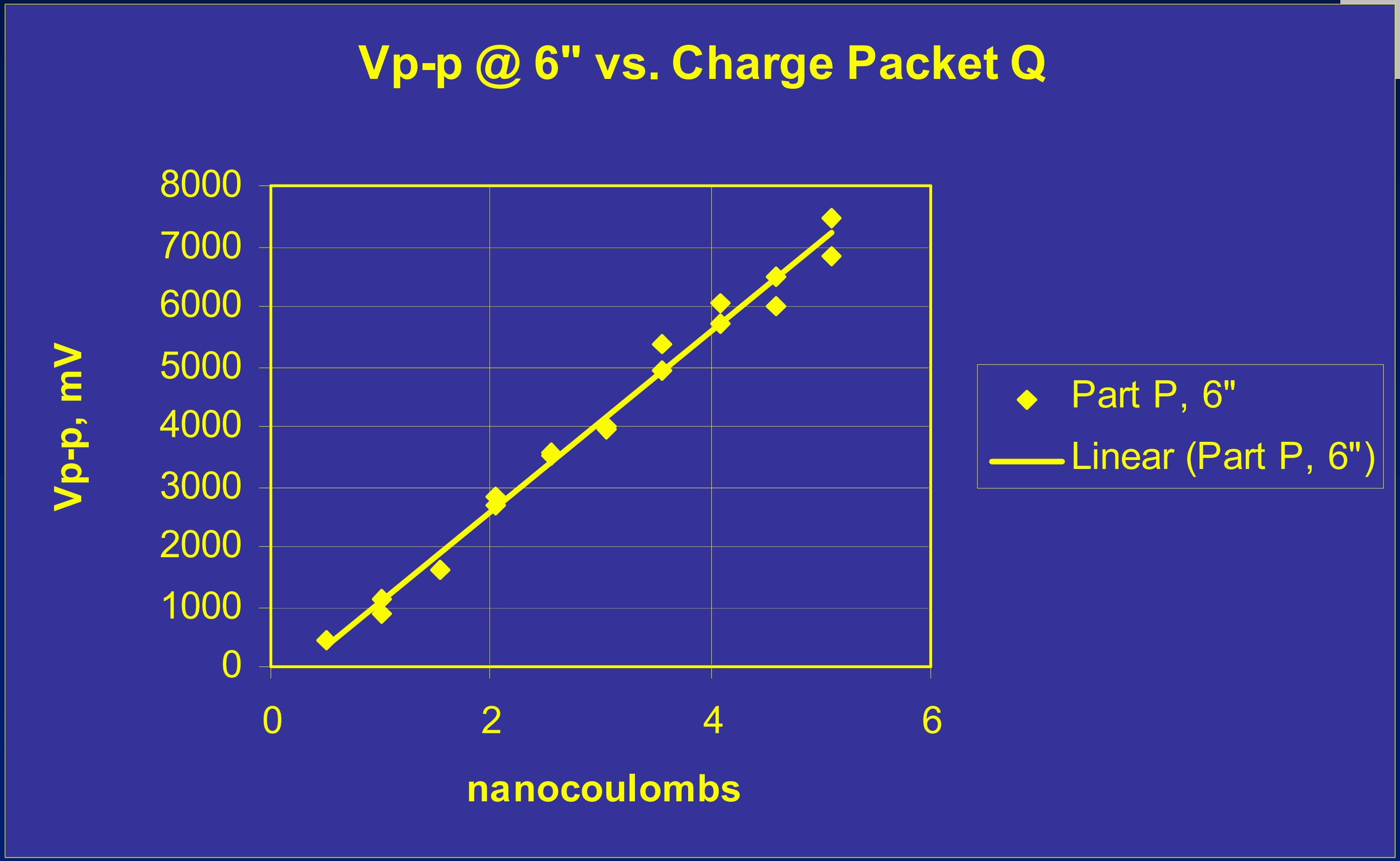
M&M, 2005

EMI from ns-CDM Tester For Various Charge Packets

M&M, 2005



Antenna Placed 6" Above Aperture



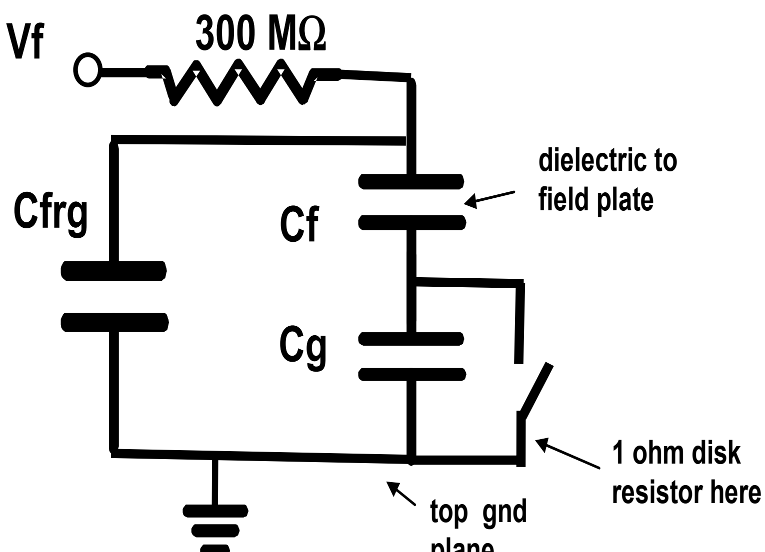
Circuit Modeling

M&M, 2005

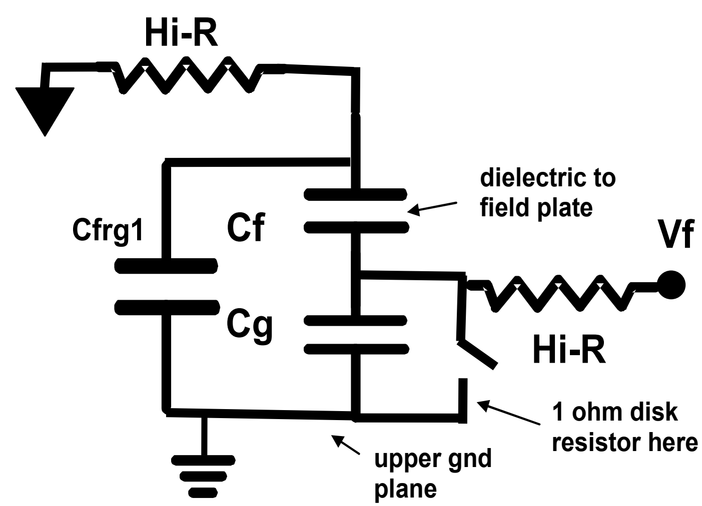
Immediate Charge for field charge ns-CDM

$$Q_{imm} = Vf\left[\frac{Cf}{Cg+Cf}\right]\left[Cg+\frac{Cf * Cfrg}{Cf+Cfrg}\right] = Q_1 + Q_2.$$

Field Charge ns-CDM

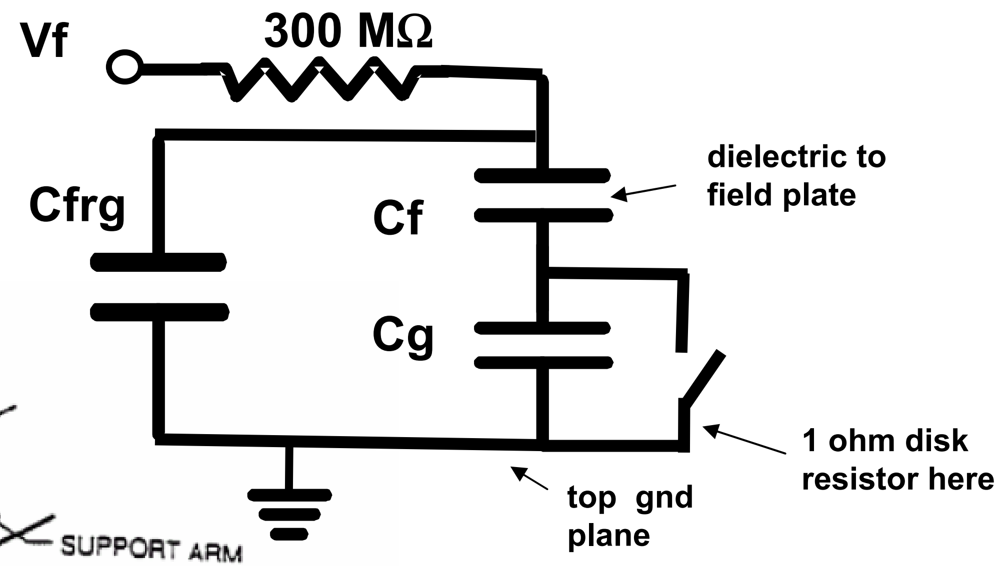


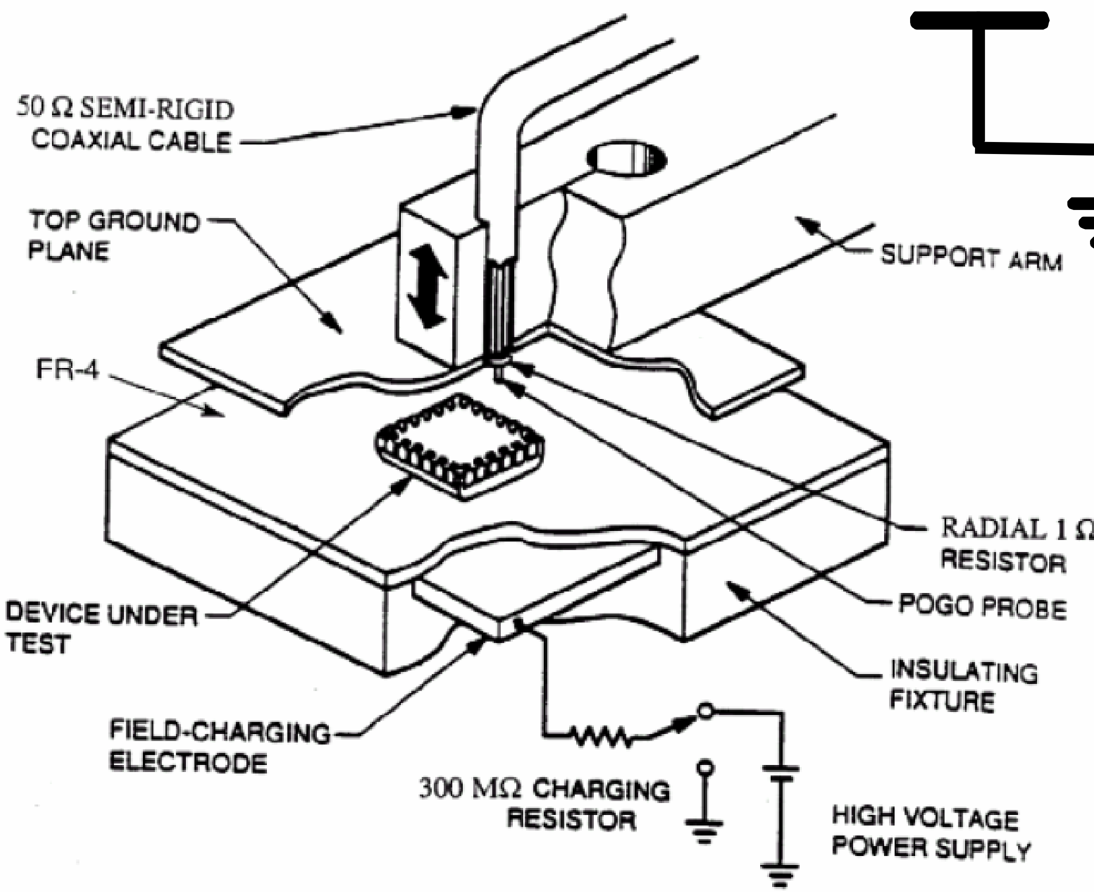
Direct Charge ns-CDM



CDM Tester simulates event

M&M, 2005





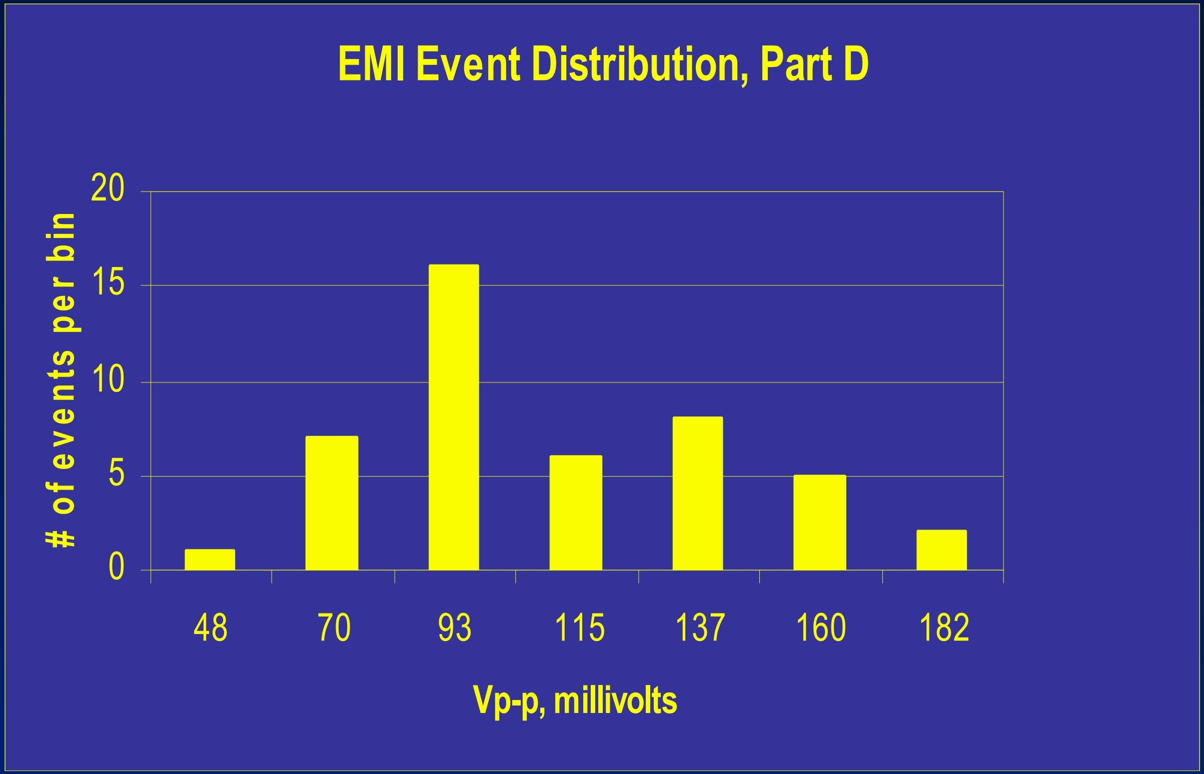
Immediate charge packet is

$$Q_{imm} = Vf\left[\frac{Cf}{Cg + Cf}\right]\left[Cg + \frac{Cf * Cfrg}{Cf + Cfrg}\right].$$

Factory EMI And Risk Assessment

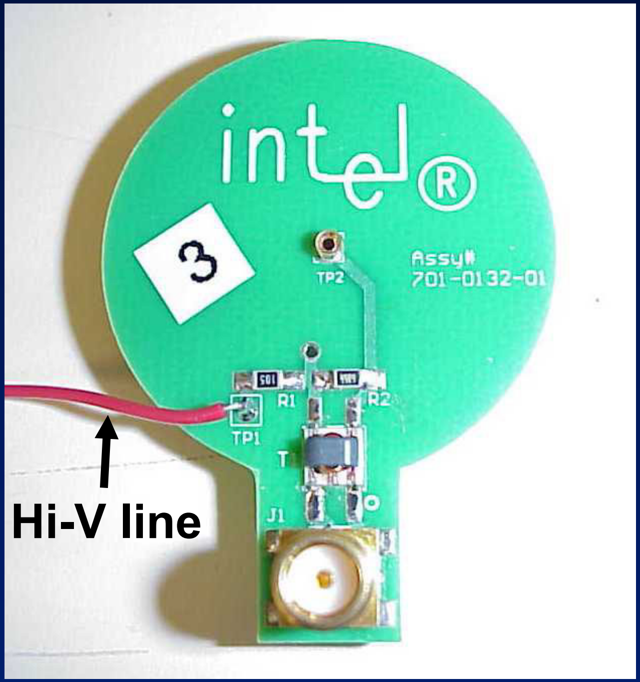
Typical Distribution of ESD amplitudes seen in production environment

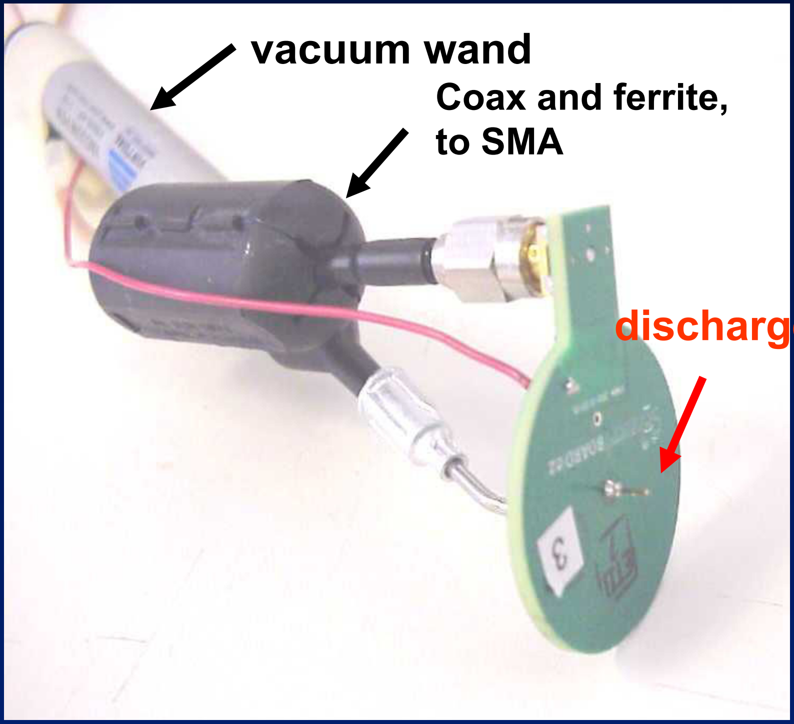
M&M, 2005



How does Vp-p correlate to CDM tester voltage and Q_{imm}?

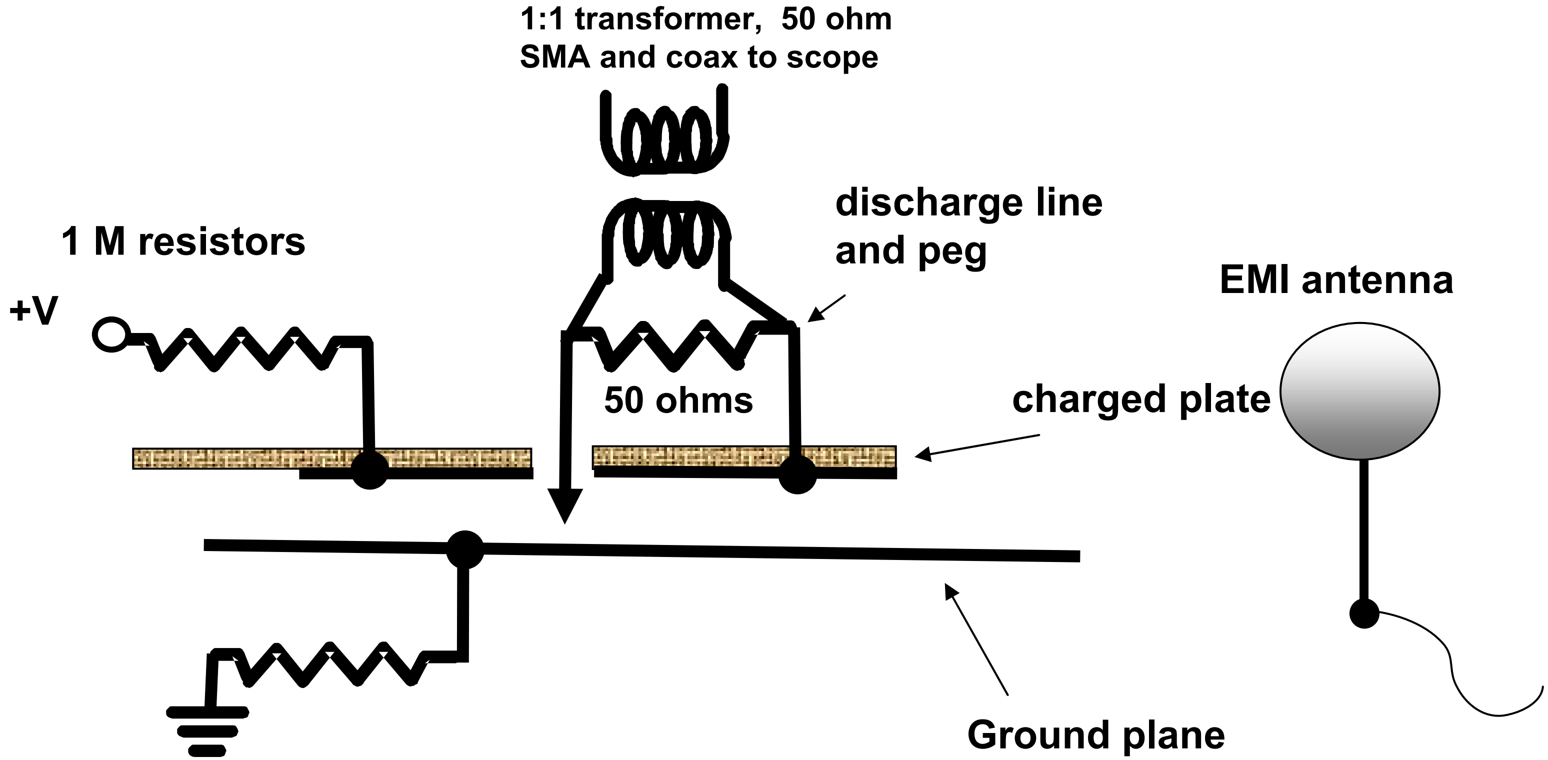
New Antenna Calibration Instrument



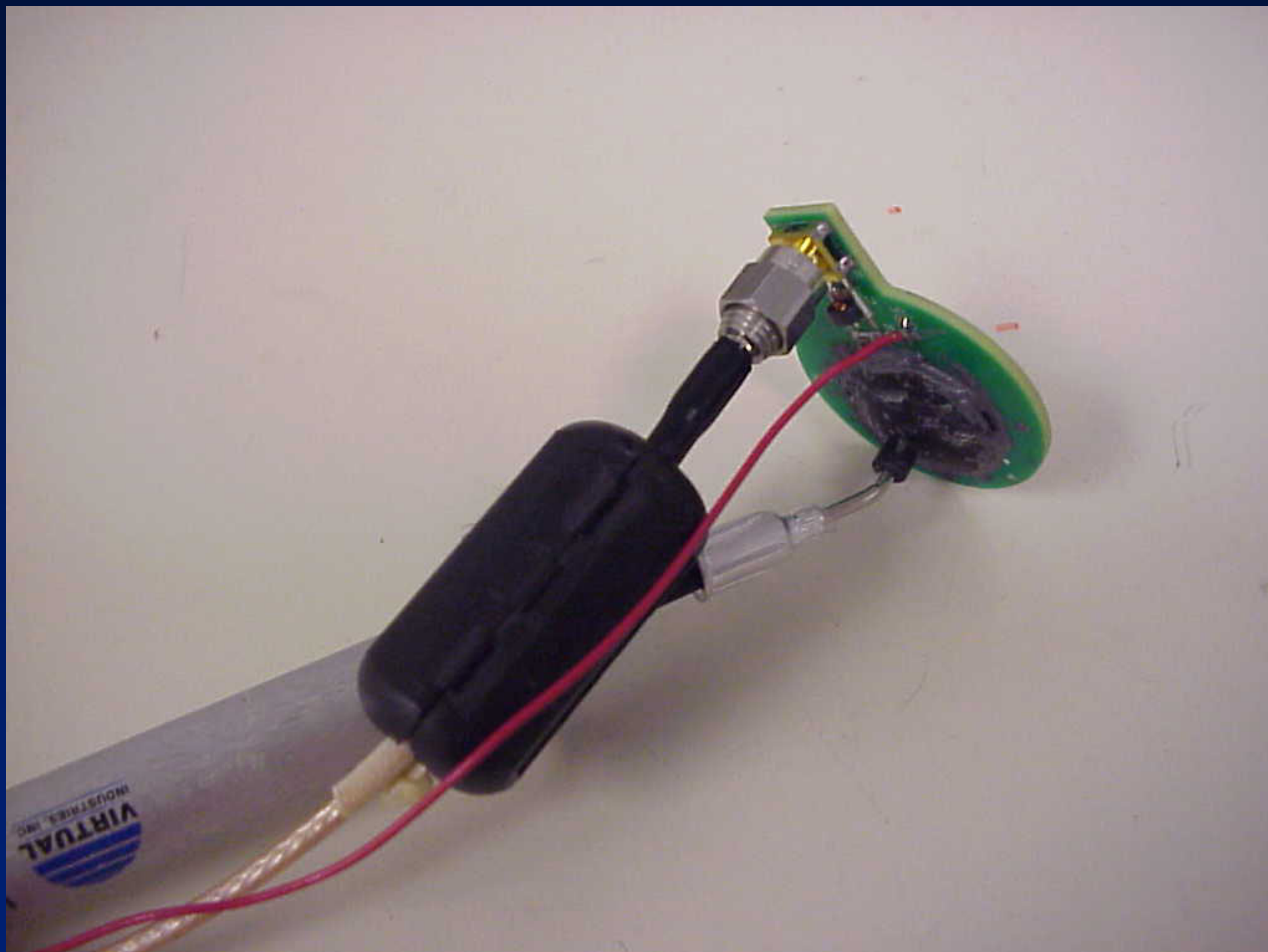


1.25" diameter circuit board, plus tab for SMA connector

Instrument Schematic

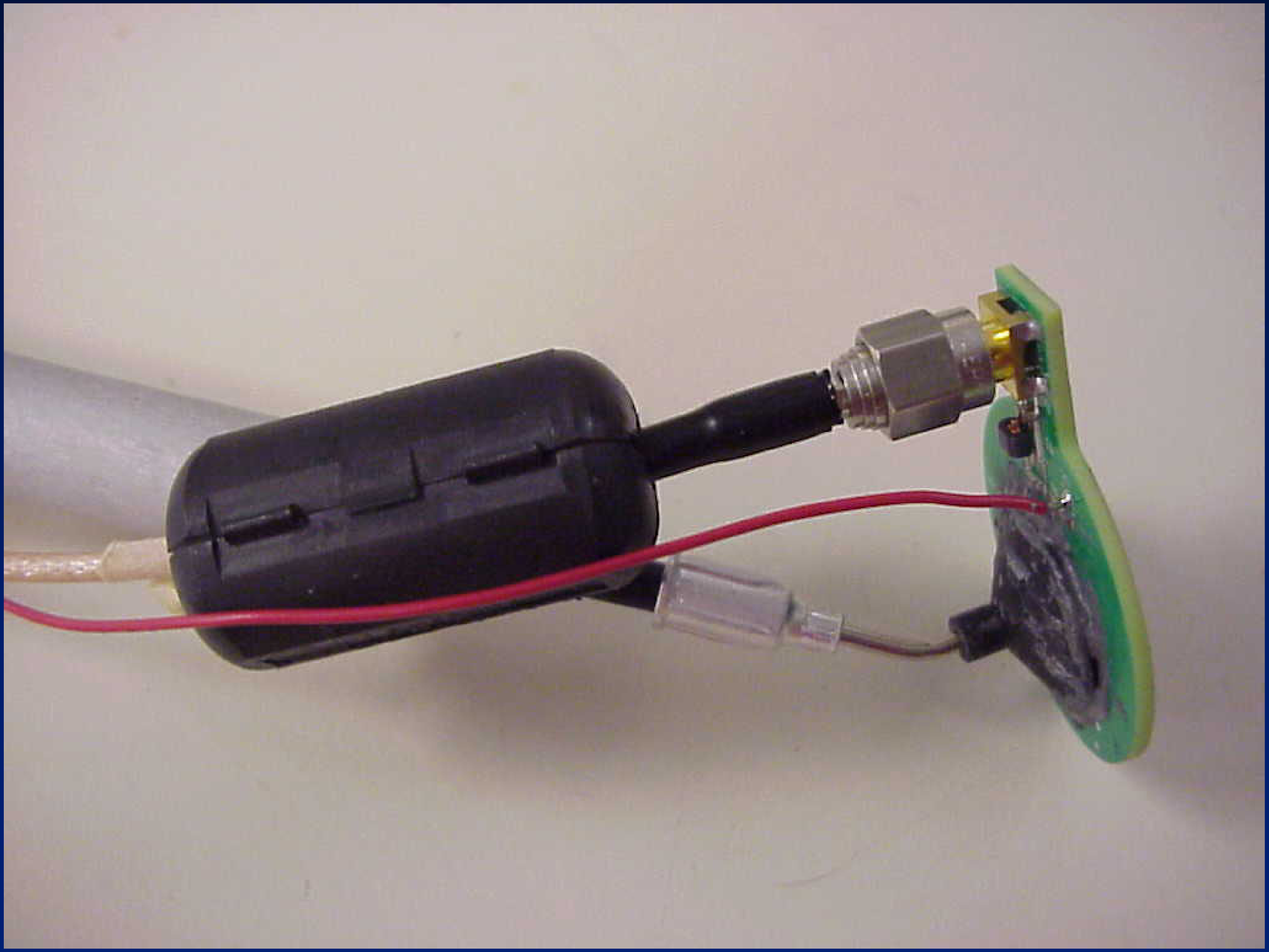


Instrument Views

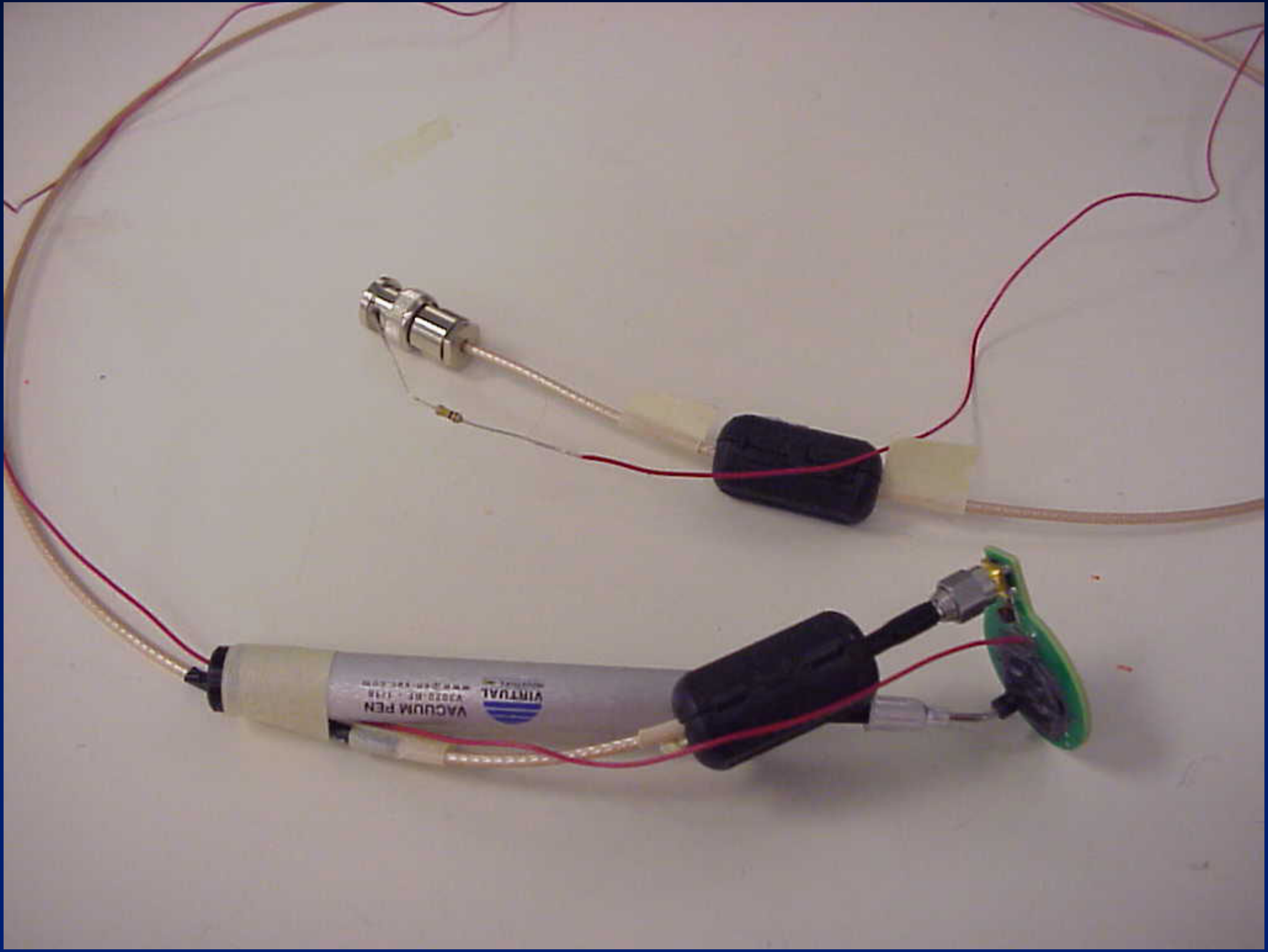


Note suction cup, attached to front with epoxy

Instrument Views

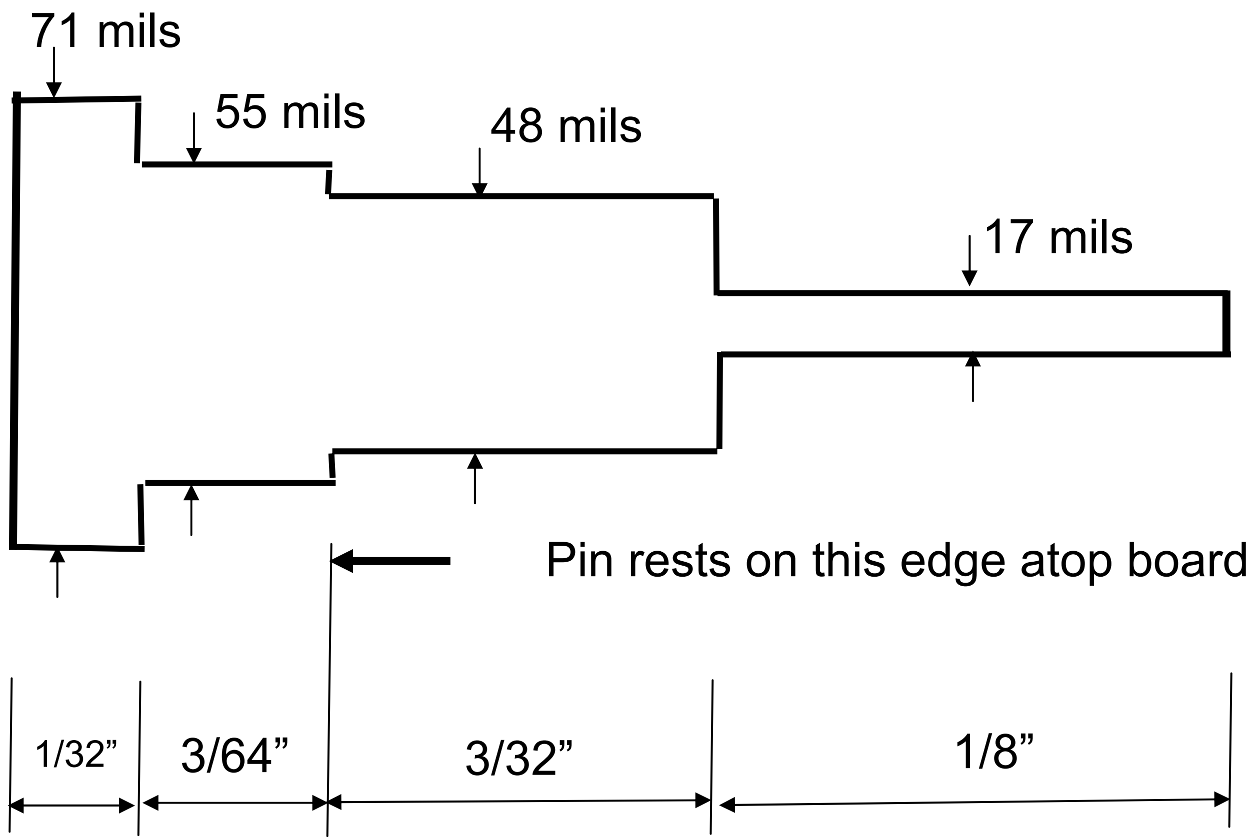


Instrument Views



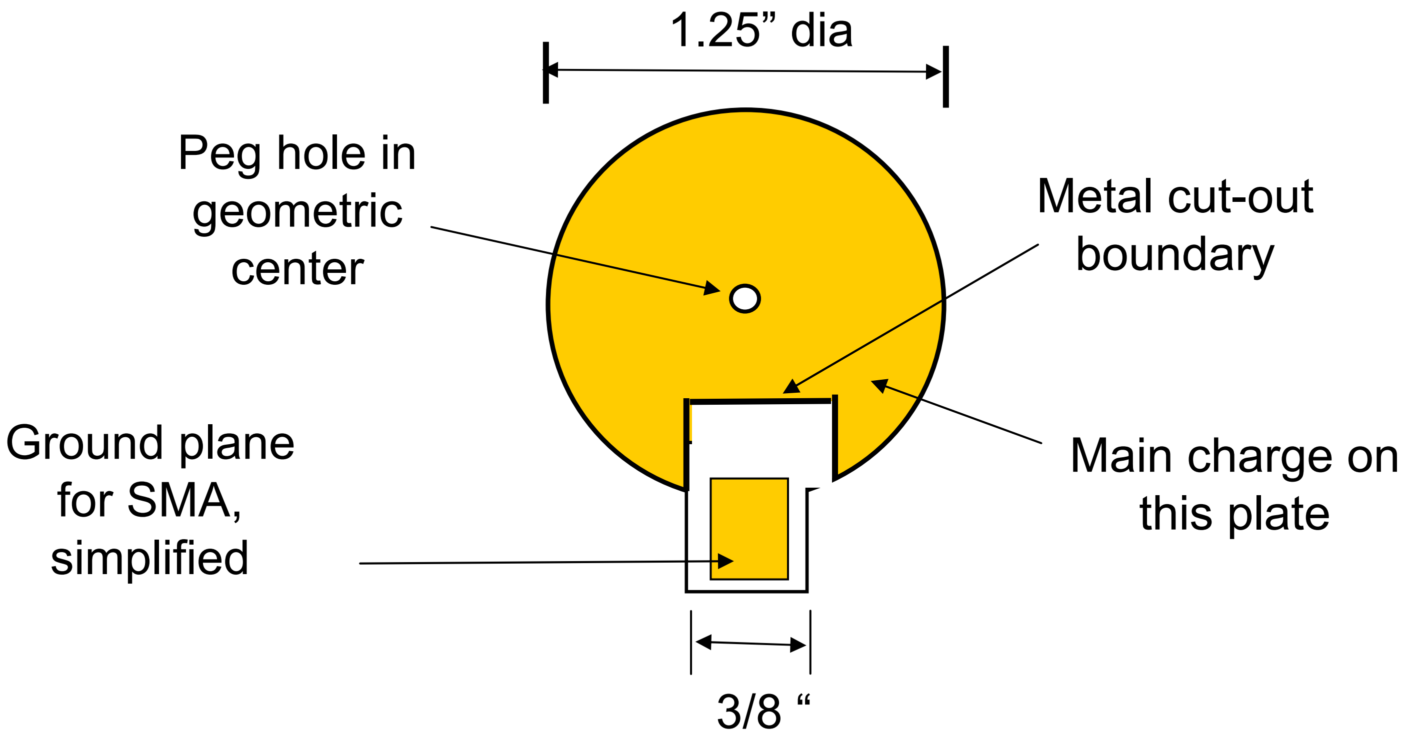
Scope end of 50-ohm cable shown

Discharge Peg Dimensions



Should be around 3-3.5 nH to “shielded” line on board

Bottom metal layer of board

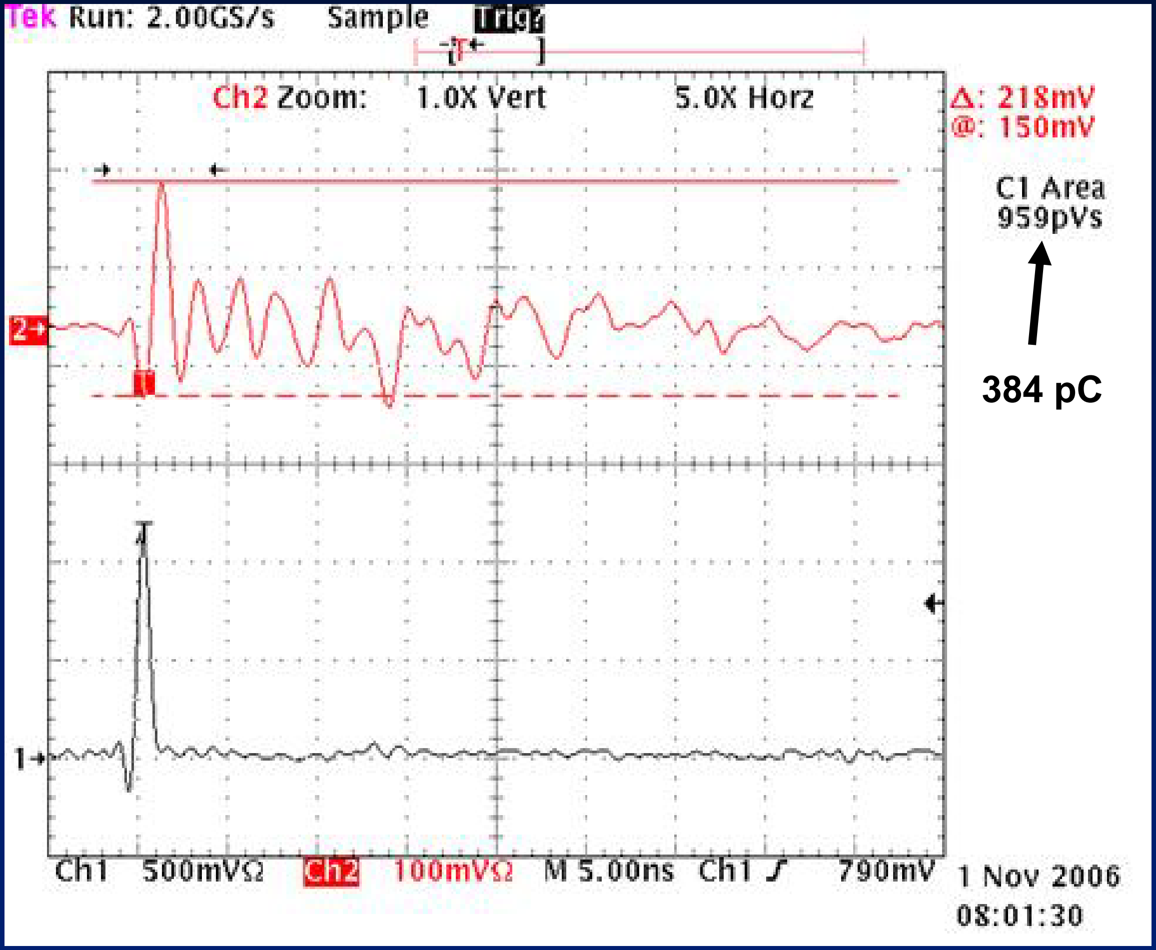


Metal cut-out avoids parasitic capacitance to xformer and SMA feed

Two-channel scope readout

antenna

instrument



100V zap on copper board, ~30 cm; 568 mV/nC

Typical Test Floor Trace, Machine #2

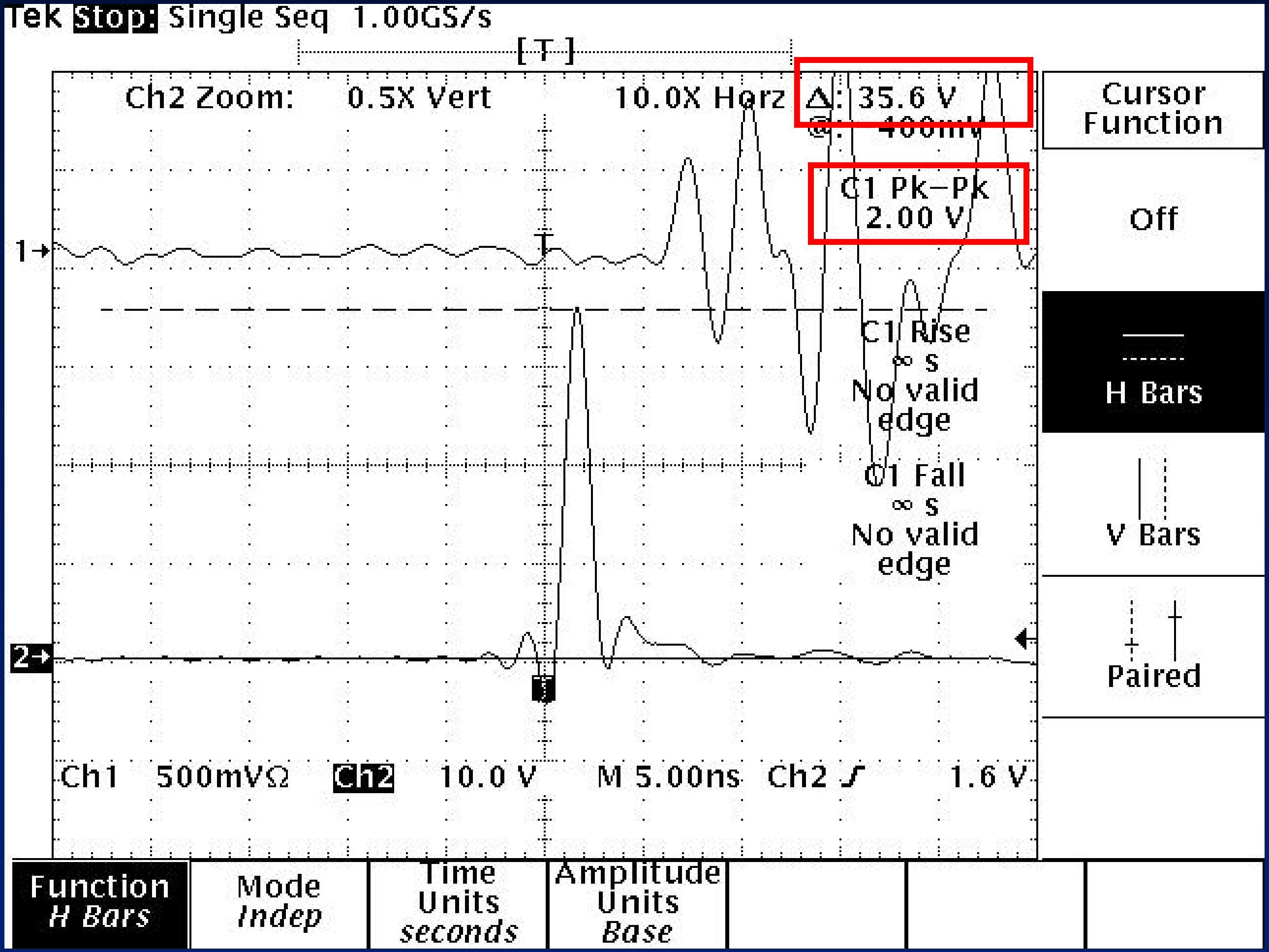
300 V

=zap voltage

15 cm antenna distance

6.17 pF

Scope Trace by ad hoc Test Floor Team



Ch2 base (2.6 nsec here) x height ÷ 50 ohms gives charge packet

This was 1.851 nC, 2000 mV p-p, thus 1080 mV/nC

Test Floor Team

TM + Julian Montoya + Elaine Olson

Photo by Vince Esqueda

Summary for Two Test Floor Machines

Machine	η (mV/nC)	C (pF) (instrument)
1	453 ± 14%	6.97 ± 29%
2	1146 ± 14.9%	5.59 ± 16.9%

Transformer readout helps a lot, given C variation and η stability

t-test shows >81% confidence that η of Machine 2 is >79% higher than η of Machine 1

Capability: Control Machine to CDM Voltage for Associated Component

- Example: Two machines handle two components
  - Suppose each is controlled to antenna voltage of 400 mV (V_{ctlmv}) peak-peak
    - Although a smaller component should produce lower zaps…
  - Component 1: 28-plcc, C_1eff = 2.06 pF
    - 12.4mm x 12.4mm
  - Component 2: 208-tqfp, C_2eff = 3.93 pF
    - 28mm x 28 mm
  - Machine 1: η_1 = 453 mV/nC
  - Machine 2: η_2 = 1146 mV/nC
    - Then V_{ijCDM}(kV) x $C_i$eff(pF) = V_{ctlmv} / η_j

$V_{ijCDM} \times C_i eff = V_{ctlmv} / \eta_j$

		Component	
		1 small	2 large
Machine	1 Low η	429	225
	2 High η	169	88.8

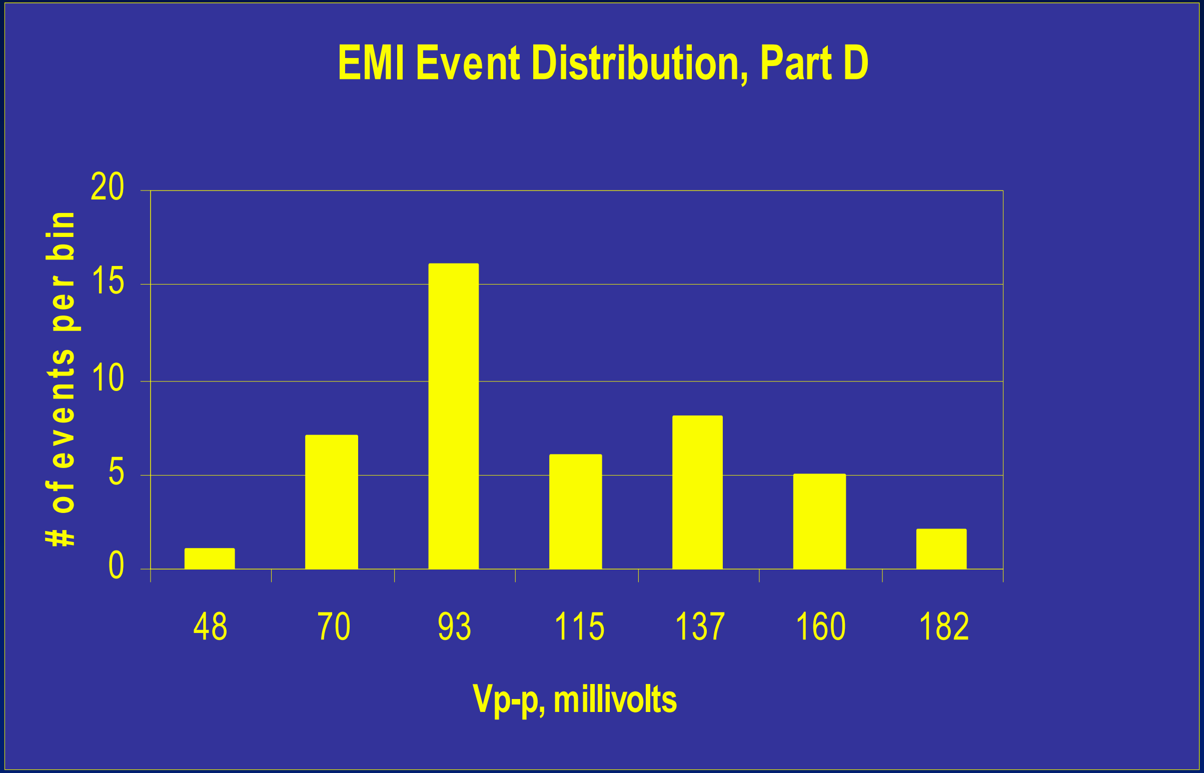
V_{ijCDM} values (volts) for V_{ctlmv} = 400 mV

Low values are good; machine is OK for a CDM pass V above listed values

$V_{ijCDM} \times C_i eff = V_{ctlmv} / \eta_j$

Re-examine (very large) Part D, 2005

M&M, 2005



V_{ctlmv} not bad (even on a bad day), $C_i$eff high, η unknown

Stochastic Modeling

Probability of Component Destruction

$$\int_{q_0}^{\infty} \frac{dF}{dq} \left[\sum_{k=1}^{m} \phi_1(k) \phi_2(q,k) \right] dq = \Delta.$$

Calculating impact in Defects Per Million

$$\boldsymbol{DPM_{mfr}} = 10^6 \sum_{\boldsymbol{i}} \Delta_{\boldsymbol{i}} \lambda_{\boldsymbol{i}} \boldsymbol{T_i} \, .$$

Sum is approximation of Poisson statistics for low failure rate; more in paper appendix

From Montoya and Maloney, 2005 EOS/ESD Symposium

What the antenna/calibration measurements do

$$\int_{q_0}^{\infty} \frac{dF}{dq} \left[\sum_{k=1}^{m} \phi_1(k)\phi_2(q,k) \right] dq = \Delta.$$

Machine control knowledge (V_{ctlmv})

CDM test data

For a given subprocess (machine) we now know Δ accurately

Conclusions

- New instrument correlates component CDM test voltage with field Vp-p antenna measurements better than ever
  - Instrument waveform is simple and charge packet can be easily calculated
  - Equipment varies by >2X in radiation efficiency η
    - Meaning of control limit varies, as we suspected in 2005
    - Ask “how LOUSY could the radiation efficiency be?”
- Matrix examples highlight how component-machine combination is evaluated with antenna/cal instrument
    - True passing CDM voltage for each machine or subprocess is found for each component given an antenna control limit
- Relation to 2005 stochastic model is shown
    - Risk assessment can be reduced to DPM estimates, taking one subprocess at a time
      - Antenna, CDM, and calibration data needed

Conclusions (cont'd)

- Other applications of instrument are possible
  - With its built-in 2nd charge detector, one could measure uncounted charge in CDM machine
    - Ask me how…
  - Redesign entire instrument for another ESD-related purpose
    - Transformer is good to 1500V
    - Charge up, zap, measure an ESD event of your choice

Reference

- J.A. Montoya and T.J. Maloney, "Unifying Factory ESD Measurements and Component ESD Stress Testing", 2005 EOS/ESD Symposium, paper 3A.6, Sept. 2005, pp. 229-237.