Undamped, Length Varying TLP Pulses Measurements and ESD Model Approximations

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***Abstract*— Since the introduction of the transmission line pulse –TLP- for the study of electrostatic discharge –ESD- events on integrated circuits –IC-, there has been many approaches on how to compare its tests results with those from other ESD models. Despite it has a very strong correlation with the industry-standard human body model –HBM-, most implementations of TLP weren't suitable for comparisons with other ESD models. This work studies the different uses of TLP equipment in order to achieve different testing waveforms, and infers results to other ESD models based upon the analysis of their results through simulations and statistic testing.**

I. Introduction

Along with the constant evolution of semiconductor devices –SD– technology, also come electrical overstress problems caused by electrostatic discharge events [1, 2]. ESD events can occur on several stages of an integrated circuit –IC– production process, from the first instances of silicon waffer cutting to the customer's board mounting of the finished product [1, 2]. Since there are different charged objects that can place vastly different ESD threats to ICs, several ESD models exist. The industry broadly accepted mainly three of them: The human body model (HBM), the machine model (MM) and the charged device model (CDM) [3, 4, 5, 6, 7, 8, 9].

Protection circuits are implemented and tested on the ICs inputs and outputs in order to provide robust protection in the case of an ESD event. Still, different ESD testers could provide inconsistent information due to different implementations, as well as misleading data of the protection circuit characteristics –this is where TLP becomes a very powerful tool [2, 10, 11]. The TLP implements a square current waveform with controlled amplitude and time length, which makes testing and information gathering of protection circuits much easier and accurate.

Despite not being a standard, the TLP is nowadays the preferred testing method to run ESD tests on ICs, and so it has become a must for ESD testing [11, 12].

This paper covers alternative implementations of the TLP in order to achieve different waveforms and yet bring the benefits of the TLP testing over other testing methods.

II. Basic waveforms

A. Standard ESD waveforms

Most ESD models standards define their waveforms through time and amplitude constraints, such as possible time lengths or peak amplitudes. Though, most of them suggest simple implementations and recommended component values, which can be used to build basic models that both comply with the standard and are easy to implement. Their waveforms are shown in Figure 1, which are typical of simple 1st or 2nd order circuits.

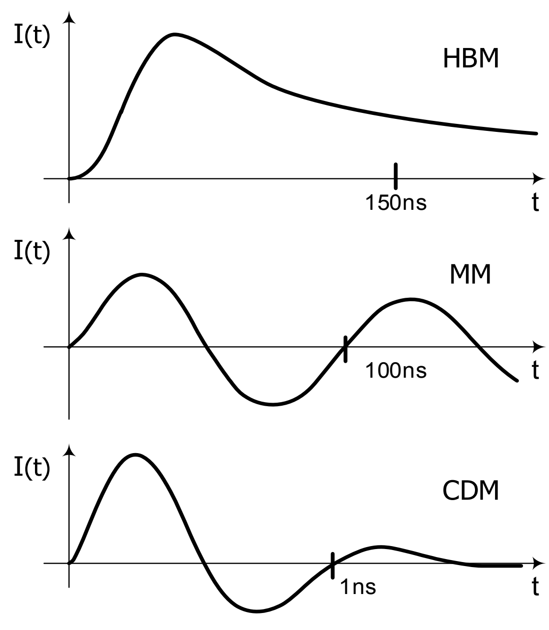

Figure 1. Waveforms of some basic ESD models.

B. The TLP: How it works

The TLP, whose basic scheme is shown on Fig. 2, discharges a transmission line on the device under test –DUT– generating a square waveform –see Fig. 3-. The transmission line is previously charged by a high impedance high voltage supply, and is later discharged on the test device, delivering a square current pulse to the device. The high voltage supply V_G controls the current waveform amplitude, while the pulse duration is set by the transmission line length, for example d = 10m [10, 13, 14].

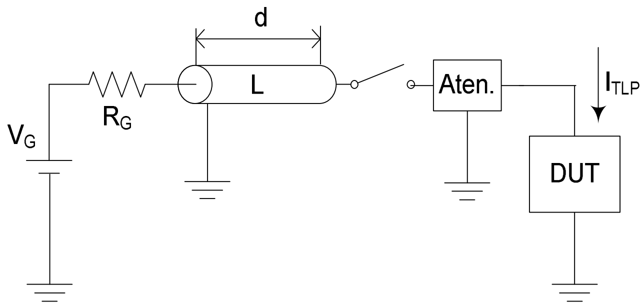

Figure 2. Basic TLP scheme

Since the DUT is designed to have low impedance during ESD events, the system will be mismatched in terms of transmission lines. This is the reason why the attenuator is introduced: it provides and input and output characteristic impedance Z_0, so the system is kept matched and independent of the DUT [12, 15].

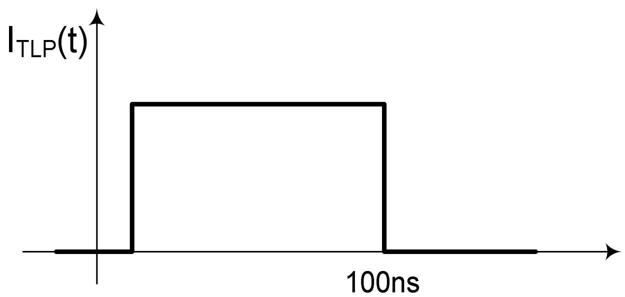

Figure 3. Typical TLP waveform

The advantage of this approach is that the pulse shape, and particularly its rise-time, is not altered, because it travels through an adapted system.

The TLP is used to obtain information of traces of protection devices. This is achieved through a series of shots which increase its initial voltage charge, and measures current and voltage across the device, until it fails [2, 16].

All tests shown in this work were performed by the authors on 1.5μm length, high width, high current and medium voltage grounded gate MOS (GGMOS) structures. Figure 4 shows a typical protection trace which was obtained by the authors with an industry standard TLP equipment, under the 1μA leakage current failure criterion.

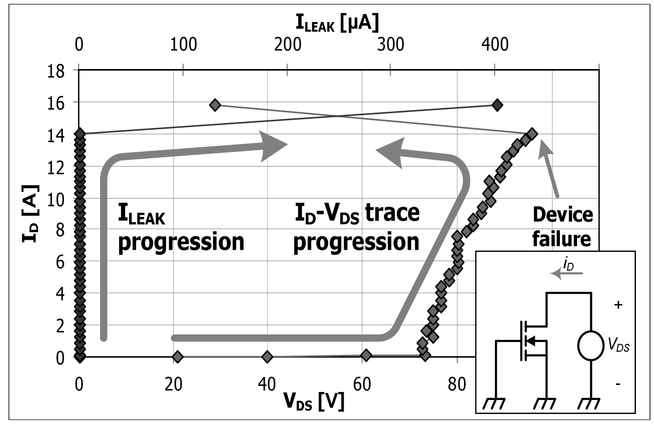

Figure 4. Typical I_D-V_{DS} trace for a 1.5μm GGMOS protection device.

III. TLP – HBM COMPARISON

It's well-known that TLP compares to HBM [4] under certain conditions for many existing technologies [1, 16]. The correlation between the two models can be found via their instantaneous peak current, which can be related to their initial charge voltages through:

$$V_{TLP} = \frac{V_{HBM} \cdot Z_0}{R_{HBM}} \qquad (1)$$

Where,

V_{TLP}: initial charge voltage of the TLP model.

V_{HBM}: initial charge voltage of the HBM model.

R_{HBM}: series resistance of the HBM (see Fig. 5).

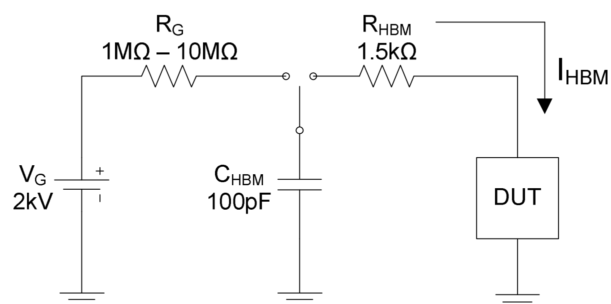

Figure 5. Proposed HBM (standard values).

To back equation (1), TLP and HBM tests were performed. The DUT were the GGMOS structures mentioned before, again with the 1μA leakage current failure criterion and using 20 samples per test.

Figure 6 is built from the acquired mean and standard deviation values of their peak current failure, and it can be seen the high correlation between the failure peak current of both models.

Despite both models have completely different waveforms, the results of one test can be inferred through the other model's testing data. But since TLP testing offers many benefits in curve tracing simplicity, it makes it preferable over the HBM.

As for other standard ESD models like MM or CDM, since they have damped-oscillating waveforms this direct comparison cannot be done, or performs badly [13, 14].

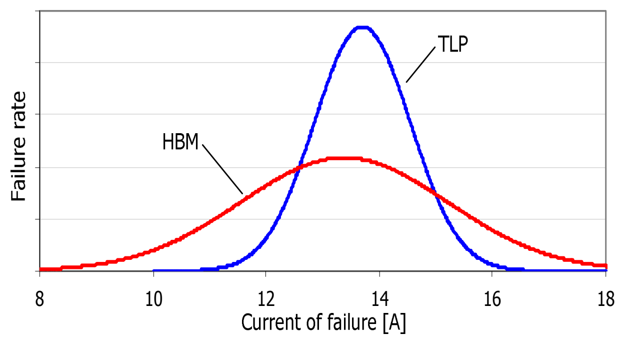

Figure 6. Statistic distributions of TLP and HBM test failures.

So, a new test model is proposed: a non-adapted TLP, to observe how it performs when comparing to damped-oscillating waveforms.

IV. THE NON-ADAPTED TLP

The non-adapted TLP –NA-TLP– removes the attenuator from the TLP previously shown, and becomes the TLP shown in Figure 7.

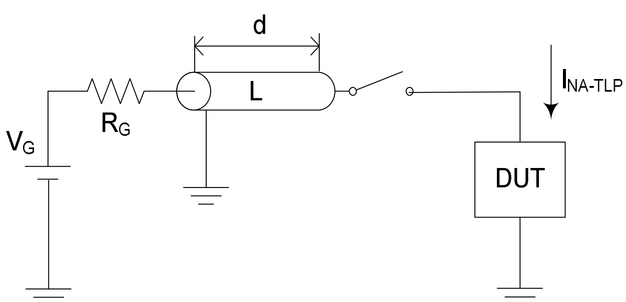

Figure 7. The NA-TLP circuit.

Removing this attenuator causes the current pulse reflected at the DUT to travel back to the power supply, where it finds a high impedance source. Then the current pulse is reflected back again to the transmission line and back DUT, but with its polarity inverted.

This leads to a series of reflected pulses that invert their polarity when they reflect on the power supply.

Yet, the waveform can be described in terms of pulse reflections for a single shot, through the reflection coefficient for each lobe amplitude:

$$\Gamma_{L,i} = \frac{V_{-,i}}{V_{+,i}} = \left(\frac{V_{BD}}{V_{+,i}}\right) \cdot \frac{Z_0}{R_{dyn} + Z_0} + \frac{R_{dyn} - Z_0}{R_{dyn} + Z_0} \quad (2)$$

Where,

V_{BD}: breakdown voltage of the DUT.

R_{dyn}: dynamic resistance of the DUT at breakdown.

$V_{-,i}$: forward voltage-waveform reflection.

$V_{+,i}$: reverse voltage-waveform reflection.

The final waveform depends on many factors; among them are the breakdown voltage and dynamic resistance of the DUT, and the amplitude of each traveling reflected voltage-wave in the line. This leads to the relative amplitudes of the series of pulses to vary on each particular test.

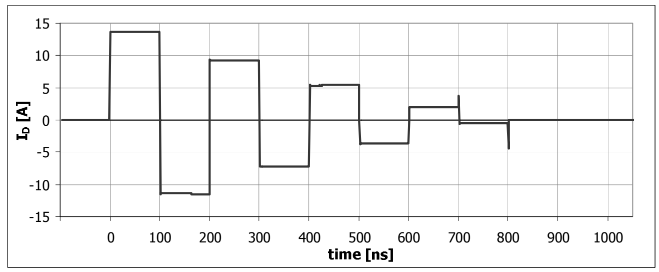

Figure 8. Typical NA-TLP waveform.

Figure 8 exposes a NA-TLP waveform for a 1.5µm technology DUT, where it can be seen the oscillating nature of the waveform when the attenuator is removed.

It is worth mentioning how simple are the modifications on some TLP equipments to implement this waveform, given the fact that the attenuator can be easily removed from the signal path on some standard TLP equipments [19].

V. NOT ADAPTED-TLP – ADAPTED TLP COMPARISON

The basic modification that can be performed in order to get closer to the MM standard values is to shorten the transmission line length, *d*, from 10m to 5m, which halves the waveform oscillation period to 100ns, and is referred to as a 50ns NA-TLP, which is the time length of its pulse lobes.

Figure 9 show the test results of the proposed NA-TLP, compared to the standard TLP. These results show that the peak current is not much affected, and so the current failure is independent of whether the system is adapted or not.

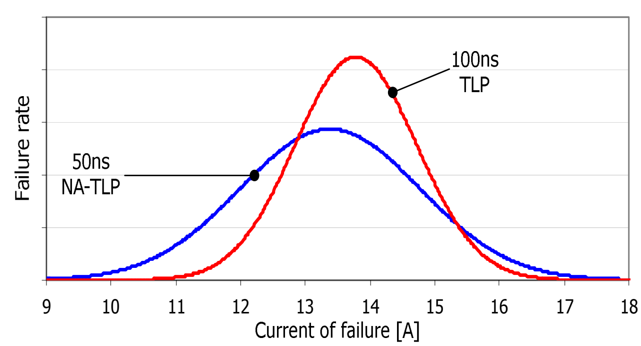

Figure 9. Peak current distributions for 50ns NA-TLP and 100ns TLP.

Figure 10 shows the different secondary pulse failures. These are failures that do no occur in the first lobe of the waveform, and thus implies that the DUT fails on a pulse with an inferior peak current.

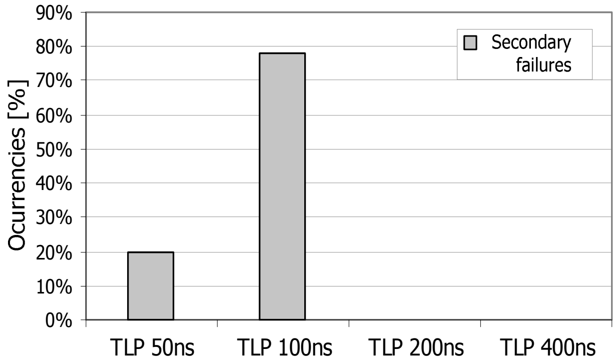

Figure 10. Point of failure: Secondary failures.

This failure mode can be strongly related to the MM, in which the alternating current can cause failures on many of its lobes [1, 13], as opposed to the HBM. So, it can be seen that the 100ns NA-TLP can have a closer correlation to the MM than the standard TLP, and other NA-TLP models.

VI. WHY 100 NS TLP

With further changes on the line length *d*, the NA-TLP pulse length was set from 50ns to 400ns. The results are shown in Figure 11, where can be seen that the line length does not much alter the current failure, keeping it between 13 and 15 ampere.

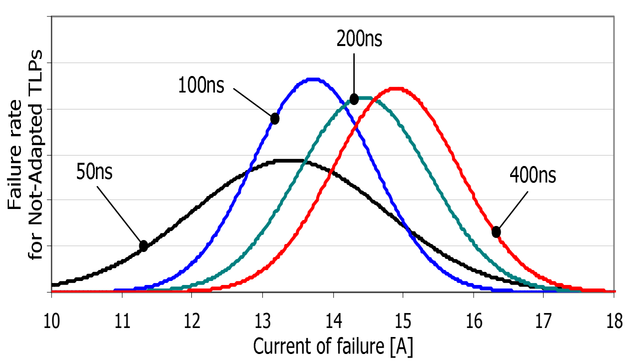

Figure 11. Failure current distribution vs. NA-TLP pulse width.

Even though, there is a qualitative difference when looking at which lobe causes the failure. It was found that the 100ns NA-TLP, in 77% of the cases, causes the DUT to fail on secondary pulses, whereas the other tested TLPs cause more failures in primary pulses.

Figures 12 and 13 show the NA-TLP waveforms used, acquired with a 1Gb/s digital storage oscilloscope.

In Figure 13(b) it can seen that the current decreases 8% due to losses in the transmission line, but the waveform still proved useful for measurements.

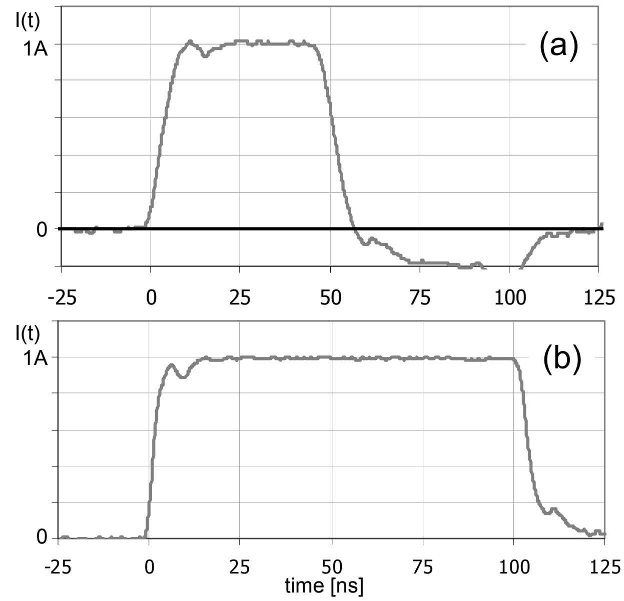

Figure 12. NA-TLP test waveforms (a) 50ns (b) 100ns.

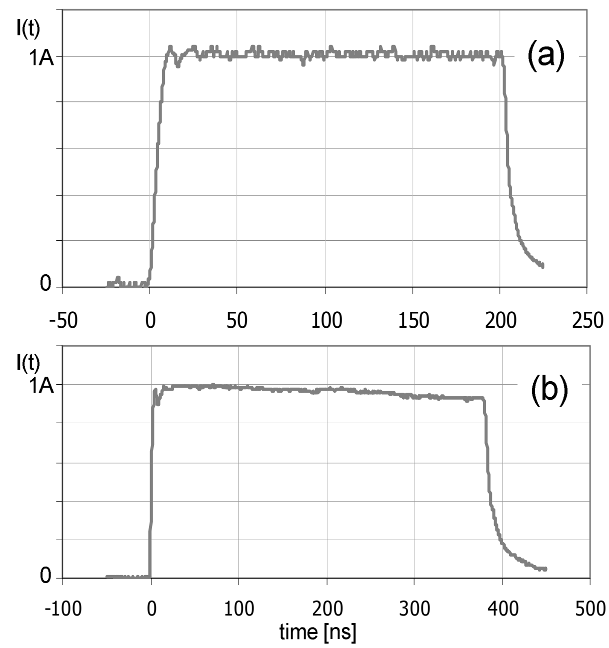

Figure 13. NA-TLP test waveforms (a) 200ns (b) 400ns.

VII. CONCLUSION

The empirical approach to obtain a TLP alternative to achieve a better MM measurement was found. Again, it's worth mentioning that the proposed NA-TLP tester can be obtained from a standard TLP tester with minimal modifications.

The obtained waveforms can comply with many standards, given slight modifications to control their period. Although the waveform is quite basic in shape when compared to the MM, it provides relevant results in the failure characteristics of the DUT.

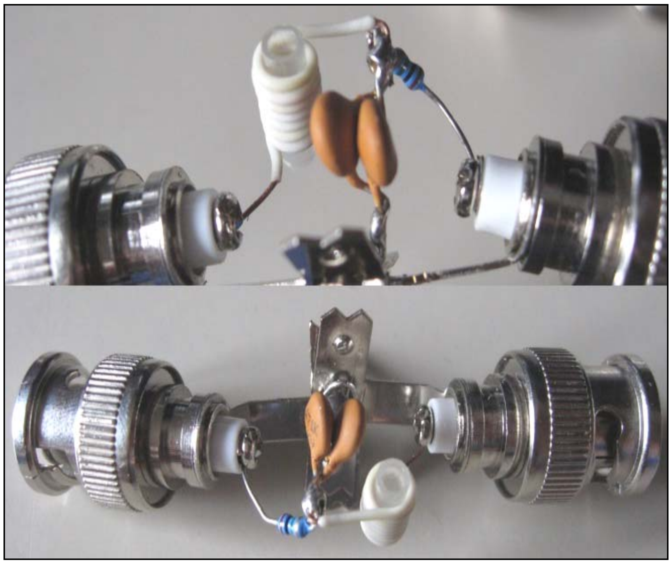

Figure 14. Filter between the NA-TLP equipment and the DUT to achieve a MM waveform.

Also, to achieve a better waveform approximation to a MM, a simple filter can be included between the NA-TLP equipment and the DUT, to partially smooth the high frequency content of the waveform. Figure 14 shows an implementation example of this filter.

Finally, this method proved to provide reliable information of the DUT characteristics, as well as a new testing method that can be done with existing standard ESD testing equipment.

ACKNOWLEDGMENTS

The authors would like to thanks to Cima Ingeniería and TLP Solutions for their collaboration and for letting us use their TLP 50 tester, and for their technical support during the tests.

REFERENCES

[1] J. Vinson and J. Liou, “Electrostatic Discharge in Semiconductor Devices: An Overview”, *Proceedings of the IEEE,* Vol. 86, No. 2 pp. 399-420, Feb. 1998.

[2] Albert H. Z. Wang, "*On-chip ESD Protection for Integrated Circuits – An IC Design Perspective*" 1st edition, Springer ISBN 0-79-237647-1, 2002

[3] "*IEEE Guide on Electrostatic Discharge (ESD): Characterization of the ESD Enviroment*", IEEE Std C62.47-1992, 1992

[4] “*MIL-STD-883G: Method 3015.7 Electrostatic Discharge Sensitivity Classification*”, Department of Defense Handbook Standard, 1989

[5] “*ANSI/ESD SP5.1.1-2006: Standard Practice for Human Body Model (HBM) and Machine Model (MM) Alternative Test Method: Supply Pin Ganging Component Level*", Electrostatic Discharge Association, 2006

[6] “*EIA/JESD22 Test Method A115-A: Electrostatic Discharge (ESD) Sensitivity Testing Machine Model (MM)*”, Electronic Industries Association, 1997.

[7] “*ANSI/ESD STM 5.2-1999, Electrostatic Discharge Sensitivity Testing - Machine Model (MM) Component Level*”, Electrostatic Discharge Association, 1999.

[8] “*JEDEC JESD22-C101C: Field-Induced Charged-Device Model Test Method for Electrostatic-Discharge-Withstand Thresholds of Microelectronic Components*”, JEDEC Solid State Technology Association, 2004.

[9] “*ESD STMS 3.1: Charged Device Model (CDM) Component Level for Electrostatic Discharge Sensitivity Testing*”, Electrostatic Discharge Association, 1999.

[10] T. J. Maloney and N. Khurana: “Transmission Line Pulsing Techniques for Circuit Modeling of ESD Phenomena”, *Proc. 7th EOS/ESD Symp.,* p. 49, Sep. 1985.

[11] H. Hyatt, A. Alonzo and P. Bellew: “TLP Measurements for Verification of ESD Protection Device Response”, *IEEE Transactions on Electronics Packaging Manufacturing,* Vol. 24, No. 2, pp. 90-98, April 2001.

[12] J. Barth, K. Verhaege, L. G. Henry and J. Richner: “TLP Calibration, Correlation, Standards and New Techniques”, *IEEE Transactions on Electronics Packaging Manufacturing,* Vol. 24, No. 2, pp. 99-108, April 2001.

[13] G. Notermans, P. de Jong and F. Kuper: “Pitfalls when correlating TLP, HBM and MM testing”, *Electrical Overstress/Electrostatic Discharge Symposium Proceedings*, pp. 170-176, 6-8 Oct. 1998.

[14] W. Stadler, X. Guggenmos, P. Egger, H. Gieser and C. Musshoff: “Does the ESD-failure current obtained by Transmission-Line Pulsing always correlate to Human Body Model tests?”, *Electrical Overstress/Electrostatic Discharge Symposium, Proceedings*, pp. 366-372, 23-25 Sep 1997.

[15] L. G. Henry, J. Barth, K. Verhaege, and J. Richner, “*Transmission-Line Pulse ESD Testing of ICs: A New Beginning*”, Compliance Engineering, http://www.ce-mag.com/ce-mag.com/archive/01/03/0103CE_046.html, March/April 2001.

[16] Julio Zola, Gonzalo Pacheco, "TLP: ESD models correlation and aproximation", *Proceedings of the Argentine School of Micro-Nanoelectronics, Technology and Applications 2009*, pp. 93-97, 2009.

[17] J. Vinson and J. Liou, “Electrostatic Discharge in Semiconductor Devices: Overview of Circuit Protection Techniques”, *Electron Devices Meeting, 2000. Proceedings. 2000 IEEE Hong Kong,* pp. 5-8, June 2000.

[18] Ajith Amerasekera, Charvaka Duvvury, "*ESD in Silicon Integrated Circuits Second Edition*", John Wiley & Sons, Ltd. ISBN 0-470-49871-8, 2002

[19] TLPSolutions, "*Model TLP50 Transmission Line Pulse Tester - User's Manual v1.3*", http://www.tlpsol.com/files/Download/TLP50 User's Manual.pdf, 2007.