CALIBRATING ESD SIMULATORS: MEASUREMENTS VERSUS COMPUTER MODELS

ESD (electrostatic discharge) testing of virtually all electronic equipment is becoming recognized as crucial to ensuring product reliability. In point of fact, equipment that passes a reasonable range of ESD tests will have a good chance of meeting both susceptibility and emission requirements over the most difficult portions of the spectrum. In effect, ESD testing can often be a quick, cost-effective solution to the EMC problem over a wide bandwidth for both commercial and military applications.

Achieving accurate results from ESD testing necessitates a working knowledge of calibrated ESD simulators. Fortunately, calibration equipment of several kinds is now commercially available. The task is to analyze the measurements that can be anticipated from typical ESD models in order to provide a basis for comparison with calibration results.

Two basic methods are available for measuring discharge current from the ESD simulator being calibrated. The first uses a coaxial resistor load or "current-viewing resistor", while the second employs a current transformer. Figure 1 shows the resistive method.

possible," which refers to the simulator's ground return during calibration. Yet in use, the IEC specifies a ground return of 2-meter length.

In the figures and discussions that follow, the ESD simulator's initial charge voltage is always taken to be 5kV, unless otherwise indicated, to allow simple intercomparisons. Results, except for the possible effects of corona at higher potentials, can be scaled for different initial charge voltages.

Figure 4 shows the computed results of using a hypothetical IEC network: 150 pFd, 150 ohms, in the simple R-C ESD simulation circuit of Figure 3. Yet, if the circuit were the simple R-C, there would be no need to specify a rise time! (It would be zero.) Nevertheless, the IEC calls for 5 ns $\pm$ 30 percent, at 4kV. Figure 5 shows the R-L-C circuit that must exist in all cases; the inductor is inherent in the wiring. Figure 6 shows computed results for the circuit of Figure 5, for two values of inductance: 0.7 μH, corresponding with typical simulator inductance when using the "shortest possible" ground return, and 1.7 μH, corresponding with the IEC's 2-meter ground return required for practical simulator applications.

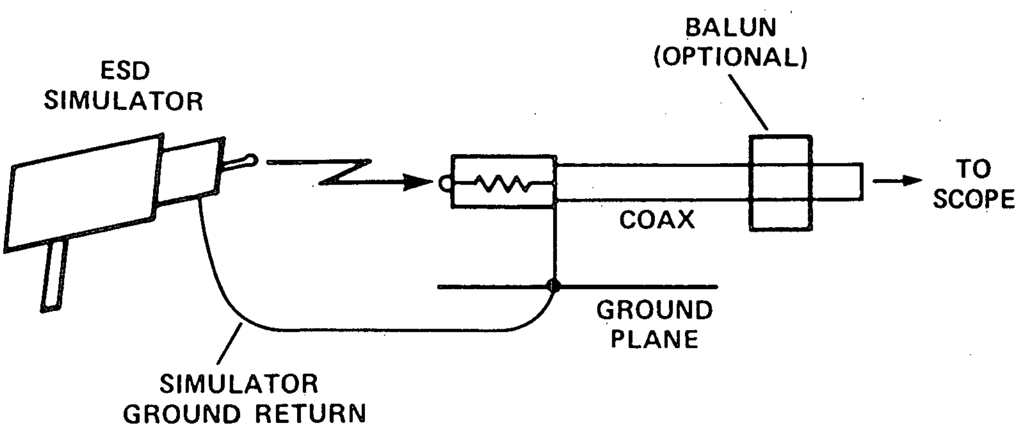

Figure 1. Calibrating an ESD Generator with a Coaxial Target or Current-Viewing Resistor.

The current-viewing resistor can either be obtained commercially or may be constructed in accordance with instructions contained in draft standard IEC 65 (secr) 80.[1] Its construction is shown in Figure 2.

The IEC ESD Standard was the first to offer instructions for calibration. Tucked into the IEC's calibration procedure is the almost-unnoticeable phrase "as short as

The computation of the waves of Figures 4 and 6 includes "filtering" to simulate the bandwidth of a 400 MHz oscilloscope, assumed to result from a single-pole network. The 400 MHz corresponds with a rise time of 0.9 ns. (Results for 100 MHz bandwidth for *these* simulator waves, at any rate, are not very different.)

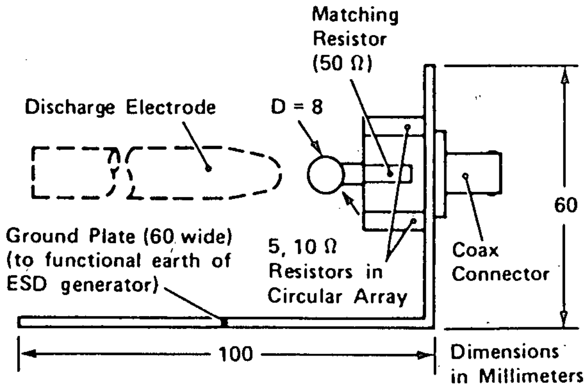

Figure 2. Coaxial Target, IEC Design.

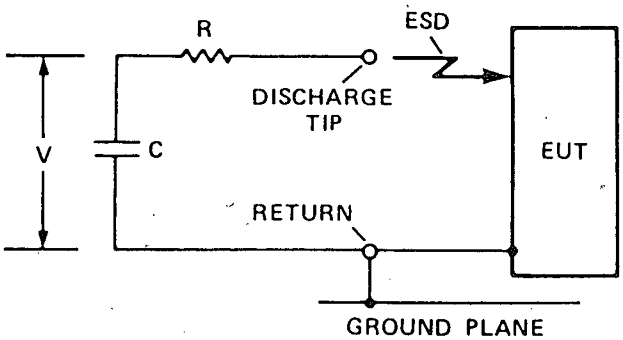

Figure 3. Simple R-C Network ESD Equivalent Circuit.

The truer R-L-C equivalent circuit of Figure 5, even including the 0.7 μH "shortest possible" ground strap inductance, gives a peak current of 25A in Figure 6, and an "efficiency" of only 75 percent versus the 5 kV stored voltage divided by the 150-ohm resistance. ("Efficiency" here refers to the ratio of delivered current peak to the peak calculated from stored voltage divided by discharge resistance.) If the real-world, 2-meter ground return is used, peak current drops to only 21A, again from Figure 6, for an efficiency of only 63 percent. If realistic arc resistance of only 50 ohms is added to the circuit, efficiencies drop still further, to 63 percent and 54 percent for the 0.7 and 1.7 μH cases, respectively. These peak currents can be easily misunderstood during calibration if the underlying causes aren't known.

It is worth noting that the IEC implicitly recognizes the efficiency limitation of the network. For its calibration voltage of 4 kV, for example, the IEC calls for a peak current with "shortest possible" ground strap of 18A $\pm$ 30 percent. (There is *no* specification for peak with the IEC-specified 2-meter long ground return.) 4 kV divided by 150 ohms is 26.7A. Thus, the basic 18A figure called for at 4 kV is already only two-thirds of the nominal V/R. If the -30 percent allowable tolerance is superimposed 18A becomes 12.6A, only 47 percent of nominal V/R. So large a tolerance may well be needed, not only because the simple R-C model neglects inductance, which in view of the IEC's 150 ohms becomes dominant, but also because the model neglects arc resistance which can be 10 to 100 ohms. Throughout this paragraph the charge voltage was taken as 4kV instead of 5kV to conform with an IEC calibration point. All of the percentages hold of course, for other voltages.

Thus, when calibrating an IEC simulator (or any other, for that matter), one should not necessarily expect to get stored voltage divided by network resistance as peak output current. The result could be far, far less. Other standard R-C networks, like ECMA's 150 pF/1000 ohms[2] or EIA's 100 pF/500 ohms[3] will give higher network efficiencies. ECMA also has a 150 pF/20 ohm network, with an efficiency *specified* at greater than 70 percent, which requires totally different techniques in simulation.

For the 100 to 150 pF capacitor values operating with ECMA's 1000 or EIA's 500 ohms, however, resistance is so much larger than the IEC's 150 ohms that the inductance effect becomes much lower and network efficiency increases.

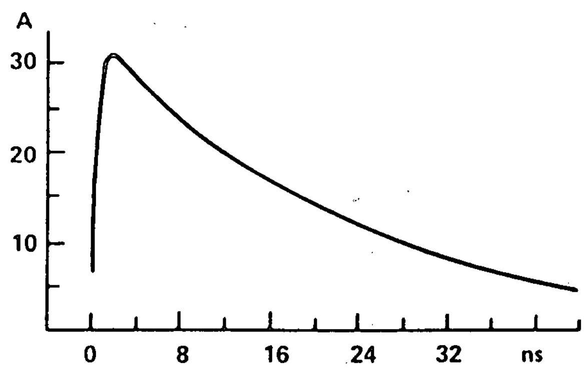

Figure 4. Computed Results for Simple R-C 150 pF/150 ohms, 400 MHz Bandwidth. 5kV Initial Charge Voltage. 5A/division, 4ns/division.

Results for different standard networks both with and without 50-ohm arc resistance are given in Table 1, for a 400 MHz bandwidth. Figures are included for both the "shortest possible" inductance of about 0.7 μH, and the real-world total inductance of about 1.7 μH that results from using a 2-meter long ground return. The IEC's 150 pF/150 ohms and ECMA's 150 pF/20 ohms are the two networks that stand out with far lower peak currents than simple V/R calculations would suggest, whether with the 0.7 or the 1.7 μH inductance, and with or without added arc resistance. This clearly has implications for both calibration and use of ESD simulators that incorporate these parameter values.

It's worth noting that it does not pay to work too hard at "squashing" the loop made by the 2-meter long ground return. In practice, reduction in inductance from 1.7 μH to not much less than 1.3 or 1.4 μH will be about the best that can be achieved.

Finally, and probably most important for real-world

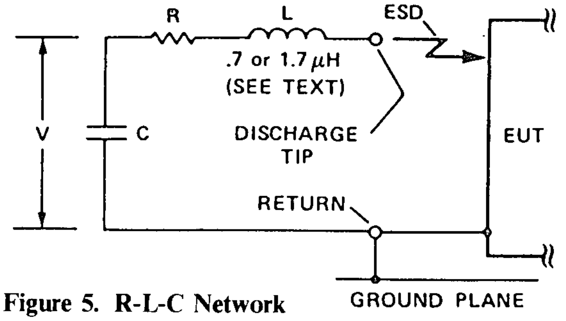

Figure 5. R-L-C Network ESD Equivalent Circuit.

testing, newer ESD testers may include configurations designed to replicate the fast initial spike that really occurs during a human discharge[7]. The <1 ns rise time and 2-4 ns

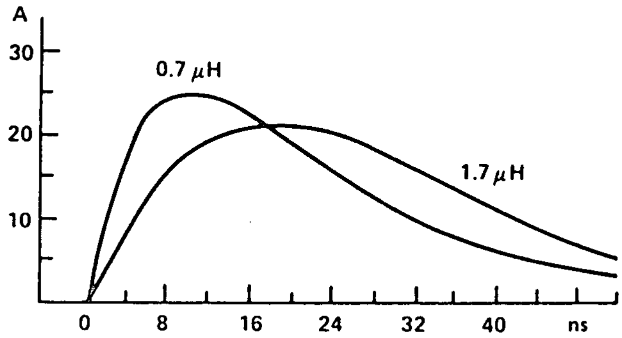

Figure 6. Computed Results for R-L-C Network 150 pF/150 ohms, 400 MHz Bandwidth. 5kV Initial Charge Voltage 5A/division, 4ns/division.

duration of such spikes imply that a 100 MHz scope will display only 55 to 60 percent of actual peak current magnitude. Calibration of such simulators, and/or measurement of the human discharge event itself, both require the performance of at least a 400 MHz oscilloscope.

			Peak Current and Efficiency η, Short Return ($\sim$0.7μH)				Peak Current and Efficiency η, Long Return ($\sim$1.7μH)			
			Zero Arc Resistance		50-ohm Arc Resistance		Zero Arc Resistance		50-ohm Arc Resistance	
Standard or Draft Standard	C(pF)	R (Ω)	I (A)	η (%)	I (A)	η (%)	I (A)	η (%)	I (A)	η (%)
IEC[1]	150	150	25	75	21	63	21	63	18	54
ECMA[2]	150	1,000	5	100	4.7	94	4.8	96	4.6	92
ECMA[2]	150	20	59	24	39	16	41	16	31	12
EIA[3]	60	10,000	0.5	100	0.5	100	0.5	100	0.5	100
EIA[3]	100	500	9	90	9	90	9	90	8	80
NEMA[4]	100	1,500	3.3	100	3.2	96	3.2	96	3.1	93
MIL[5]	100	1,500	3.3	100	3.2	96	3.2	96	3.1	93
SAE[6]	300	5,000	1	100	1	100	1	100	1	100

Table 1. Peak Current as a Function of Ground Return and Arc Resistance. All Figures for 5kV Initial Charge Voltage and 400 MHz Bandwidth (Efficiency = Peak Current ÷ V/R).

REFERENCES

1. International Electrotechnical Commission IEC 65 (Secr) 80 Draft Standard: Electrostatic Discharge (for Industrial Process Control). Now IEC Pub. 801-2, 1984.
2. ECMA (European Computer Manufacturers' Association), Electrostatic Discharge Susceptibility, TR/23, Sept. 1984.
3. EIA (Electronic Industries Association) Standards Project PN-1361, Environmental and Safety Considerations for Voice Telephone Terminals, Draft 5, Nov. 24, 1981.
4. NEMA, Residential Controls, Environmental Testing for Electronic Controls, Part DC33, Proposed June 24-25, 1982.
5. MIL-STD-883B, Test methods and Procedures for Micro Electronics.
6. SAE Standard Recommended Practice Information Report J-1211, June 1978, p 20.99.
7. P. Richman and A. Tasker, ESD Testing: The Interface Between Simulator and Equipment Under Test, Proceedings of The Sixth EMC Symposium, Zurich, Switzerland, March 5-7, 1985.

This article was written for ITEM 85 *by Peter Richman, President, Key Tek Instrument Corporation, Burlington, MA.*