The “Real” Cost of ESD Damage

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Anyone who has worked in Quality or Reliability in a large corporation knows that developing and presenting credible failure cost information can be difficult. This is particularly true for ESD, where the events are invisible and not nearly as well understood as other more obvious classes of failure, such as mechanical or contamination. The "real" cost of ESD can be a hot topic of discussion each year when program budgets are being developed for manufacturing and R&D programs. The challenge is that every year there are new high-level people in the financial and planning organizations who are not technical experts and who are asking hard questions about the justification for the ESD investment. In years when revenue is down, the questions become more difficult and better evidence is often demanded. The author was directly involved in this process for 15 years, starting in 1986. At the time the following quote was a part of many ESD funding discussions; "… in the electronics industry, losses associated with ESD are estimated at between a half billion and five billion dollars annually." The exact original reference for this assertion has been lost, at least to this author. Nonetheless it was used many times over the next few years in presentations to the corporate check writers. Furthermore, during research for background information for this article, the exact same quote appeared (unattributed) in an article from 1992[1] and in a book published in 2006[2]. Needless to say, a well-stated assertion of value can go a long way – at least in trade literature. However, this author can also report that the usefulness of this, inside the corporation, eroded much faster. By 1990, a well-known director in Bell Labs said; "… that was then… I think this problem has been solved!" Many of us would scoff at such a declaration, knowing full well that ESD problems were continuing to occur. However, the directors' challenge was an appropriate one. His experience came from the semiconductor process world where he had seen significant ESD sources eliminated and device thresholds (albeit HBM only) steadily increase. Corporations would like their investments to be justified by more timely and relevant data and observations. They ask, "What is the "real" cost?"

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[1] Sandia Science News, February 1992

[2] T. Trost, **Electrostatic discharge (ESD) - Facts and faults - A review**. A 1995 article in Packaging Technology and Science, Volume 8, Issue 5, Pages231 – 247 published on-line in 2006. (Wiley)

Of course the immediate "real" cost information is very difficult to determine. In fact the use of the term "real" in the title reflects the collective skepticism ESD program managers and champions typically encounter. The $5 billion dollar loss number which applies to everyone, but not to one's own situation, carries little weight in the final analysis. As a result it is necessary to resist the temptation here to assert an updated number for world-wide losses due to ESD. Instead, this article revisits the collective argument that ESD losses are potentially significant and that pressures that produced high failures rates (based on evidence published in the past), will increase with technology trends. Further, the current cost is probably not the most significant metric. This is true of most quality, reliability, or maintainability metrics. The entire justification for the investment (which is typically viewed as expense by the financial organization) is really cost avoidance. Later in the article there will also be an argument that there are other, possibly even more important reasons for investing in ESD control and design. Making convincing arguments about potential losses have historically been very difficult as they must depend on studies done off-line or in the early days of implementation. In this article some of the important studies and articles that have appeared over the last 30 years regarding cost/benefits are reviewed. These include some classic split lot experiments that showed the immediate impact of implementing an ESD program where none previously existed. In other more recent studies the investigators did not have the luxury of turning their program on and off, but nonetheless they were able to extract good information for the overall value proposition. There is no claim made here that this is a comprehensive collection of the most significant work. Rather, it represents studies that are known to this author and many colleagues and which are available as public information. There were many other proprietary internal studies which established the economic justification of programs that cannot be described here.

In 1989 the ESD Association published a collection of papers[3] from the first ten years of the EOS/ESD Symposium. This collection, **An ESD Management Focus,** was intended to provide ESD program advocates with a single source of significant work in supporting ESD programs and highlighting management issues. To this day it is still a useful source of information as 7 of the 19 articles in the collection directly address cost and benefits of the programs. Several of the studies are summarized here.

Early "split-lot" Experiments

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[3] *An ESD Management Focus, 1989 EOS/ESD Association*

At the time of the first EOS/ESD symposium in 1979 there were few mature ESD programs, but many companies were trying to establish them. Some of these companies were also developing their case for management through actual split lot experiments.

Western Electric Denver Works (1981)[4]- In this study the initial deployment of a basic ESD program was observed with careful collection of yield loss data for five key operations. Documented yield improvement up to 10.73% was observed, and with the assistance of the plant financial organization, the return-on-investment was estimated to be in the range of 900-2300%, depending on assumptions. This study was also significant in that it demonstrated that an effective program could be implemented in a very dry environment such as Denver, Colorado's without humidity control.

Western Electric North Andover Works (1983)[5]- This work included three separate definitive experiments on the effectiveness of ESD programs. Again, since ESD controls of any kind had not yet been implemented, simple split-lot experiments could be conducted. In these experiments as many as 1275 units were processed in single experiment with and without controls. Clearly, it would be difficult to justify taking these risks today. Ratios of the number of failures in the unprotected and protected lots ranged from 1.9:1 to 5.5:1. The return on investment (for implementation of wrist straps and some ESD-protective transport materials) was as high as 950%. The quality assurance organization also studied the quality of outgoing product. The controls instituted in the factory resulted in a 3:1 reduction of defect rates.

Lockheed Missiles and Space Company (1983)[6] – In this study failure data before and after program implementation was collected and explicit cost avoidance estimates were made. A detailed itemization of implementation and maintenance costs was weighed against extrapolated expected failure costs and an annual savings of almost $2 million/year was demonstrated.

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[4] "The Economic Benefits of an Effective Electrostatic Discharge Awareness and Control Program – An Empirical Analysis", W. Y. McFarland, EOS-3, pp. 28-33 (1981)

[5] "ESD – How Often Does It happen?", G. T. Dangelmayer, EOS-5, pp.1-5 (1983)

[6] "ESD Control Implementation and Cost Avoidance Analysis", M. H. Downing, EOS-5, pp.6-11 (1983)

No doubt there were many other studies done similar to these. The fact that no one is willing to risk doing these studies again is a testimony to the broadly accepted expectation that it would cost a lot of good product and precious production output. Some useful papers have also been published which describe in general terms how to gather cost information[7], estimate ROI[8], and provide basic understanding of the statistics of failure[9]

Correlating Program Effectiveness and Yield

Studies that have followed the early split-lot work have had to detect the correlation between the strength of the ESD program and its effectiveness in improving yield. However, finding the data to support this correlation has proved difficult as well. In one example[10] a factory was able to track ESD-related failures, as determined in Failure Mode Analysis, with deviations from specified procedures (Figure 1). It is rare that data can be de-constructed in this way and there were some fortunate circumstances that allowed it in this case. In another very meticulous study[11] investigators were able to track yield at specific facilities and correlate it with the relative auditing scores. Based on this they were able to estimate the return-on-investment (3:1 in one study and 11:1 in another) of the specific procedures followed at the "exemplary" factories.

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[7] "Estimating ESD Losses in the Complex Organization", S. A. Halperin, EOS-8, pp 12-18 (1986)

[8] "ESD Control and ROI", R. C. Allen, Evaluation Engineering (November 1999)

[9] "Cost Benefit Analysis – How Much Is Enough", R. Y. Moss, EOS/ESD Technology Europe (Spring 1990). Also available at http://www.esdjournal.com/techpapr/eosesd/analysis/enough.htm

[10] G. T. Dangelmayer, *ESD Program Management, 2nd Edition (1999), p58*

[11] "ESD Protection Measures Return on Investment Calculation and Case Study", K. Helling, EOS-18, pp. 130-144, (1996)

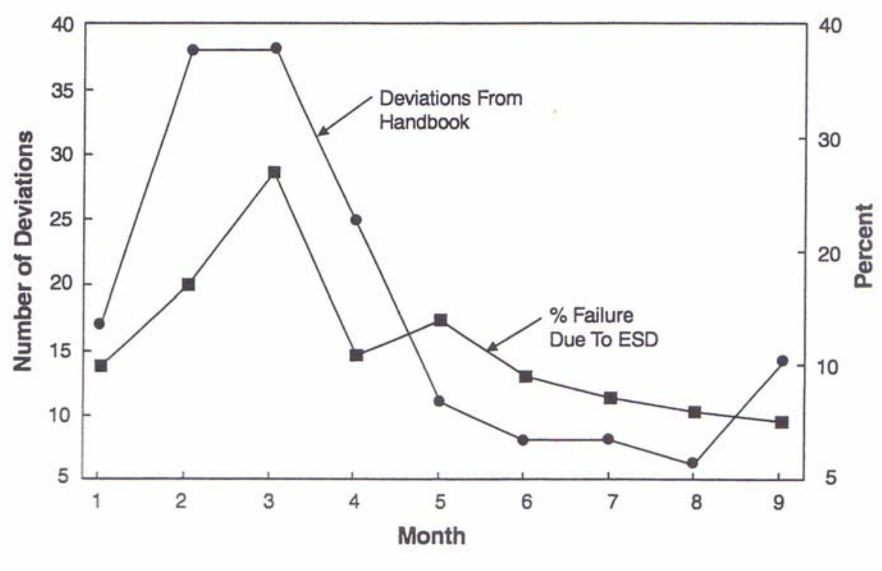

Figure 1: Correlation of ESD failure occurrence and deviations from ESD (Handbook) procedures

Misdiagnosis of ESD as EOS

Understanding the cost of ESD requires accurate and timely Failure Mode and Root Cause Analysis. A relatively recent body of work suggests that some designations of failure modes need to be reconsidered. Most ESD testing and characterization of components is done on stand-alone parts. IC failure analysis data, which is usually based on knowledge of failure signatures seen in standard HBM and CDM tests, has caused many to conclude that ESD failures are relatively rare when compared to other electrical failures commonly classified as electrical overstress (EOS). Recent data and experience reported by several companies and laboratories now suggest that many failures previously classified as EOS may instead be the result of ESD failures due to Charged Board Events (CBE).[12] The reason for this is that boards may store considerably more charge than is stored in the standard CDM tests. The resulting failure signature shows more physical damage (Figure 2) than a stand-alone device failure would and thus FA experts unfamiliar with this phenomenon often make the wrong diagnosis. In addition, similar observations have been made regarding the misdiagnosis of Cable Discharge Events (CDE) as EOS.[13] Some companies have estimated that about 50% of failures originally designated as EOS were actually CBE or CDE.

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[12] "Real-World Printed Circuit Board Failures," A. Olney, B. Gifford, J. Guravage, A. Righter, EOS/ESD Symposium Proceedings, EOS-25, pp. 34-43, 2003.

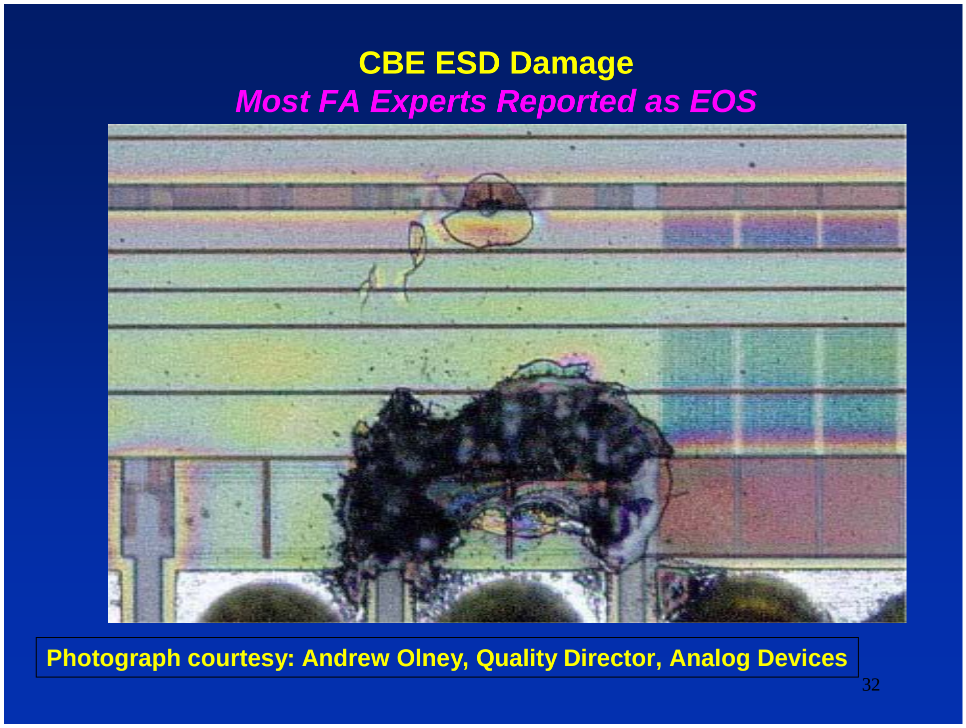

Figure 2: A Charged-Board ESD Event Failure Signature Resembles EOS

The Real "Real" Cost of ESD – The Crisis

[13] "EOS versus ESD Misdiagnosis: Charged-Board Events Are a Growing Industry Concern" G. T. Dangelmayer, T. L. Welsher, and A. Olney, Medical Electronics Manufacturing, Spring 2009

The studies described above and many others like them have served the advocacy of ESD program implementation well. While they are each very specific, it is easy to argue that the effects are general. They are also posed and conducted in terms that fit well with conventional financial metrics. However, the greatest costs due to ESD have come from a different source. Each of us who has been working in this area very long knows that the most obvious example of ESD cost is the “crisis”. When viewed this way an ESD program is more like insurance to shield the organization from disaster. Many of these crises have become the source of symposium papers and case histories. It could be argued that even if the ROI estimates from the studies above showed that the ROI was 1:1 or even a little less, most companies would still need good ESD programs. Crises affect a different set of metrics: productivity, time-to-market, time-to-profit, timely delivery and, of course, customer perception and confidence. This is why composite failure data is so misleading. A 1% of cost of sales failure level for ESD across the industry does not reflect the fact that perhaps 0.01% led to unacceptable damage to these other metrics. Some organizations go through cycles of crisis and cost reduction, particularly when there are management changes and a lack of long term data reporting.

Effect of Device Thresholds – Control/Protection Balance

Mitigation of ESD damage in electronics manufacturing depends on a dual strategy. In this discussion the focus has been on the ESD control program. However, these programs would not be nearly as effective in maintaining high yield manufacturing if it were not for the parallel efforts of device designers to provide built-in ESD protection. This situation is illustrated in Figure 3. The front line in keeping yields high is at the point where devices become so sensitive that the “usual” procedures are not sufficiently effective. Of course experts are not in complete agreement as to where this point is and what additional controls are necessary. The point is that the risk of increased damage and higher costs will accelerate quickly as this regime is approached. The industry as a whole has arrived at a balance between these efforts, which are primarily driven by costs involved in the two parallel approaches, and which is weighed against the performance and function the customers are demanding, while of course maintaining a reasonable or decreasing product cost.

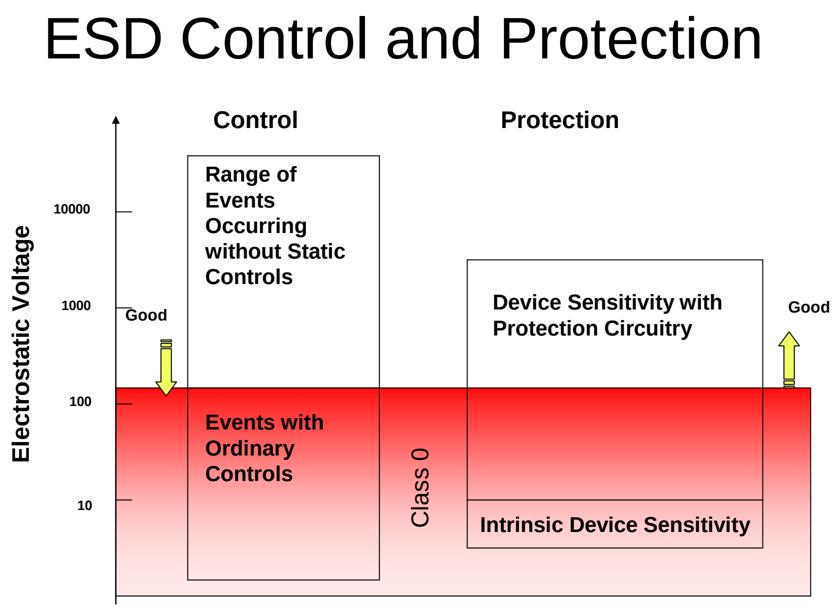

Figure 3 – Cost Effective Programs Balance Factory Control with Built-In Protection

For several years this balance was tipped in favor of high device thresholds because the technology allowed it. Specifically, there had been a *de facto* standard of 2000 volts for the Human Body Model (HBM) ESD thresholds of integrated circuits. Recently an industry group, the Industry Council on ESD Targets, has issued two white papers addressing this issue for both HBM[14] and the Charged-Device Model (CDM)[15]. These studies have demonstrated that the *de facto* targets, especially the HBM level, amount to substantially increased cost with little benefit. The increased cost of maintaining these targets in increasingly dense IC technologies results in very poor ROI. The studies on CDM, whose target was less widely used at about 500 volts, further suggest that improved implementation of CDM controls will be required. This is because the CDM targets for future technology nodes will at 250 volts and, for some high performance devices, 125 volts.

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[14] ESD Industry Council White Paper I: A Case for Lowering Component Level HBM/MM ESD Specifications and Requirements

[15] Industry Council **White Paper II: A Case for Lowering Component Level CDM ESD Specifications and Requirements**

Conclusion

In this article an attempt is made to bring the ESD value proposition up to date. The significant experiments done in the early development programs are relevant to today's processes. On-going yield losses have been estimated and the operational ROI has been demonstrated many times to be significant. This alone suggests the investment in ESD control programs is a sound practice. The most significant effects, however, are the avoidance of crises, process excursions, downstream effects on higher value-added products, and maintaining positive customer perception. Technology trends suggest that the value of ESD control programs will increase and that more attention will be needed to maintain and improve them.

Dr. Terry L. Welsher is currently Senior Vice President of Dangelmayer Associates. He began his career in Bell Labs in 1978, where he worked on electrolytic corrosion failure mechanisms in electrical interconnection materials. In 1986 he began directing Bell Laboratories' core expertise in electrostatic discharge (ESD). The newly formed group proceeded to produce a string of ground-breaking contributions to the field and played a key role in advancing industry standards. At his retirement from Lucent Bell Labs in 2001, he was Director of the Quality, Reliability and Test Center of Excellence. Dr. Welsher has served as Chairman of the ESDA Standards Committee and Technical Program and General Chair of the EOS/ESD Symposium. He is currently a member of the ESDA Boards of Directors, and is serving as the 2010 Vice President of the ESDA. He has also been active in the JEDEC Quality and Reliability Committee and Board of Directors. Most recently he has co-led the effort to harmonize and merge JEDEC and ESDA device testing standards. He holds a B.S. in Chemistry from Florida State University and a Ph.D. in Chemical Physics from the University of Texas at Austin. Terry and his wife, Karyl, live in Suwanee, Georgia.