

ESD TR5.5-03-14

ESD Association Technical Report

ESD TR5.5-03-14

*For Electrostatic Discharge
Sensitivity Testing –*

*Very-Fast Transmission Line
Pulse (VF-TLP) –
Round Robin Analysis*

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FOREWORD

The ESD Association's working group 5.5 subcommittee conducted a round robin study to determine if the current VF-TLP standard practice (SP) yielded test results which would allow the elevation of the SP, with suitable modifications to a standard test method (STM). This technical report (TR) covers both the data taken and the analysis methods used to develop a precision statement for VF-TLP. This study involves seven test sites with eleven different test structures evaluated at each site. This paper summarizes these findings.

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ESD Association Technical Report for Electrostatic Discharge (ESD) Sensitivity Testing – Very Fast – Transmission Line Pulse (TLP) – Round Robin Analysis

1.0 INTRODUCTION

ESD Association working group 5.5, (ESDA WG 5.5), conducted a round robin (RR) study for the purpose of elevating the current very fast - transmission line pulsing (VF-TLP) standard practice [1] (SP) to a standard test method (STM). The round robin study will demonstrate the precision of the VF-TLP measurement technique when following the ESDA WG5.5 VF-TLP standard practice. This technical report (TR) reviews the RR measurements and analysis used to support the elevation of the VF-TLP document from SP to STM status. It also discusses some of the lessons learned about VF-TLP and the performing of a RR experiment. VF-TLP is defined as TLP testing using pulses of 10 ns or shorter [1]. The analysis of the data was based on ASTM E691, "Standard Practice for Conducting Inter-laboratory Study to Determine the Precision of a Test Method" [2].

This document is divided into 4 sections:

- 1.0 – Introduction
- 2.0 – Measurements
- 3.0 – Analysis of Measurements
- 4.0 – Conclusions

1.1 TLP Background

Transmission line pulse (TLP) was first introduced in the field of ESD in landmark papers by N. Khurana and T. Maloney in 1985 [3, 4]. Later Whalen and Domingos [5] used pulse lengths down to 3 ns on RF structures. Since that time, TLP has become an important tool in the development of ESD protection structures for integrated circuits, primarily for human body model (HBM) protection. TLP for HBM analysis has usually used pulse lengths in the 70 to 200 ns range with 100 ns becoming the de-facto standard. The widespread use of TLP, and the desire of ESD engineers to be able to trust the TLP data published in the literature, led the ESDA to develop a SP for TLP; which was later upgraded to a STM [6]. The ESDA defines a SP as a test method, drafted by a working group of experts, which represents the best way to measure a property based on sound engineering judgment. An SP has not, however, been proven to be a repeatable and reproducible test method. A STM is a measurement procedure that has been proven to provide repeatable and reproducible measurements. The elevation of an SP to an STM requires data collection in the form of round robin experiments to demonstrate the test method's repeatability.

Very fast – transmission line pulse was introduced by Gieser et.al. in 1996 [7]. VF-TLP is often defined as TLP with pulse lengths less than 10 ns and was aimed at determining protection properties with similar time and current levels of charged device model (CDM) [8]. The move from TLP at 100 ns to VF-TLP with pulse lengths less than 10 ns would at first appear to be a simple change of pulse length, with no significant change in measurement procedure. In some sense this is true, but the change from TLP to VF-TLP crosses important practical boundaries. TLP typically uses rise times of 2 to 10 ns, similar to HBM [9]. For VF-TLP rise times are usually a small fraction of a nanosecond, similar to CDM. To maintain these rise times it is necessary to use high frequency test fixtures which provide 50-ohm impedance all the way to the device under test (DUT). Failure to maintain 50-ohm impedance to the DUT test pin will also result in ringing due to reflections, which will not settle out during VF-TLP's short pulse width [10]. Standard TLP at 100 ns pulse widths can often use simple clip leads to connect to the DUT without adverse effects on the pulse shape due to the order of magnitude longer time for signal settling.

Perhaps the most obvious difference between TLP and VF-TLP comes from the increased bandwidth requirements of VF-TLP measurement system. The voltage and current probes must

be of 2 GHz or higher frequency response, and a wide band oscilloscope with fast sampling rates boost the equipment costs of VF-TLP systems. While 50-ohm wafer probes can be used, the best VF-TLP performance is obtained with fixed pitch RF probes which have ground-signal-ground or signal-ground configuration [11]. In both VF-TLP and TLP, the DUT voltage and current at the DUT is the sum of the measured incident and reflected pulses. For standard TLP's 100 ns pulse length, the incident and reflected pulses typically overlap at the measurement point. This provides a significant measurement advantage. If the incident and reflected pulses are of opposite sign their addition is a small signal. This occurs for voltage pulses on a low impedance device and for current pulses on a high impedance device. If the incident and reflected pulses overlap at the measurement point the oscilloscope gain can be adjusted to provide more accurate measurements. This is often called adaptive ranging. With VF-TLP's short pulse lengths it is hard or impossible to have the incident and reflected pulses overlap at the measurement point. This is mainly due to the amount of cable length required between the measurement probes and to the DUT interface. Even very short cables will have enough delay to separate the incident and reflected pulses in time. It is therefore necessary to add the incident and reflected pulses mathematically, introducing considerable measurement error due to limited resolution of the 8-bit analog-to-digital converters of high speed digital oscilloscopes when the result is a small value as well as other noise in the measurement system which naturally increases with bandwidth.

These practical differences between TLP and VF-TLP prompted the ESDA to develop a SP specifically for VF-TLP [1]. The round robin study analysis being presented here shows that the VF-TLP SP is sufficient for elevation to a STM.

1.2 Brief Description of VF-TLP

As discussed above, VF-TLP is TLP with pulse lengths less than 10 ns, although most VF-TLP measurements are for pulse length of 5 ns and below. The most basic TLP system is the time domain reflection (TDR) system shown in Figure 1. The transmission line on the left produces the pulse which travels through an attenuator (to reduce multiple reflections), and travels down a delay line to the device under test (DUT). Probes in the delay line connected to a high speed oscilloscope measure voltage and current. The voltage at the DUT is characterized by the sum of the measured incident and reflected voltage and current pulses. In standard (100 ns) TDR TLP these pulses overlap and no math is needed to determine the DUT voltage and current. In TDR VF-TLP the pulses are too short and the addition of the incident and reflected pulses must be done mathematically from waveforms captured by the oscilloscope.

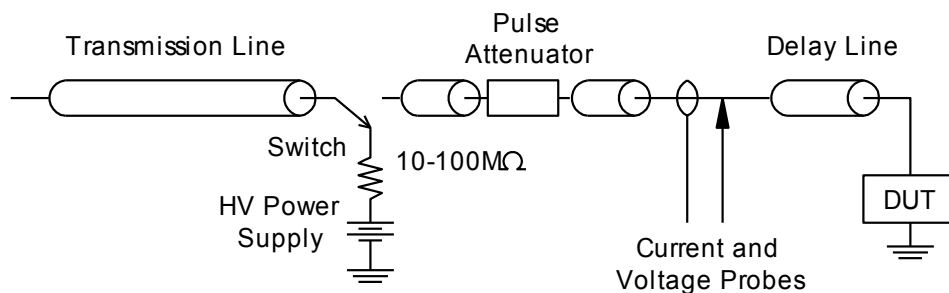
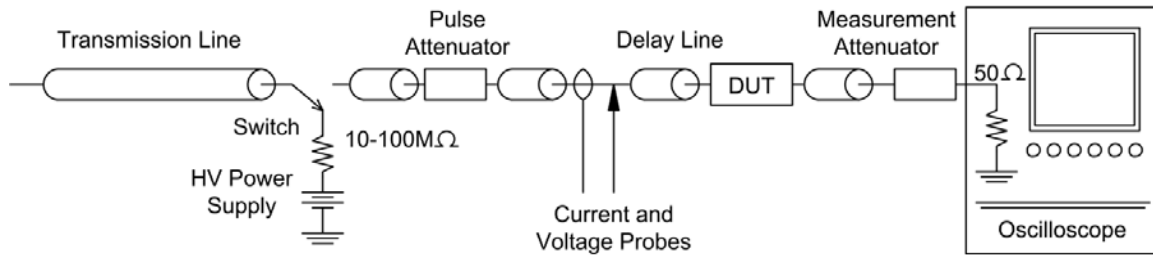


Figure 1: Time Domain Reflection (TDR) TLP system

A second VF-TLP configuration discussed in this document is the time domain reflection and transmission VF-TLP system shown in Figure 2. In this configuration the current through the DUT is directly measured by the 50-ohm input to the oscilloscope. Determining the voltage across the device in this configuration requires a more involved calculation including the incident and

reflected voltage pulses as well as the voltage on the oscilloscope channel used to measure the DUT current.

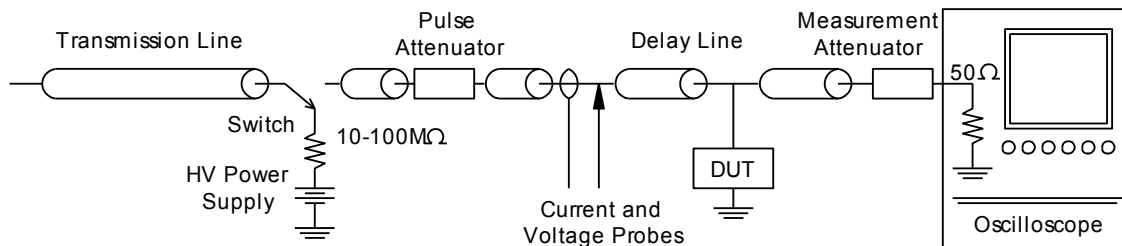


Recommended Pulse Attenuation: 6dB to 20dB

Recommended Measurement Attenuation: 20dB to 40dB

Figure 2: Time Domain Reflection and Transmission VF-TLP System

A final VF-TLP configuration, not explicitly mentioned in this document, is time domain transmission (TDT) shown in Figure 3. In TDT VF-TLP the voltage across the DUT is directly measured by the oscilloscope. Current through the DUT must be calculated based on incident and reflected pulses, with careful correction for the 50-ohm shunt resistance across the DUT.



Recommended Pulse Attenuation: 6dB to 20dB

Recommended Measurement Attenuation: 6dB to 20dB

Figure 3: Time Domain Transmission VF-TLP System

1.3 VF-TLP Round Robin Background

WG 5.5 planned a very ambitious series of VF-TLP RR experiments and a great deal was learned from the experiments. The full series of experiments is described in Section 2.0 on measurements. Much of what was learned from the measurements could be seen in the raw IV plots and did not require statistical analysis. These lessons will be discussed in the measurements section. Some of these lessons impacted on which data sets were best suitable to statistical analysis and what types of analysis could be performed.

Section 3.0 on analysis of measurements will discuss how data was chosen for statistical analysis from the wide variety of data taken and what types of analysis based on ASTM E691 was possible. The proper question to ask when verifying the appropriateness of elevating an SP to STM is not "Is the SP repeatable and reproducible?" but "Does the SP produce results with sufficient precision for its intended application?" The lack of precision in a measurement is a combination of variability due to lack of repeatability and lack of reproducibility. Section 3.0 will

discuss how precision statements were developed for the measurement of voltage and current for VF-TLP and how measurement sets were chosen to base the precision statements on.

2.0 MEASUREMENTS

2.1 Round Robin Guidelines

Seven test laboratories were used in this study. Each site has a VF-TLP system from one of three manufacturers. Each test site was given identical test structures to evaluate. Minimal test conditions were specified because the main goal of the round robin study is to determine if measurements made using the VF-TLP SP would produce repeatable measurements, both within a single laboratory and between laboratories. Additional directives were limited to parameters explicitly stated within the VF-TLP SP to affect measurements and instructions needed to satisfy the requirements of ASTM E691 [2].

It is known that as pulse width changes, the I-V characteristic may change due to the time dependent response of the structure; therefore, specific pulse widths were defined. The data collection required documentation (as listed below) so that data discrepancies could be analyzed properly. Any other decisions in test configuration were left up to the user and his/her interpretation of the ANSI/ESD SP5.5.2 VF-TLP document [1].

Each test site was provided with a set of wafer probable structures that could be taken to failure that is referred to as Set I. A second set of test structures that were mounted on a PCB and connected using SMA connectors was also evaluated but not taken to failure; this set is referred to as Set II. For this second set of measurements all test sites tested the exact same structures. The second data set is needed to decouple the variations due to test structures from those due to the VF-TLP operators and systems.

The specifics of the test method were as follows:

- Record the measurement window for I-V calculations (% into pulse and % duration).
- Record the scope specifications in terms of manufacturer, bandwidth and sample rate.
- Record the type of cable and length from VF-TLP unit to device under test, DUT.
- Record type and manufacturer of probes.
- Record rise time setting.
- Document calibration and procedure.
- Collect one set of data on the GaAs structures (Set I) at a pulse width of 5 ns.
- Collect a second set of data on GaAs structures (second set of Set I) at a pulse width of 1.25 ns.
- Collect one set of data on the SMA fixture structures (Set II) at 5ns (not to destruction).
- Take down system, recalibrate and re-measure the SMA fixture structures again (not to destruction).
- Repeat last two steps at 1.25 ns.
- Ship the SMA structures to next test site.

It is also noted here that the systems used in this RR study have incident and reflected pulses separated and the voltage and current shown in the I-V characteristic is calculated from measured data points.

2.2 Test Structures

2.2.1 Set I: Passive Structures

The first set of structures was wafer probable and fabricated in a Gallium Arsenide (GaAs) process. These included both active and passive structures. The passive structures were an open, a short, a 5-ohm resistor, and a 50-ohm resistor. These were selected because they are well behaved and can be used as a part of the calibration and validation procedure. All of the test structures in Set I were designed so that RF probes with any pitch between a 100 and 300 μm