# Active Tester Interface Unit Design For Data Collection

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## Abstract

*During device characterization it is not uncommon to find test and product engineers spending hours and hours of time on the ATE to verify AC measurements using Oscilloscopes and Time Interval Analyzers. Device performance boards are carefully designed with controlled impedance paths to match the tester Pin Electronics Card to the DUT. For getting more accuracy than available from the ATE, scopes and TIA's are used in production testing to guarantee specific parameters such as pll jitter and clock frequency measurements. With the recent emergence of source synchronous busses on high speed devices, external equipment is used to make output-to-output AC measurements during device validation. Taking such measurements on a 64-pin bus device over several operating voltages and temperatures with a pair of probes may take several days. This manual approach, in addition to being time consuming, is also prone to operator errors and suffers from poor repeatability. This paper describes an approach using a unique performance board design, with embedded resistors to emulate scope probes close to the DUT and high speed muxes on the board, to cut the data collection time from hours or even days to minutes. Data collected using the manual and automated method are compared.*

## 1 Introduction

Traditionally, characterization AC measurements on the device under test are done on the ATE using one of several well established methods. The most popular and often used method is the timing search, which moves the tester driver or comparator timing while functionally testing the device and observing a fail to pass transition. Often the ATE hardware has a built in time measurement unit (TMU) [3] . The tester's drive signals are routed to the TMU in a loop back mode. The DUT output is digitized by the tester's comparators and the digitized signals are routed to the TMU. Another tool, called the Scopetool, provides a similar capability but also changes the comparator levels, producing a voltage vs. time plot. Instead of using a central resource like a TMU or a scope ATE also uses its comparator circuitry together with capture memory to plot the tester-generated signals and the device response and, in turn, to compute AC parameters. All of these methods make measurements from an input to an output, between two inputs or between two outputs. The accuracy of the measurements is bounded by a combination of driver, comparator and TMU accuracies and has been discussed widely in several papers [1]. During validation of I/O timing of the DUT, it is necessary to minimize errors from all sources during AC measurements to get the most accurate reading. During characterization, test engineers wheel in an expensive oscilloscope and connect it to the device interface board and make timing measurements while the tester is looping on a set of patterns stimulating the DUT. This manual characterization methodology has three principal drawbacks:

- It takes a very long time to get the results.
- Results have poor repeatability.
- Results are prone to operator errors.

### 1.1 Automation

This paper describes an automated method developed at Intel for the timing data validation (DV) of the Madison 64-bit Microprocessor source-synchronous data bus that eliminates all the drawbacks above. This method uses a specially designed active tester interface unit (TIU) containing embedded resistors emulating oscilloscope-like 500 ohm probes, and on-board mux circuitry to route device under test (DUT) output signals to an external Time Interval Analyzer (TIA). The TIA, Wave Crest 2075, is used to make accurate source synchronous measurements, eliminating tester inaccuracies. What makes this DV method unique is the fact that no TIU has ever been designed with embedded resistors deposited in an internal layer. This active TIU with the automated DV software has replaced an established manual DV collection method for future devices from the same microprocessor family.

### 1.2 Paper Organization

Section 2 presents the details of the manual method of data collection and discusses the amount of time taken to collect DV data. This leads into section 3 on the details of the active TIU design and the calibration and diagnostic software involved for verifying the TIU. Section 3 also discusses the validation of the active TIU after fabrication and the challenges overcome in order to make the TIU functional. Section 4 gives the performance of the active TIU in terms of correlation with the older manual method and the efficiency of data collection. The paper concludes with future enhancements planned for the DV automation program.

## 2 Background

In source synchronous operation the device produces its own clock, which travels in parallel with the data. In this way, the clock suffers the same delay and drift as the data, enabling the data to be reliably clocked into the receiving device. It is common for the clock signal to be delayed at the originating device such that the clock occurs at the center of the data. This ensures that there is enough setup and hold time at the receiving device's input register. This is shown in Figure 1 where the double pumped data has a timing specification with respect to the differential output clock signal. A 64-bit data bus is thus broken into eight groups of eight pins and associated with each group is a clock, also known as strobe. The Tvb and Tva measurements are output-to-output timing measurements, and when these are performed by an ATE using conventional search methods, the accuracy of the result is influenced by twice the overall timing accuracy of the tester. By carefully designing the device TIU with controlled impedance and judicious location of probe points, more accurate instrumentation such as the TIA can be used to improve the accuracy of the measurements.

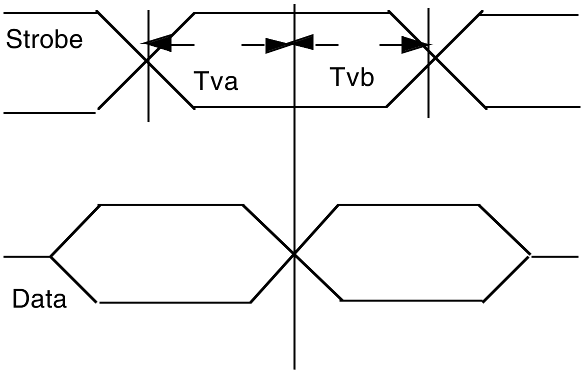


**Figure 1. Source Synchronous Transfer**

Since the time of the McKinley processor, data collection using external TIA was adopted for source synchronous timing parameters. The data validation (DV) requires the following additional hardware:

Wavecrest 2075

Oscilloscope to view signals and/or verify triggers

Wavecrest probe holder

(2) Tektronics P6427 differential probes

(2) Probe holders

Probe power supply found in the DV cabinet

Device and TIU

Co-ax cables

The method in use involves the steps outlined below.

### 2.1 Pattern preparation using scripts

The only thing that needs to be done prior to getting on a tester is choosing an appropriate pattern to use. Then a preamble is added to allow enough time for the PLL's to lock. The pattern file is preprocessed by searching for all time sets specified by the user. Keyword s_s (for source synchronous) means the chip is in data output mode. This is the transaction for Tva/Tvb. For all these transactions, the script will look at the data. If the data toggles, it will create an entry in a file. An example of this is:

!SyncRMA = 17912,17912

TPD-+ 1 1 17912 63280 316388.0

So at vector 17912, the tester will emit a trigger. The Wavecrest will look for the delay between the 1st falling edge on channel 1 and the 1st rising edge on channel two. For every data pin, a .cmd file will be created. These files will take on the name

Tva/Tvb .cmd files: <pattern name>__<data pin>.cmd

### 2.2 Wavecrest set up and test program operation

The Wavecrest needs to be plugged in and warmed up before usage. An internal calibration should be run 30 minutes after power up. The GPIB port should be connected to the tester. The TIU should be mounted and the Wavecrest probe holder should be put on top of the TIU. The part will run very hot, so a thermal compensator must be used. The Tektronix probes are connected to the pins on the TIU that need to be measured. If the signal is double ended, care must be taken to make sure the positive strobe point goes to the positive signal. If the signal is single ended (like a data pin) then the positive end is on the data pin and the negative is on a ground pin.

The other end of the probe is connected to the probe power supply. The probes must be set at %10 attenuation or the signal will swing more than one volt (in which case, the Wavecrest will clip). For Tva/Tvb data, Channel one of the Wavecrest is data. Channel two is strobe. The third channel (the arming channel) comes off the test head itself. These channels can be observed through an oscilloscope or connect directly to the Wavecrest.

The test program is intended to be run on the ITS900 KX tester from Credence. Once the program is loaded and initialized, a global dialog box is used to set the various options of the Wavecrest to suit the DUT.

DTS_ARM_VTH = trigger voltage for the arm of the Wavecrest. This is set pretty consistently to -0.460 V from the test head.

DTS_CH1_VTH = event threshold for channel 1, usually set to 0 V.

DTS_CH2_VTH = event threshold for channel 2, usually set to 0 V.

DTS_DATA_PIN_INDEX = the data pin on which the measurements are taken. The formatting is similar to standard pin names. So you will need to enter the name "xxD7t0nn3" to look at data pin 3.

DTS_GPIB_PORT = GPIB port of the Wavecrest. By default this is set to 3. This can be changed as long as it matches the setting on the Wavecrest.

DTS_INDIR_NAME = the directory of your .cmd files which store the vector number and measurement type.

DTS_OUTDIR_NAME = directory the output data acquired is to be placed. Output files follow the same prefix naming convention as the input .cmd files.

DTS_PATTERN_NAME = pattern name loaded.

DTS_SYNC_VECTOR = location of external sync to trigger. This is only used if you use the "scope_sync_loop" user function.

DTS_TRIGGER_NAME = trigger pin.

In the flowtool three user functions do the following tasks.

scope_sync_loop - This user function executes the most recent test into a loop and exciting the trigger at the vector specified in the global "DTS_SYNC_VECTOR". This user function must be preceded by a functional test.

IF_Characterize_FSB - This is the user function that actually performs the Wavecrest calculations. Once everything is set up correctly and a test is executed and passed, the system will prompt the user to read Tva/Tvb data. Once the correct choice is made, the user function will read the appropriate .cmd file and output the results.

dts2070 - This user function simply checks the GPIB bus and makes sure a Wavecrest device is found on the GPIB port specified in the globals.

So the standard execution will be to

1. Set up all the hardware and have all the preprocessing done before hand. Launch the test program and do the appropriate initialization.

2. Load the pattern which has the preamble already added to it.

3. Make the changes to the global variables so as to capture the correct data.

4. Open up one of the FTEST blocks in the Wavecrest composite segment. Add the name of the new pattern and execute. Leave the FTEST block open.

5. Optional- Run the scope_sync_loop user function and use the oscilloscope to verify that the chip is working and the trigger is located at the appropriate place.

6. Optional- Run the dts2070 user function to make sure the Wavecrest is visible to the tester.

7. Execute the IF_Characterize_FSB user function to collect data for one pin.

Step 7 is repeated after changing the probe connection to a different DUT pin. Once the probes are hooked to the Wavecrest, it is possible to use the Wavecrest device as an oscilloscope. There is a software suit called Visual Instruments which allows the user to access extended functionality of the Wavecrest. The scope tool is useful for finding the midpoint thresholds for the channels. To find the threshold for the trigger, use the DTS pull-down menu and select "Pulse Find Dialog". Make sure the pattern is in a loop, then click the pulse find on the new window. The max and min for all the channels and the arm can be seen. The data collection for a single unit takes as much as 16 hours without taking into the one hour for Wavecrest warm up and calibration. The data collected using this manual method has been validated against bench and other systems test data. It does have the drawbacks outlined in the last section such as repeatability, operator error and total time spent.

## 3 Automation using active TIU

The automation of the manual method is made possible by the availability of Ohmega-Ply®, a thin film resistor- conductor material[2], used in board manufacturing. Using standard subtractive printed circuit technology, integral resistors are formed on circuit layers. These resistors can be buried within a multilayer circuit board or used on the board surface. While typical resistor values have been in the 50 ohm to 100 ohm range, recently the available resistor value has approached 500 ohms. Embedding 450 ohm resistors close to the device socket inside a TIU and using 50 ohm trace connections from them, emulates multiple 500 ohm scope probe connections to the DUT are emulated. Figure 2 serves to illustrate this. The tolerance of these resistor implementations are from 5%-10%. Since the DUT input and output are operating in a matched 50 ohm environment a 500 ohm on the DUT will cause no

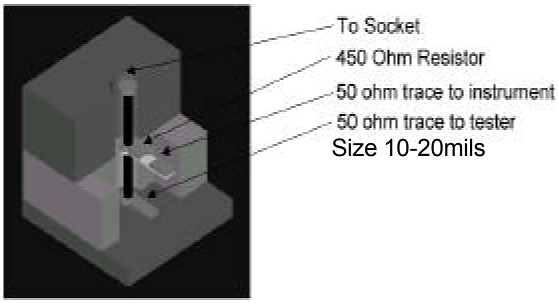


Figure 2 Probing Signal From DUT

more attenuation and reflection effects than a 500 ohm scope probe. This also implies that only a small portion (1/11 or 9% ) of the signal is picked off by the probe and consequently needs to be amplified. With multiple signals to connect to the Wavecrest, muxes can be added to the TIU and the mux selection control can come from the utility control lines of the tester. Figure 3 shows a high level block schematic of the circuitry which could be implemented on a tester interface unit. The details of the actual design and implementation are presented in the next section. The only drawback of this method is the extra cost of the TIU which is far outweighed by the productivity improvement it brings to the test engineer. The main advantage of embedding the resisors over surface mounted resistors is the proximity to the DUT pin and the reduction of the overall area required on the TIU.

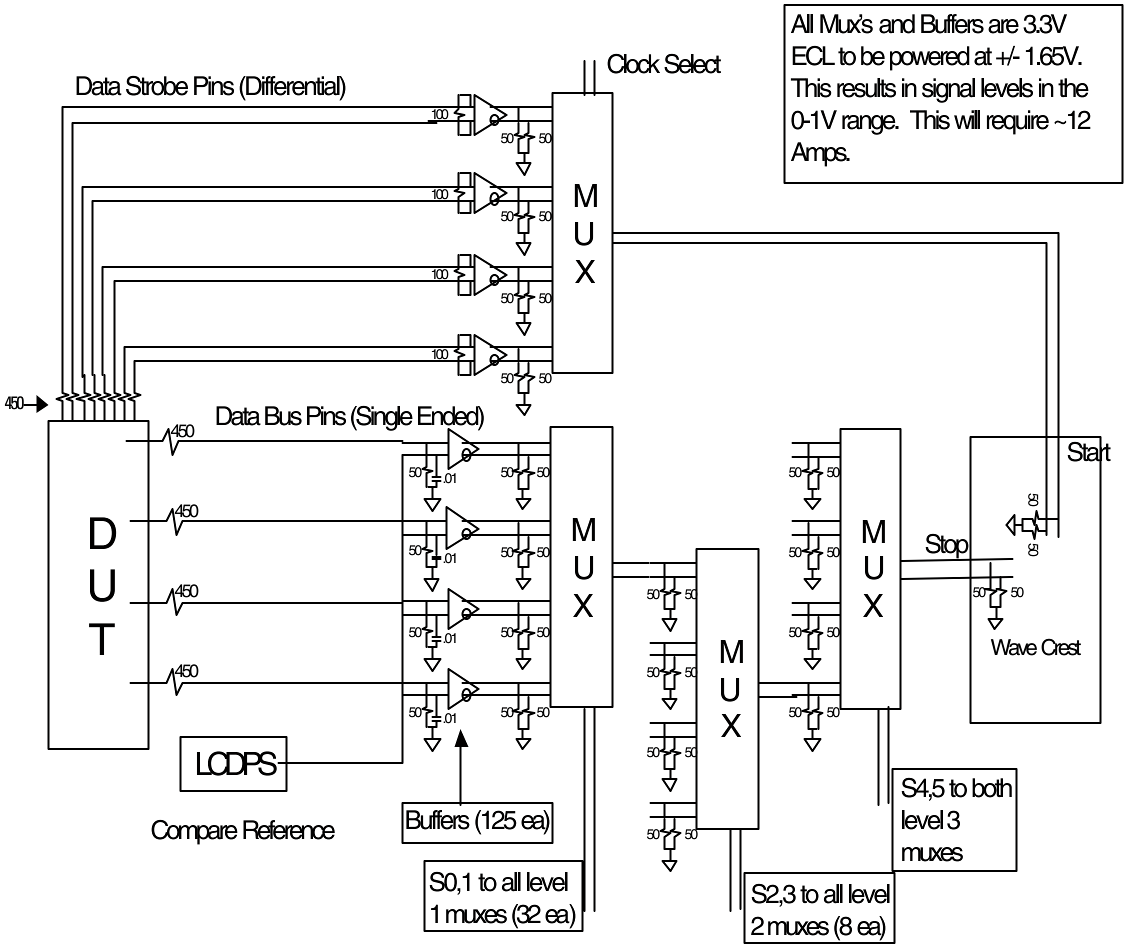


Figure 3. Madison Active TIU Circuitry

## 3.1 Active TIU Design

The Active TIU has been designed to automate the collection of Tva and Tvb parameters of the source synchronous bus for the Itanium$^{TM}$ Processoor family of devices starting with the Madison. Prior to this, a characterization program developed by Intel engineers has been in use to collect the same data but using operators to manually connect the source synchronous signals to a Wavecrest instrument. The manual method has been used with the McKinley device and correlated successfully to oscilloscope readings. The active TIU will replace the manual TIU for Madison. The existing characterization program will be updated to accommodate the active TIU. From this point forward this will be referred to as the char program.

### 3.1.1 Active TIU Circuitry:

The active TIU uses the same exact design of the Madison TIU and adds the following circuitry. This TIU will accommodate half of the desired signals on the Madison device.

- For each signal identified as a source synchronous signal, an embedded 450 ohm resistor is added in an additional signal plane. This simulates an oscilloscope 500 ohm probe. An additional trace carries this attenuated signal through a buffer (PECL type) to a set of muxes.

The buffers are differential and are biased with a device power supply to control the crossover point. The device has 128 data bus pins and 8 differential strobes. In order to preserve the size of the TIU and limit its cost, only 64 data pins and 4 differential strobes were incorporated in the first design. If the methodology is successful a second TIU would be used for the remaining source synchronous signals.

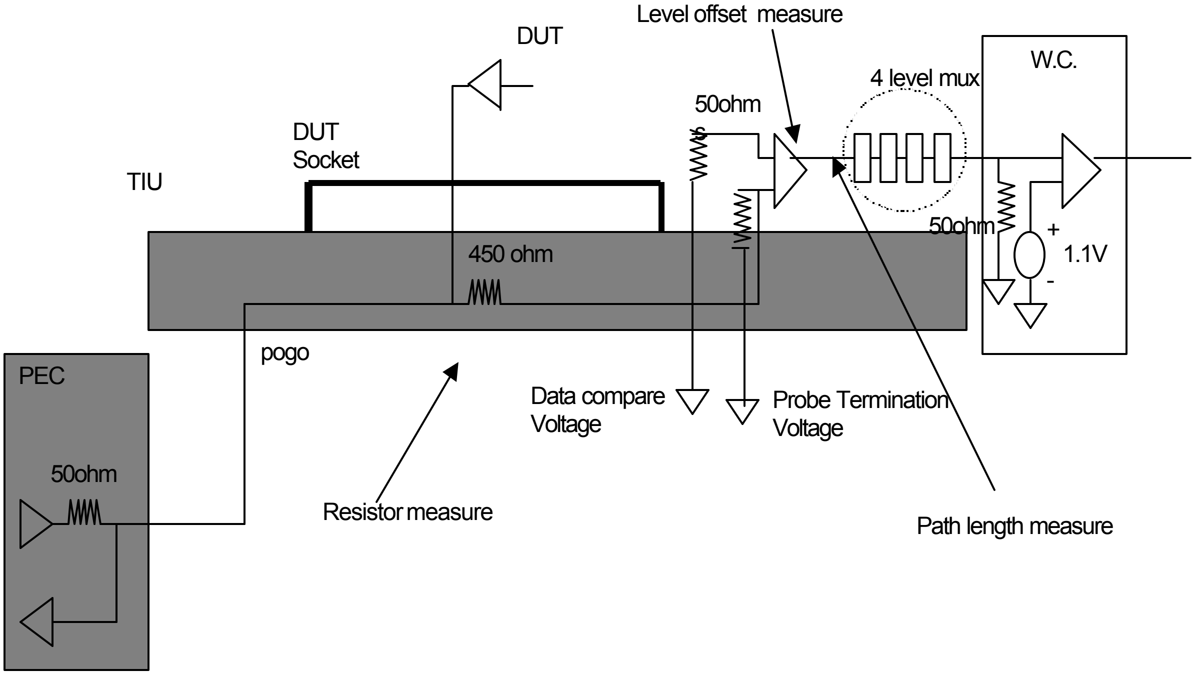


**Figure 4. Block Diagram Of One Path To Be Calibrated**

- The 4:1 muxes are differential and are controlled by EIR bits from the test head. Source synchronous data strobe signals are routed through a set of muxes, and the final stage mux output is connected to a high bandwidth sma connector and then on to the start input of a Wavecrest box. Similarly, Source synchronous data signals are routed through a set of muxes and final stage mux output is connected to a high bandwidth sma connector and then on to the stop input of a Wavecrest box.
- A pair of ring oscillators located on opposite sides of the TIU to aid in monitoring temperature drift. The ring oscillator's frequency will decrease as temperature increases.This will be characterized to formulate a linear approximation for the propagation delay versus temperature of the active TIU.
- Power regulators and dc-dc converters which generate Vcc and Vee for the active TIU circuitry are obtained from test head +15, -15 and +5 volt user sources.

Figure 4 shows the block diagram of a single sourcesignal path on the active TIU. A normal TIU has two wires/traces coming together at the device socket. One is the bond wire from the DUT die through the package and the other is the tester signal cable coming from the pin electronics card (PEC) via pogo pin block to the TIU trace. The active TIU adds a third connection via the embedded 450 ohm resistor. The next section describes the calibration and diagnostic test program for the active TIU on board circuitry.

### 3.2 Calibration and Diagnostic:

The calibration program measures the embedded resistors and the path length of each source synchronous signal from the embedded resistor to the Wavecrest connector. In addition it measures the offset voltage for the buffer circuits and the frequency of the ring oscillators. All the measured values are stored in files to be used by the char program. In the best case scenario only the path length values will need to be used as calibration corrections to the raw Tva/b data generated by the char program using the following equation

- **Tva/b = Raw Tva/b - (Tstp - Tstrt)**

**Tstrt** is the path length of the source synchronous data signal and **Tstp** is the path length of the source synchronous clock signal as measured by the calibration program. However, during the design of the active TIU it was considered prudent to check for the input offset of the buffer circuits and compensate for them if the offsets are in the millivolt range rather than the micovolt range. In order to measure the input offset, the value of the embedded resistors need to be measured as well. Should the offset value be higher than 10mV (which will give rise to an error of 4ps on a 1V 400ps edge rate signal) the probe compare voltage will be adjusted prior to each Tva/b measurement. In order to monitor and compensate for temperature effects, the ring oscillators circuits have been designed in the active TIU. The ring oscillator is implemented using 7 buffer stages and a single stage mux. As a first approximation it will be treated as an 8 stage oscillator. Using a thermal stream/ heat gun, the period of the ring oscillator will be measured at several different temperatures from room to hot to verify a linear relationship between propagation delay and temperature. The formula for temperature correction for a single buffer/mux in the path is

- **Tpdelta = (Tpx - Tproom )/8**

**Tpx** is the average period of the ring oscillators during the data collection process, **Tproom** is the average period of the ring oscillator at room temperature. So the final equation for the correct value of Tva/b is

- **Tva/b = Raw Tva/b - (Tstp - Tstrt) -2*Tpdelta**

The diagnostic program is identical to the calibration program except that it does not store any data but checks that the results are within pre-defined limits. A switch function is used to select between the calibration and diagnostic flow. In phase 1 of the active TIU the ring oscillator calibration was not planned for implementation. Depending on the performance of the active TIU circuitry it was planned for Phase 2. The next subsections detail the different calibration steps.

### 3.2.1 Resistance Measurement

Figure 5 shows the circuit involved on the active TIU near the DUT socket. The tester power supply DPS0 is used to provide the provide the termination voltage, and DPS3 provides the comparator voltage. In normal operation of the active TIU a portion of the device output signal ($1/11^{th}$) is riding on the termination voltage. This is amplified by a high gain differential buffer and sent to the next level of muxes. For resistance measurement during active TIU calibration there is no DUT in the socket. A DC test is executed on each input and the result is convert ed to resistance value to be used by the offset calibration program.

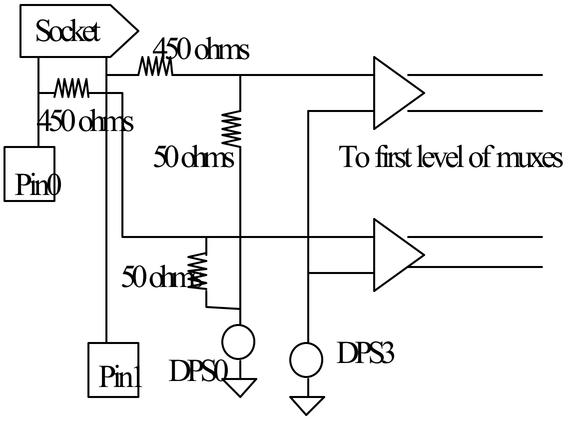


**Figure 5 Resistance Measurement**

### 3.2.2 Offset Measurement

This process will be accomplished by performing a Linear Search. Figure 6 shows the circuit involved. In the normal operation of the active TIU the differential buffer amplifies the low level single ended data signal and forwards it the start or stop input of the Wavecrest TIA as a differential signal. In order to compensate for the different offsets of all the comparators, the offset of each needs to be calculated and applied as a correction. The offset is found as follows. With No device in the socket, force (VOH_mad+VOL_mad)/2 at DPS3 and at the PEC and search which value of DPS0 toggles the buffer-comparator. VOH_mad is the Madison device typical output high volatge and VOL_mad is the Madison device typical output low voltage.The actual resistance measured is used instead of the 450 ohm shown in the figure.

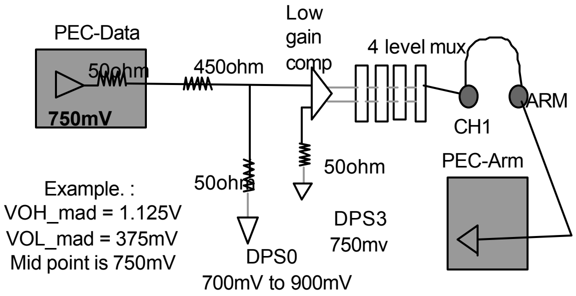


**Figure 6 Offset Measurement**

### 3.2.3 Path Length Measurement

Since the number of data and strobe signals are different data and strobes are going through two different mux-trees, one with four levels of muxes and the other with two. It is essential to measure and compensate the path length difference between the data and clock paths for the final Tva/TVb measurements. A special technique using a custom shorted device in the DUT socket was developed. A 30ns negative pulse is sent on all data and strobe channels except on the data or clock path to be measured.

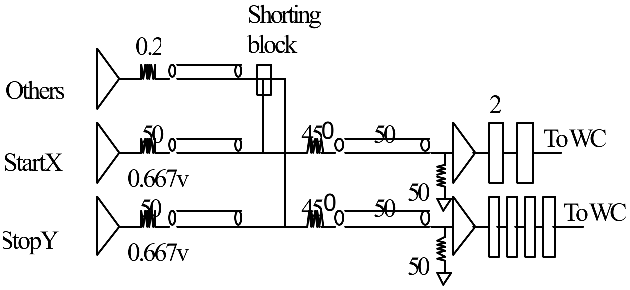


**Figure 7 Path Measurement**

The shorting device is placed in the DUT socket. By programming the muxes, this path is selected by the Wavecrest and the path length is measured. This shown in figure 7. The path length differences are stored for later use with the char program.

### 3.2.4 Automating the Data collection

After the the active TIU has been calibrated, automating the data collection is very basic. What needs to be done is to modify the existing routines in the char program to collect data manually to incorporate the data from the calibration files (comparator offset and path length difference) generated by the active TIU calibration. Set the usual globals (same as manual method) to identify directory and pattern names, trigger levels, output levels for the Wavecrest and the pins on which to collect data.

DTS_INDIR_NAME, DTS_OUTDIR_NAME, DTS_PATTERN_NAME

DTS_TRIGGER_NAME = “NC_DBI7t0[4]”

DTS_CH1_VTH = 290mV (Mux output is always the same; 20mV to 545mV)

DTS_CH2_VTH = 290mV (Mux output is always the same; 10mV to 570mV)

DTS_ARM_VTH = 125mV (Set NC_DBI7t0 to VOL = 0V & VOH = 500mV in the level block)

DTS_START_DATA = 0

DTS_STOP_DATA = 63 (to collect Data from Data0 to Data63)

Load and install the char program and run the modified data collection function. Since the same user function is used as before, the data format and post processing remains the same.

## 4 Active TIU Performance

The design and fabrication of the active TIU took four months during which all the needed software for calibration and checkout was written. When the active TIU was received, the following necessary steps were carried out to validate it.

Functionality check after preliminary assembly:

- Run Wavecrest (WC) IO patterns on char test program on the active TIU and get a pass.

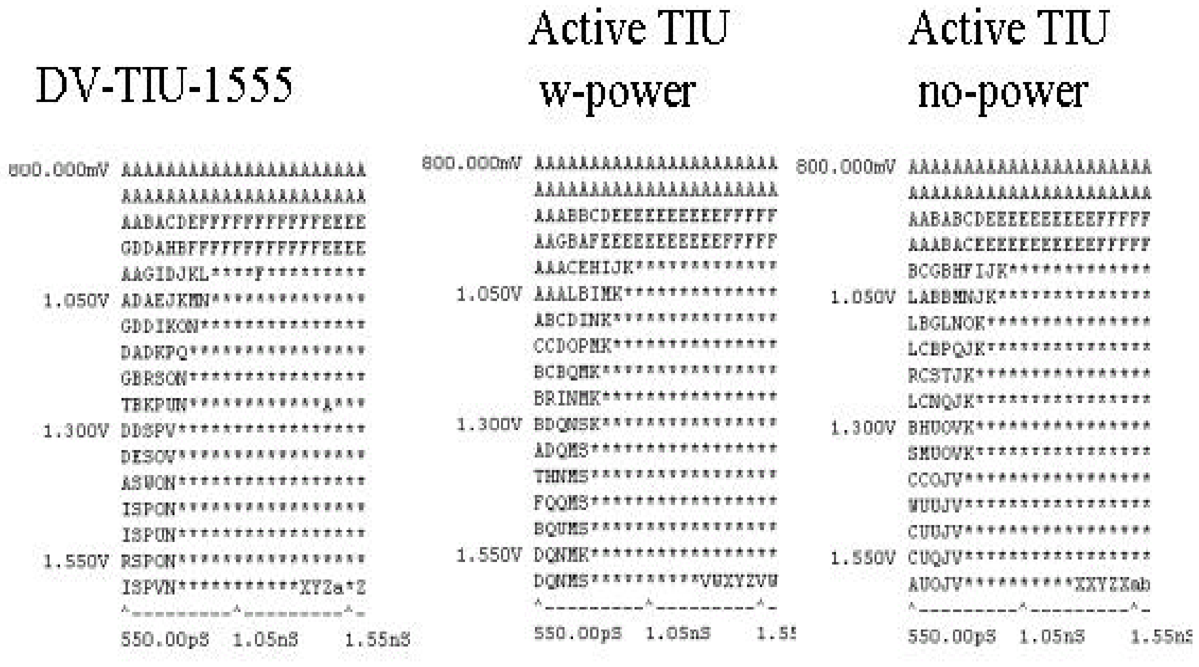
Functionality Check after full assembly: Run WCIO patterns on char program. Compare basic performance using current production TIU against new active TIU:

- Shmoo Vcc/frequency.
- Select 1 pin with embedded resistor and one pin without embedded resistor to perform level searches for vih, vil, voh, vol and timing searches for Setup, Hold, Tva/Tvb and Tco.

Compare signal integrity between Active Tiu and existing TIU

- Using Infineon scope look at Strobe to Data signal on specific input and output cycles
- Look at the signal of Bclkp/n for both data and clock trees.
- Measure rise time of signals and compare.

All the steps were completed and the results were satisfactory. This is shown by the shmoo in figure 8. The shmoo shape looked good with hot/cold temperature correlating with the DV TIU shmoo.



DV-TIU-1555

```
800.000mV AAAAAAAAAAAAAAAAAAAAAA
          AAAAAAAAAAAAAAAAAAAAAA
          AABACDEFFFFFFFFFFFEEEE
          GDDAHBFFFFFFFFFFFFEEEE
          AAGIDJKL****F*********
   1.050V ADAEJKMN**************
          GDDIKON***************
          DADKPQ****************
          GBRSON****************
          TBKPUN************A***
   1.300V DDSPV*****************
          DESOV*****************
          ASWON*****************
          ISPON*****************
          ISPUN*****************
   1.550V RSPON*****************
          ISPVN***********XYZa*Z
          ^---------^---------^-
          550.00pS  1.05nS    1.55nS
```

Active TIU w-power

```
800.000mV AAAAAAAAAAAAAAAAAAAAAA
          AAAAAAAAAAAAAAAAAAAAAA
          AAABBCDEEEEEEEEEEFFFFF
          AAGBAFEEEEEEEEEEEFFFFF
          AAACEHIJK*************
   1.050V AAALBIMK**************
          ABCDINK***************
          CCDOPMK***************
          BCBQMK****************
          BRINMK****************
   1.300V BDQNSK****************
          ADQMS*****************
          THNMS*****************
          FQQMS*****************
          BQUMS*****************
   1.550V DQNMK*****************
          DQNMS**********VWXYZVW
          ^---------^---------^-
          550.00pS  1.05nS    1.55
```

Active TIU no-power

```
800.000mV AAAAAAAAAAAAAAAAAAAAAA
          AAAAAAAAAAAAAAAAAAAAAA
          AABABCDEEEEEEEEEEFFFFF
          AAABACEEEEEEEEEEEFFFFF
          BCGBHFIJK*************
   1.050V LABBMNJK**************
          LBGLNOK***************
          LCBPQJK***************
          RCSTJK****************
          LCNQJK****************
   1.300V BHUOVK****************
          SHUOVK****************
          CCOJV*****************
          WUUJV*****************
          CUUJV*****************
   1.550V CUQJV*****************
          AUOJV**********XXYZXab
          ^---------^---------^-
          550.00pS  1.05nS    1.55n
```

**Figure 8 Correlation Between Active TIU And Manual Data Validation (DV) TIU**

The difference of The Active TIU versus the DV TIU for AC timing measurements is within tester EPA limit. Table 1 shows the result of running several devices with both TIU and collecting setup, hold and delay measurements.

| Experiment | distribution | Active TIU | DV TIU | Difference |
|---|---|---|---|---|
| cc_tsetup | Max | 640ps | 660ps | 20ps |
| | Min | 520ps | 510ps | 10ps |
| cc_hold | Max | -440ps | -390ps | 50ps |
| | Min | -570ps | -570ps | 0ps |
| cc_tco_max | Max | 1.66ns | 1.68ns | 20ps |
| | Min | 1.45ns | 1.46ns | 10ps |
| cc_tco_min | Max | 1.45ns | 1.44ns | 10ps |
| | Min | 1.14ns | 1.1ns | 40ps |
| ss_tsu | Max | 90ps | 100ps | 10ps |
| | Min | -50ps | -120ps | 70ps |
| ss_thold | Max | 140ps | 190ps | 50ps |
| | Min | 30ps | 0.85ps | 29ps |

**Table 1. AC Measurements Correlation**

## 4.1 Active TIU circuitry performance

The TIU performed as well as the regular TIU for functionality. However, during the debug of the operation of the on board circuitry for automated Tva/Tvb measurements the following major challenges were uncovered.

### 4.1.1 Embedded resistor values are on the high side

The values were designed for 450 ohms (+-10% tolerance) but the actual values were near 550-650 ohms. This caused the signal level at the buffer comparator circuits to be lower than expected and the S/N ratio was high, leading to very noisy output with oscillations. A considerable amount of time was spent on locating the source of the noise. It turned out to be a 100khz ripple from the switching regulator used to convert the 15V test head user supply to 3,3V for the on-board muxes and buffers. The switching regulator was replaced by a bench power supply (linear regulator), and the noise was reduced considerably. In order to further reduce the noise which was still high on the buffers of the single ended data signals, a lower gain buffer was used as a replacement, which eliminated the noise on the outputs of the muxes.

### 4.1.2 Shorted block calibration yields poor results

The calibration using the shorted block yielded longer results for path lengths than expected values. It is still under investigation. This step was replaced by a standard path length measurement using the Wavecrest without the shorting block and just sending a pulse on the clock and data tree paths and measuring the difference.

### 4.1.3 Active TIU Tva/Tvb data collection results

After fixing a few other minor hardware issues on the active circuitry such as broken caps and non-performing devices, the data was successfully collected and the active TIU has been in use since October 2003. Figure 9 shows the distribution of Tva collected using active TIU. Figure 10 shows the same for data collected with the same device using manual TIU. Figures 11 and 12 show this for Tvb measurements. Tva/tvb automation measurement from Active TIU is very close to the Wave Crest manual measurement ~30 to 50ps. Hardware setup is 45 minute setup time (including the warm up) for manual and automation process. However, the automation setup time is simpler because no probes are needed which reduces operator errors. Automation process takes 7 minutes for data collection versus 16 hours for manual process using the regular TIU.

## 5 Conclusion

This paper has shown how a TIU with embedded resistors has successfully correlated with the existing manual data collection method and improved the productivity in the test floor. Further work is planned in this active TIU methodology in terms of design and layout for better over all performance and investigation into shorted calibration block application for better calibration.

## 6 Acknowledgements

The authors wish to thank Howard Maassen in lending expert advice on debugging noise problems on the TIU. Acknowledgements are also due to Bob Hickling for the initial design of the active TIU and simulation of the shorted block calibration methodology. Thanks are due to Barry Cotter for designing the user functions for calibration and diagnostics. Recognition is also due to James Kwan for helping with the check out of the user functions, creation of scripts, DC tests and setting up base line D/V program for manual data collection.

## 7 References

[1] ITC 2000 - An Approach to Testing 200ps Echo Clock to Output Timing on the Double Data rate Synchronous Memory - Dieu Van Dinh, Virginia Rabitoy

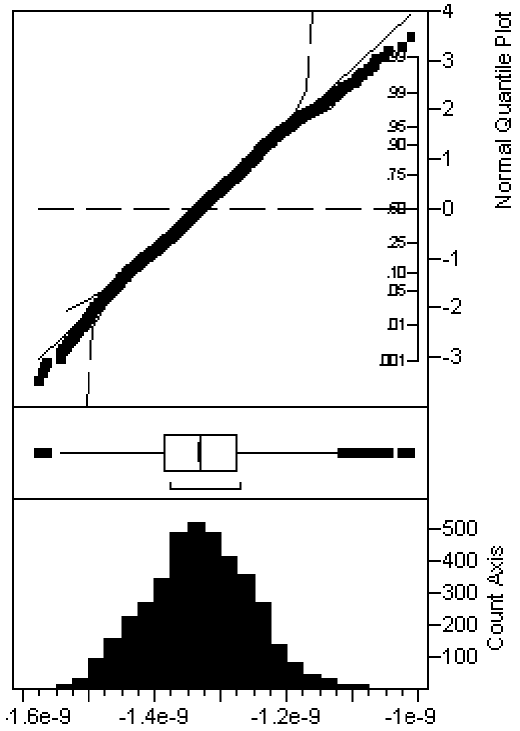
[2] http://www.ohmega.com

[3] [90ITCWest]ITC1990 - Sequencer Per Pin Test System Architecture- Burnell G. West, Tom Napier.

**Distributions**

FIGURE 9 Distribution Data On Tva Using Active TIU

**data**



**Quantiles**

| | | |
|---|---|---|
| 100.0% | maximum | -1.011e-9 |
| 99.5% | | -1.095e-9 |
| 97.5% | | -1.166e-9 |
| 90.0% | | -1.232e-9 |
| 75.0% | quartile | -1.277e-9 |
| 50.0% | median | -1.332e-9 |
| 25.0% | quartile | -1.385e-9 |
| 10.0% | | -1.44e-9 |
| 2.5% | | -1.487e-9 |
| 0.5% | | -1.523e-9 |
| 0.0% | minimum | -1.577e-9 |

**Moments**

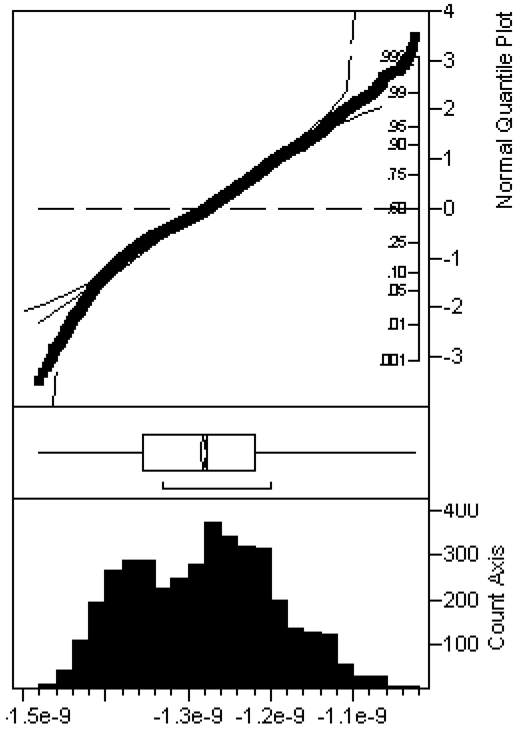
| | |
|---|---|
| Mean | -1.331e-9 |
| Std Dev | 8.124e-11 |
| Std Err Mean | 1.281e-12 |
| upper 95% Mean | -1.329e-9 |
| lower 95% Mean | -1.334e-9 |
| N | 4023 |

**Quantile plot has Tva on the x axis**

**Distributions**

FIGURE 10 Distribution Data On Tva Using Manual TIU

**data**



**Quantiles**

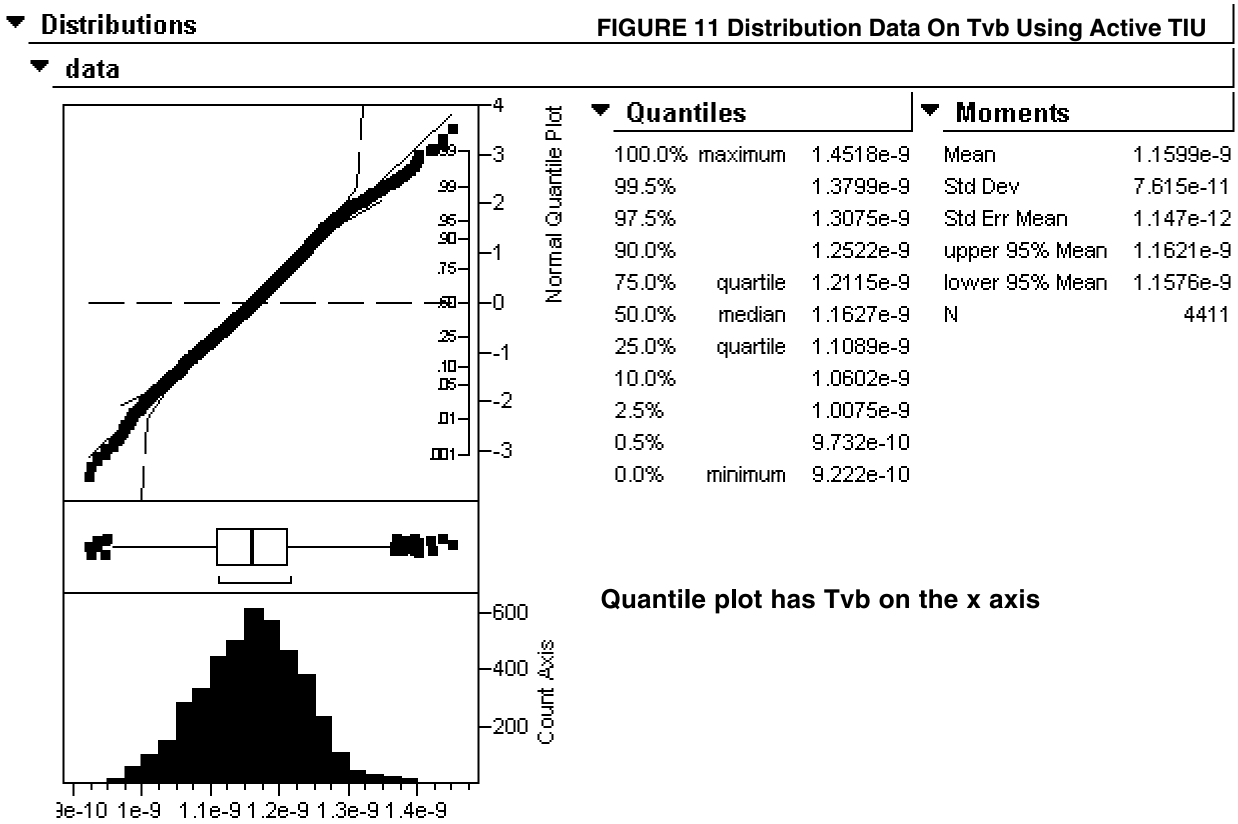
| | | |
|---|---|---|
| 100.0% | maximum | -1.025e-9 |
| 99.5% | | -1.064e-9 |
| 97.5% | | -1.112e-9 |
| 90.0% | | -1.164e-9 |
| 75.0% | quartile | -1.219e-9 |
| 50.0% | median | -1.277e-9 |
| 25.0% | quartile | -1.353e-9 |
| 10.0% | | -1.397e-9 |
| 2.5% | | -1.428e-9 |
| 0.5% | | -1.45e-9 |
| 0.0% | minimum | -1.481e-9 |

**Moments**

| | |
|---|---|
| Mean | -1.281e-9 |
| Std Dev | 8.703e-11 |
| Std Err Mean | 1.372e-12 |
| upper 95% Mean | -1.278e-9 |
| lower 95% Mean | -1.284e-9 |
| N | 4023 |

**Quantile plot has Tva on the x axis**

FIGURE 11 Distribution Data On Tvb Using Active TIU



**Quantiles**

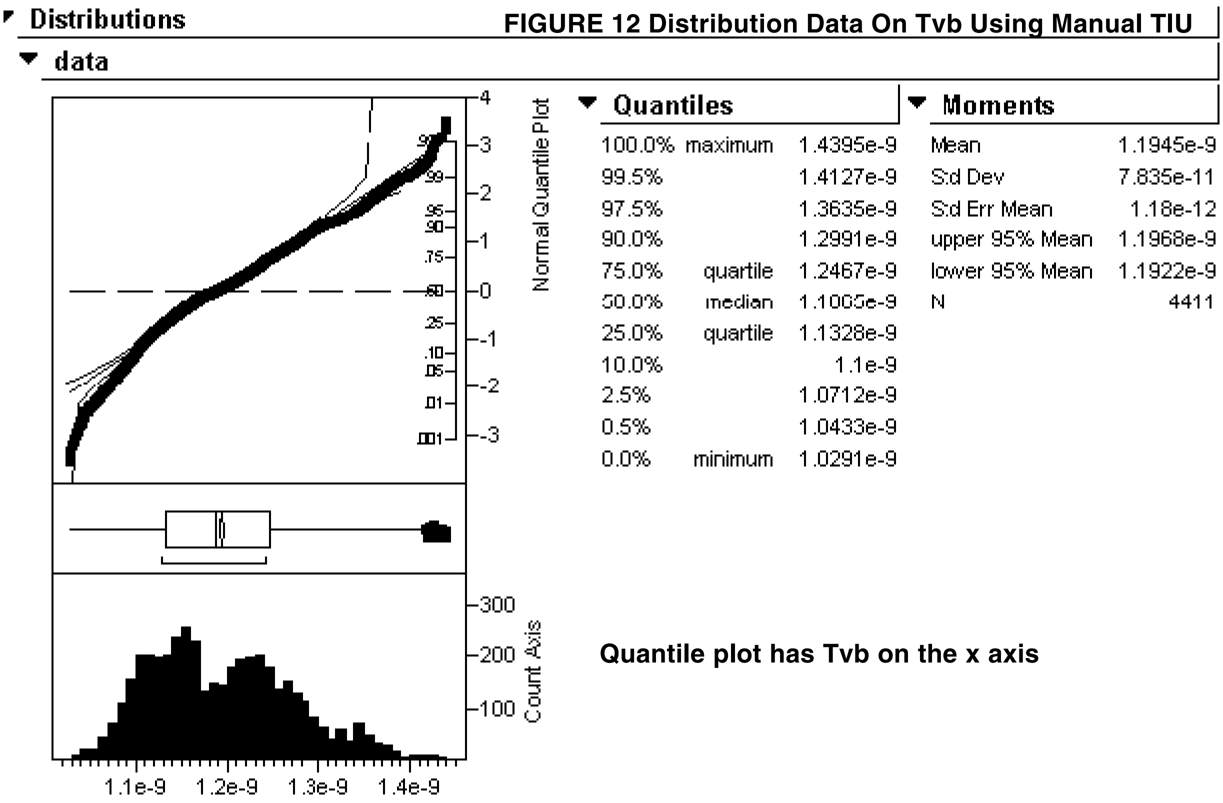
| | | |
|---|---|---|
| 100.0% | maximum | 1.4518e-9 |
| 99.5% | | 1.3799e-9 |
| 97.5% | | 1.3075e-9 |
| 90.0% | | 1.2522e-9 |
| 75.0% | quartile | 1.2115e-9 |
| 50.0% | median | 1.1627e-9 |
| 25.0% | quartile | 1.1089e-9 |
| 10.0% | | 1.0602e-9 |
| 2.5% | | 1.0075e-9 |
| 0.5% | | 9.732e-10 |
| 0.0% | minimum | 9.222e-10 |

**Moments**

| | |
|---|---|
| Mean | 1.1599e-9 |
| Std Dev | 7.615e-11 |
| Std Err Mean | 1.147e-12 |
| upper 95% Mean | 1.1621e-9 |
| lower 95% Mean | 1.1576e-9 |
| N | 4411 |

**Quantile plot has Tvb on the x axis**

FIGURE 12 Distribution Data On Tvb Using Manual TIU



**Quantiles**

| | | |
|---|---|---|
| 100.0% | maximum | 1.4395e-9 |
| 99.5% | | 1.4127e-9 |
| 97.5% | | 1.3635e-9 |
| 90.0% | | 1.2991e-9 |
| 75.0% | quartile | 1.2467e-9 |
| 50.0% | median | 1.1065e-9 |
| 25.0% | quartile | 1.1328e-9 |
| 10.0% | | 1.1e-9 |
| 2.5% | | 1.0712e-9 |
| 0.5% | | 1.0433e-9 |
| 0.0% | minimum | 1.0291e-9 |

**Moments**

| | |
|---|---|
| Mean | 1.1945e-9 |
| Std Dev | 7.835e-11 |
| Std Err Mean | 1.18e-12 |
| upper 95% Mean | 1.1968e-9 |
| lower 95% Mean | 1.1922e-9 |
| N | 4411 |

**Quantile plot has Tvb on the x axis**