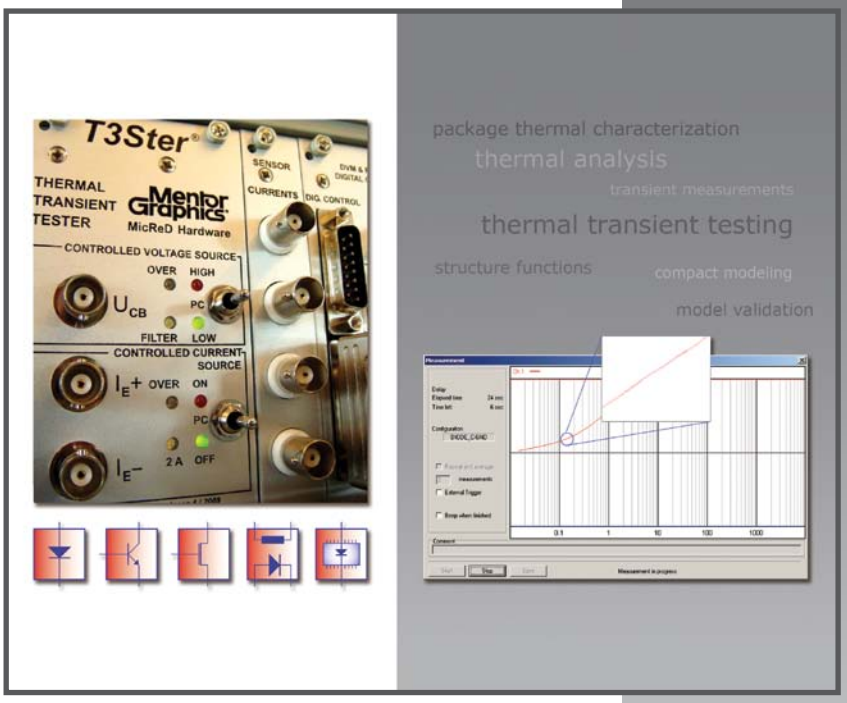
T3Ster®

Thermal Transient Tester Technical Information



Mentor Graphics®

M E C H A N I C A L A N A L Y S I S

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INTRODUCTION

T3Ster® (pronounced "tri-ster") – "The" thermal transient tester is an advanced thermal tester for thermal characterization of semiconductor device packages. Originally introduced to the market in 1997 by MicReD®, it already had more than a decade of R&D effort behind it. *T3Ster* has been designed to produce fast, repeatable and accurate thermal characteristics from a wide range of ICs, including stacked-die and system-in-package devices as well as other semiconductor components. Aside from measurement of existing packages, *T3Ster* results can be used to create thermal analysis models for further verification. The data can be used by the market leading electronics cooling software FloTHERM and FloTHERM PCB to predict device performance in various applications. Together, *T3STer* and FloTHERM, enable engineers and developers to take full advantage of a comprehensive thermal design solution.

THE *T3Ster* TECHNOLOGY

T3Ster technology is comprised of a flexible range of hardware, including the thermal transient tester station itself and numerous accessories (thermostat, booster, thermocouple pre-amplifiers, JEDEC standard still-air chambers, test-boards and special fixtures e.g. for TIM measurements). The measurements are controlled through a USB port; the advanced results post-processing program enables easy viewing and comparison of the results. The connection to the world of lighting is the *TERALED* system – aimed at testing power LEDs. Using a smart implementation of the JEDEC static-test method (JESD51-1), the thermal tester forces a packaged semiconductor chip from a "cool" to a "hot" state using a single step change in input power, and uses the measured internal transient temperature response to generate a complete thermal characterization of the package in just a few minutes. The equipment yields very accurate temperature vs. time trace for a packaged chip in a given environment. This information can then be used for various purposes, for example to obtain metrics like R_{thJC}, R_{thJB} or R_{thJA} directly from the measurements, to get information about the heat-flow path to find and locate failures like die attach delamination or to create a compact thermal model of the part. Because *T3Ster* can be used to characterize the heat-flow path from the heat source to the environment, it can also be used for characterizing complete systems or thermal management devices such as heat-sinks and heat pipes, and the resistance of thermal interfaces. What separates *T3Ster* from all other thermal characterization equipment on the market is its:

- speed and ease of use
- wide applicability
- accurate temperature measurements (0.01°C)
- 1 micro-second measurement resolution in time

This combination produces unrivaled accuracy and highly repeatable thermal impedance data.

APPLICATIONS INCLUDE:

- Heat-flow path reconstruction
- Die attach qualification
- Study of stacked die packages and other laminated structures
- Characterization of power LEDs
- In-situ, non-destructive failure analysis
- Material property identification (i.e., thermal conductivity of TIM)
- Thermal model verification
- In-situ thermal testing of parts in application environment, in live systems

T3Ster's multi-channel architecture enables most package varieties to be characterized with the minimum number of measurements, including stacked-die packages, MCMs and RGB LED modules. Semiconductor manufacturers and packaging companies are the clear beneficiaries, but end-users of packages can also use *T3Ster* to produce their own highly accurate thermal models. As a result, system-builders can quickly create an in-house library of validated thermal models resulting in a significant competitive advantage in thermal design.

SCALABLE SYSTEM

The *T3Ster* system consists of a Main System Unit having a **USB interface** to the measurement control computer (any desktop or notebook PC with the Windows® operating system), a **power driving module** for heating up the components to be measured, **sensor current sources** and up to eight **measurement channels**. The equipment can be ordered in different configurations with any number of measurement channels between two and eight. Hardware add-on components provide further scaling options.

MAJOR CHARACTERISTICS OF *T3Ster*

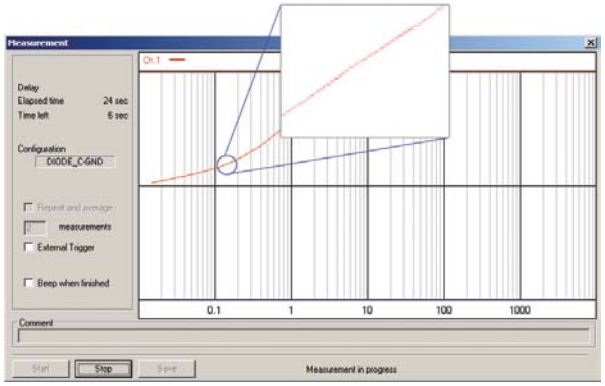
KEY FEATURES

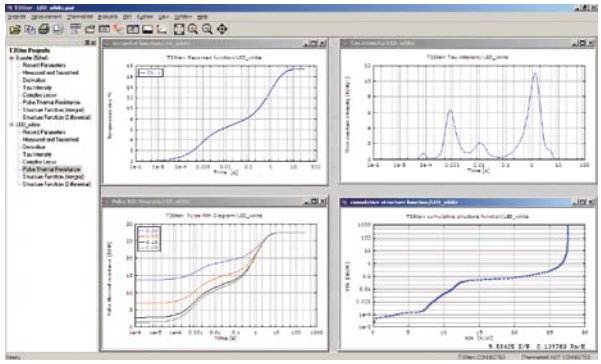
- Scalable equipment-rich set of hardware add-on options
- JEDEC compliant thermal resistance measurements
- Real-time measurement
- Continuous development, solid scientific background and worldwide consulting services
- Measurement control from any desktop or notebook computer
- *T3Ster* has the highest figure of merit among test appliances available on the market

ACCURACY, RELIABILITY, VERSATILITY, SCALABILITY

REAL-TIME MEASUREMENT

T3Ster carries out real-time measurements in conformance with the static test method described in the **JEDEC JESD51-1** standard. This "continuous measurement" technique combined with precision hardware results in capturing **very accurate, noise-free, real thermal transient curves at high time resolution.**





RESULTS POST-PROCESSING

The equipment comes with the *T3Ster* software. The standard software - besides measurement control - provides results post-processing options as well. With our unique evaluation technology the MicReD *T3Ster* software automatically derives:

- device response to pulsed periodic excitation (pulse thermal resistance)
- device responses to periodic excitation shown in frequency domain (complex loci)
- time constant spectra
- structure functions; all derived from the measured thermal impedance curves

Structure functions are ideal means for the identification of:

- junction-to-ambient thermal resistance and other JEDEC standard thermal metrics such as junction-to-case thermal resistance (using the latest JEDEC standard JESD51-14)
- partial thermal resistances and related thermal capacitance values along the heat-flow path
- material properties and geometrical dimensions of the heat-flow path

Hardware add-on options include :

- **additional measurement channels**
- **power booster** to raise the power driving capability of the main system unit from 100 W to **multiple kilowatts**
- **extension boxes** to provide additional power driving channels for simultaneous powering of multiple junctions
- **thermocouple pre-amplifiers** to interface J, K or T type thermocouples to the measurement channels of the main system unit
- a Peltier-based dry **thermostat** used as a device calibrator or as a cold-plate with an automated control from within the *T3Ster* measurement software
- a special test environment called *TERALED* for the combined thermal and radiometric measurement of power LEDs
- test environments such as JEDEC standard 1ft^3 **still-air chamber** or dual cold-plates

T3Ster MAIN SYSTEM UNIT: MAJOR SPECIFICATIONS

POWER DRIVER UNITS:

Controlled voltage source
U = ±10.24 V, LSB = 5 mV
Controlled current source
I = ±2 A, LSB = 1 mA
R-switch,
max. switched power 50 V, 2 A

A separate power booster (as an add-on option) can be used for 10 to 40 times higher driving capability.

Typical power levels with the base unit:
Transistor (3 pole device) measurement
Voltage step mode:
U_{CB}=10 V, I_E=2 A 20 W
Current step mode:
U_{CB}=50 V, I_E=2 A 100 W
Diode (2 pole device) measurement
Current step mode:
U_{diode}~ 1 V, I=2 A ~2 W
Generic resistive heater
R-switch mode:
U_{max}=50 V, I_{max}=2 A 100 W

With power boosters multiple kWatts of switched power can be achieved.

THE MEASUREMENT METHOD

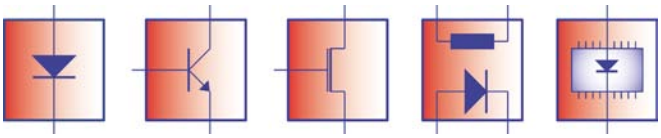
In accordance with the JEDEC standard static test method (JESD51-1), *T3Ster* forces a semiconductor package change between "cool" and "hot" states, using a single step change in input power, and while waiting for the new steady-state it continuously measures the internal transient temperature response of the device under test. The temperature change of the packaged semiconductor chip is measured by the electrical test method: a temperature sensitive parameter (TSP) of the semiconductor chip (e.g. forward voltage of a PN junction or the threshold voltage of a MOSFET) is used as a temperature indicator.

BASIC CONFIGURATION (PN: 240172)

The measurement requires **power driving units** that can switch the power abruptly, within one micro-second and **measurement channels** that capture the temperature transient very accurately. The *T3Ster* Main System Unit hosts these components together with the necessary **control circuitry** and **computer interface**. The main system unit can be equipped with up to eight measurement channels. The *T3Ster* hardware is completed with a **measurement control & results evaluation software** which runs on Windows® platforms. The USB interface allows using desktop or notebook computers for measurement control. With three different types of power driving options, *T3Ster* is suitable for measuring many different chip structures, such as:

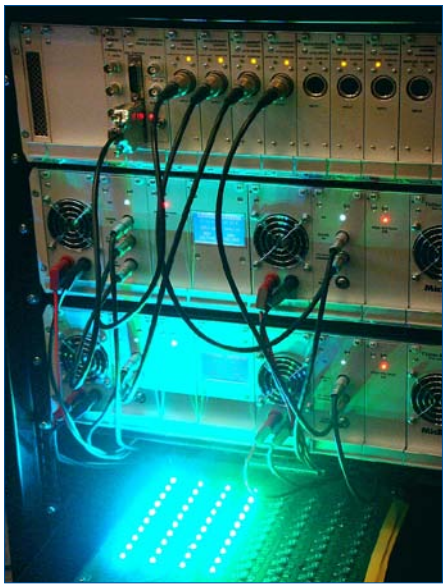
- discrete or integrated bipolar transistors, MOS transistors diodes, power LEDs and live integrated circuits of any complexity
- dedicated thermal test chips with separate heater and temperature sensors

Live IC chips can be typically measured through their substrate diodes. In a given measurement configuration one of three power driving options is available.

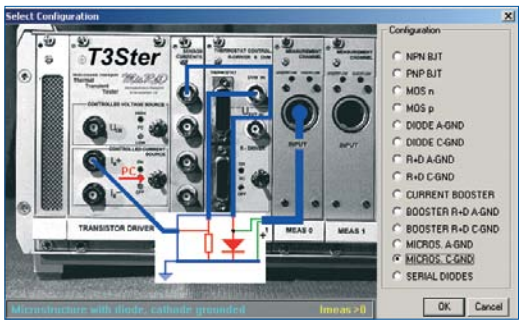


The power step can be created in different modes:

- Current step mode: programmed current step at fixed voltages
- Voltage step mode: programmed voltage step at fixed current
- R-switch mode: voltage and current is changed and measured



For the type of device under test (DUT) chosen, the measurement software suggests the appropriate measurement mode using graphical help to show the user how to connect the DUT to the main system unit. Simple device adaptors are provided as standard accessories to facilitate easy connection of the various types of devices.



MEASUREMENT CHANNELS (PN: 239868)

Voltage ranges: 400 mV / 200 mV / 100 mV / 50 mV

Resolution: 12 bit (i.e. least significant bit equals to 25 µV in the 100 mV range)

Noise: ±1 bit (prior to software filtering)

With a diode sensor having a sensitivity of 2 mV/K the 100 mV range corresponds to a temperature change of about 50 °C, the temperature resolution is Δ_{temp}= 0.01 °C. Eight measuring channels can be installed. On the parallel channels measurement and data acquisition takes place simultaneously.

Thermocouple and infrared sensors need an external pre-amplifier (available as an add-on option). With these typical LSB corresponds to 0.025 °C.

Minimum figure of merit: ~ 10000 W/°C
(diode measurement, without booster)

HIGH FIGURE OF MERIT

High precision, differential input amplifiers are the key elements of the measurement channels. Their high signal-to-noise ratio allows very sensitive measurements. This way one does not need to apply high heating power to be able to measure the temperature elevation of the junction. The quality of thermal test equipment can be well described by the figure of merit - a number independent of the equipment. *T3Ster* provides the **highest figure of merit** of all thermal test equipment available on the market.

FIGURE OF MERIT

The major sensitivity and accuracy parameters of thermal test equipment can be lumped into a single characteristic value, the figure of merit. It is defined as

$FM = P_{max} / \Delta_{temp} = SNR / R_{thJA}$

where P_{max} is the maximal power driving capability of the equipment, Δ_{temp} is the temperature resolution of the measurement, **SNR** is the signal-to-noise ratio and R_{thJA} is the total junction-to-ambient thermal resistance.

WHY USE *T3Ster*?

The sophisticated mathematics of the NID-method (network identification by deconvolution) embedded in the *T3Ster* software can only be fully exploited when applied to highly accurate and continuous real thermal transients, like the ones provided by the *T3Ster* hardware. Moreover, the equipment with hardware and software add-ons provides a complete thermal testing station, a single tool that allows a wide range of thermal measurements. Besides classical package characterization the structure function concept helps locate failures and irregularities in the heat-flow path such as die attach voids in single chip and stacked die packages, soldering failures, mechanical problems in cooling assemblies in a cost-effective, non-destructive way and provides alternative means of identification of material properties as well. *T3Ster* with its software provides input data directly from measurements for compact thermal models of packages. The models can be used in industry standard simulation tools such as FloTHERM.

T3Ster MAIN SYSTEM UNIT, DEVICE CALIBRATION

MEASUREMENT FEATURES

Smart device calibration, fast transient measurement:

- K-factor is identified at operating current levels
- measurement takes place in real-time, "on the fly"

Flexible sampling rate: The sampling rate is controlled by the measurement software. The hardware supports individual programming of sampling intervals between 1µs and 8s. Typically 200-300 data points are collected in an octave with a quasi-logarithmic variable sampling rate.

THERMOSTAT FOR *T3STER* (PN: 239869)

This Peltier-cell cooled, dry thermostat is designed mainly for the calibration of temperature sensing semiconductor structures in the devices under test. It is directly controlled by the measurement software and can be used as a single-sided cold-plate as well.

The thermostat module of the measurement control software provides automatic temperature excursion and calculation of the sensitivity parameter of diode or resistance sensors. Thus the calibration diagrams are automatically generated within a few minutes. In manual mode the thermostat control module of the *T3Ster* software can treat the thermostat as a cold-plate during the measurements. This way the thermostat may serve as a "hard thermal boundary".

MAIN PROPERTIES

Temperature range:	5...90°C
Accuracy:	±0.2 °C
Power sinking capability: min. 8 W	(above 30 °C)
Overheating protection	above 95 °C

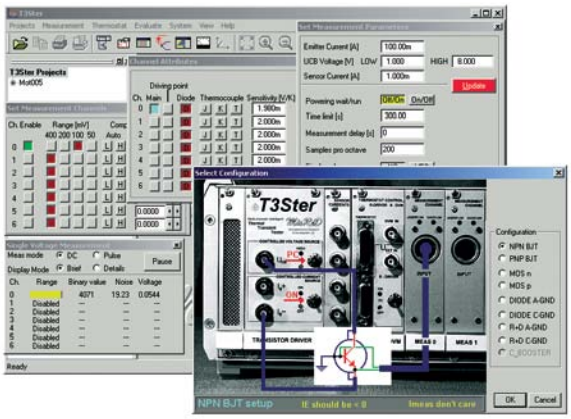
DUAL COLD-PLATE (PN: 239886)

Third party, liquid based thermostats can also be used for calibration and measurement. Dual cold-plates are available from Mentor Graphics for that.

In addition to the control of Mentor Graphics' own thermostat, manual and automatic control of third party liquid cooled thermostats (models from JULABO©, Cole-Parmer©, Lauda©, Haake©, Hart Scientific© or Arroyo Instruments©) is also included in the *T3Ster* software.

STANDARD SOFTWARE

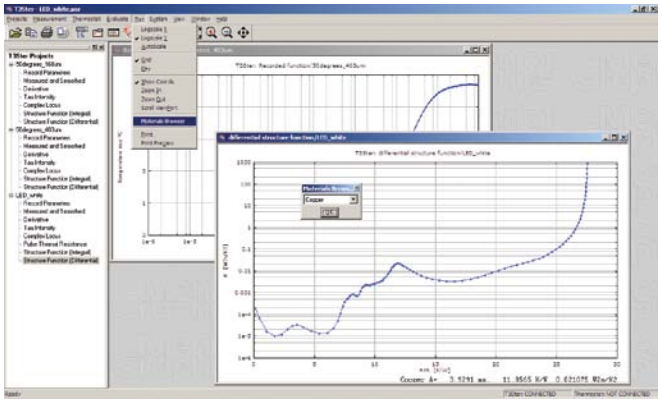
The *T3Ster* Measurement Control & Evaluation Tool is a mandatory component of any *T3Ster* configuration. The program runs under the Windows® operating system. Using a USB interface, any notebook computer can be used to control the measurements: after completing the measurements, the results can be taken back to the office on the notebook computer.



All equipment parameter settings such as voltage ranges, current levels, heating on/off state are controlled from appropriate dialog boxes in the software. The proper connection of the DUT to the Main System Unit is supported by graphics. During measurement the actual thermal transient is displayed in a window as it is captured.

In addition to the measurement control, results evaluation (based on the NID method) is also provided. Evaluation of the results takes place within a couple of seconds. The calculated results are the descriptive functions of the device tested.

A built-in materials browser can be used to facilitate the identification of geometrical data (e.g. cross-sectional area of the heat-flow path) from the structure functions.



EXTENDING THE POWERING OPTIONS OF *T3Ster*

MULTI-CHANNEL POWERING

The *T3Ster* Multi-channel Power Driving units (or *T3Ster* extension boxes in short) were designed to multiply the power driver channels of the *T3Ster* equipment. Extension boxes provide additional power switching modules and sensor current sources housed in the same type of enclosure as the Main System Unit.

PROPERTIES OF EXTENSION BOXES

Switching modes:
- current step mode
- voltage step mode

Number of power driving channels:
- Max. 3 / extension box

Number of sensor current sources:
- Max. 12 / extension box

Current load of a power driver unit:
- Max. 2 A

Total allowed current:
- Max. 5 A / extension box

Interface:
- 2 SPI ports: to the Main System Unit and/or another extension box

Up to two extension boxes can be installed.

THE *T3Ster*-BOOSTER FAMILY

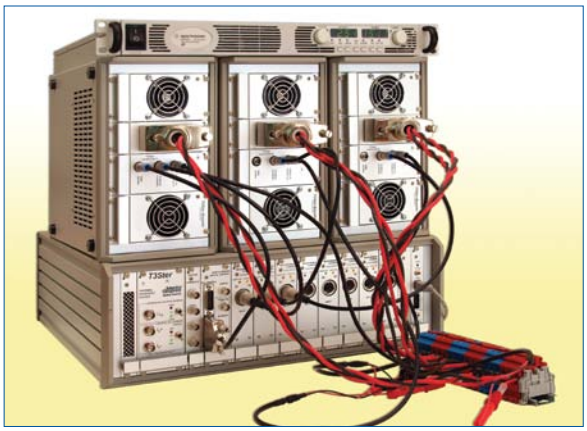
T3Ster-Boosters are add-on options of *T3Ster*. They are used to raise the switched power driving capability of *T3Ster*. They are external devices which follow the multi-channel architecture of *T3Ster*. The baseline model of the booster family provides switched power in the order of magnitude of kWatts. Two kinds of boosters are available: low voltage / high current or high voltage / low current, depending on the required application such as IGBT measurements or testing long LED chains.

EXAMPLES OF BOOSTED POWER

IGBT measurement in current step mode:
U_{CB}=50 V, I_E=20 A 1000 W

LED-line measurement in current step mode:
ULED=100 V, I=2 A 200 W

Generic resistive heater in R-switch mode:
U_R=70 V, I_{max}=20 A 1400 W



A T3Ster system with three high current boosters and an external Agilent power supply aimed at high current applications such as IGBT measurements.

Typical applications of *T3Ster*-Boosters include:

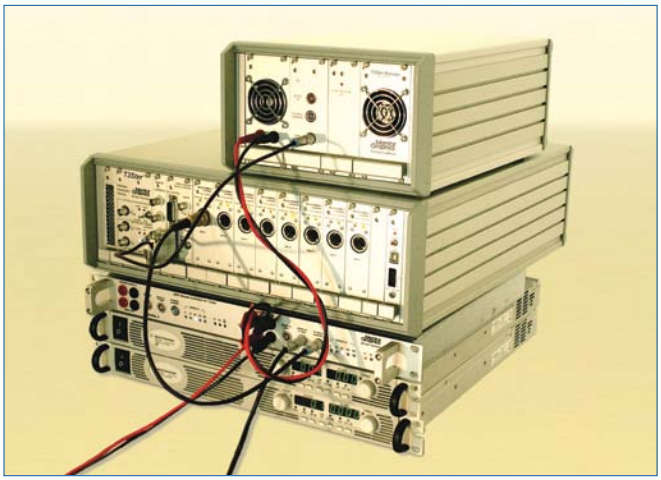
- measurement of power devices such as thyristors or IGBTs
- measurement of power LED assemblies such as LED lines
- measurement of large area VLSI chips through the substrate diode

A single channel high current booster PNs: 239874, 239875

A single channel high voltage booster PN: 245899

BOOSTER SCALING AND UPGRADE OPTIONS

Each power booster includes an internal power supply and sensor current source. To achieve the highest rated power, external power supplies are needed. Selected models from Agilent© are supported through the *T3Ster*-Booster plug-in module of the *T3Ster* measurement control software.



A single channel 280V test setup

Boosters can be upgraded. For example, lower voltage ratings can be extended to higher voltages, and single channel boosters can be upgraded into dual channel ones. Up to 280 V of voltage is available through a voltage shift and safety switch - ideal for testing AC mains driven LED modules.

Dual channel high current booster PNs: 245935, 245936

Dual channel high voltage booster PN: 245938

Dual channel 280V booster extension box PN: 245900

BOOSTER CONFIGURATIONS AND UPGRADE OPTIONS

High Current models		High Voltage models		
Single channel		Single **channel**		
38A/40V PN: 239875	50A/30V PN: 239874	10A/100V PN: 239880	10A/150V PN: 245899	10A/280V PN: 245900
			Upgrade PN: 245948	Upgrade PN: 245949
Dual channel		**Dual channel**		
38A/40V PN: 245936	50A/30V PN: 245935		10A/150V PN: 245938	10A/280V PN: 245939

MIL-STD 750E INTERFACE

When connected to high current T3Ster-Booster, this box serves as constant VCB generator for measurement of BJT-s according to MIL-STD 750E. By using this connected to the T3Ster main system unit and the high current T3Ster-Booster, all current and voltage sources are available according to the requirements of the classical MIL-STD E750 while providing the superior transient measurement capabilities of the latest T3Ster technology of Mentor Graphics.

MIL-STD 750E interface PN: 251496

MEASUREMENT CHANNEL OPTIONS

THERMOCOUPLE PREAMPLIFIERS

Thermocouple preamplifiers are provided for easy interfacing of J (PN: 239882), K (PN: 239883) or T (PN: 239884) type thermocouples to the Main System Unit. They assure simultaneous measurement of external package or PWB temperatures along with the junction temperature. The amplifiers have cold point compensation and provide an output voltage range matched to the measurement channels of *T3Ster*.

MEASUREMENT CHANNELS (PN: 245945)

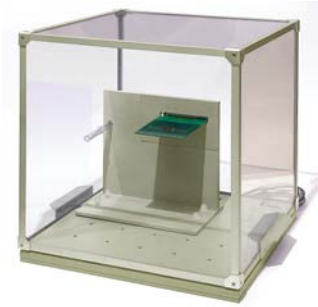
T3Ster's fast thermal measurements are possible through an advanced realization of the first stage of the measurement channel that gets rid of parasitic electrical transients quickly. Typically the data samples in the first few micro-seconds belong to the parasitic electrical transient inherently present in the measurements. Data points belonging to the junction temperature transients are captured from about 10 microseconds after the time instance of switching the power. Capturing thermal transients from as early time as possible results in a more detailed image of the package internals in the junction-to ambient heat conduction path shown by the structure functions. Such details are very important in die attach failure analysis applications and characterization of power LEDs.

The base *T3Ster* model is equipped with two measurement channels. Up to six additional channels can be added to the system in a plug & play manner: the measurement control software will automatically recognize the new channels added.

TEST ENVIRONMENTS

JEDEC STANDARD STILL-AIR CHAMBER (PN: 239885)

Mentor Graphics offers a still-air chamber (1 ft^3) to assure JEDEC JESD51-2 compliant setup for thermal transient measurements in a natural convection environment. The chamber can be easily adjusted to any JEDEC standard thermal test board size and to any edge connector type.



DUAL COLD-PLATE (PN: 239886)

Cold plates are not only used for device calibration but are also used as test environment. Both plates are identical and provide high heat transfer coefficient for the packages under test. The plates can be detached and can be used separately as well. They can be used as test environment for junction-to-case thermal resistance measurements based on the JEDEC JESD51-14 standard.

THE *TERALED* SETUP FOR POWER LEDs

WHAT IS *TERALED*?

In power LEDs, a significant amount of the supplied electrical energy is converted to light. Thus, when thermal characterization of LEDs is performed by the electrical test method, the emitted energy also has to be measured. The *TERALED* system provides combined thermal and radiometric/photometric characterization of high-power LEDs in an automated way. Thermal metrics as well as other properties such as luminous flux or efficiency can also be measured as a function of temperature and operating current.

The system can be used as a stand-alone optical measurement system for LEDs or as an add-on to the MicReD *T3Ster* equipment. The optical measurements are performed in thermal steady-state and once they are completed, the LED under test is switched off and its cooling transient is measured by the *T3Ster* equipment.

TERALED HARDWARE (PN: 239888)

TERALED hardware contains a total flux measurement system to allow photometric and radiometric measurements, using a high precision detector system with revolving filters and a reference light source, complete with control electronics.

Temperature stabilized LED fixture

A **300 mm** diameter integrating sphere hosts the temperature stabilized DUT fixture, the reference LED and a detector with different filters. A fiber optics port allows attachment of external devices such as a spectrometer.

The *TERALED* control electronics interfaces all devices attached to the sphere with the measurement control computer. Through biasing the LED under test it allows a stand-alone operation. Combined thermal and radiometric measurements are possible when the biasing of the LED under test is provided by the *T3Ster* equipment or the power booster.

Temperature stabilized LED fixture has a mounting area of **40x40 mm²** and is capable of sinking heat up to **10 W**. This Peltier-based device is controlled by the *TERALED* electronics. Its temperature can be programmed in the *TERALED* software between **10 °C and 90 °C**. This fixture is attached to the DUT port of the *TERALED* integrating sphere.

TERALED SOFTWARE

The easy-to-use *TERALED* software automates procedures like measurement of emitted flux (photometric or radiometric), efficiency or color coordinates as function of temperature and/or operating current. The LEDs' electrical characteristics as well as thermal calibration diagrams are also measured. Results are presented in form of plots, similarly to the *T3Ster* software. The *TERALED* software automatically cooperates with the *T3Ster* and the *T3Ster*-Booster control software; thus even high voltage LED devices (110 V or 230 V) mounted on metal core printed circuit board (MCPCB) can be measured.

MEASUREMENT OPTIONS WITH THE *TERALED* SYSTEM:

- *K-factor calibration of the LED under test*
  - for sensor current level (1 mA.. 25 mA range)
  - for operating point current levels (up to 2 A)
- *Photometric and/or radiometric measurements in thermal steady-state*

  The LED under test is measured in a stabilized state at a programmed current and at a programmed temperature. Depending on the filter in use
  - total radiant flux,
  - total luminous flux (filter matched to the CIE V(λ) function within 1.5%) and scotopic flux,
  - X, Y, Z tristimulus values

  can be measured.
- *Measurement of optical properties as function of temperature & operating current*
- *Measurement of efficiency*
- Combined with the *T3Ster* equipment JEDEC compliant thermal metrics of the LED are identified, considering the actual emitted optical power. After having measured R_{thJA} of the LED under test temperature dependence of optical parameters is provided as functions of the exact junction temperature.

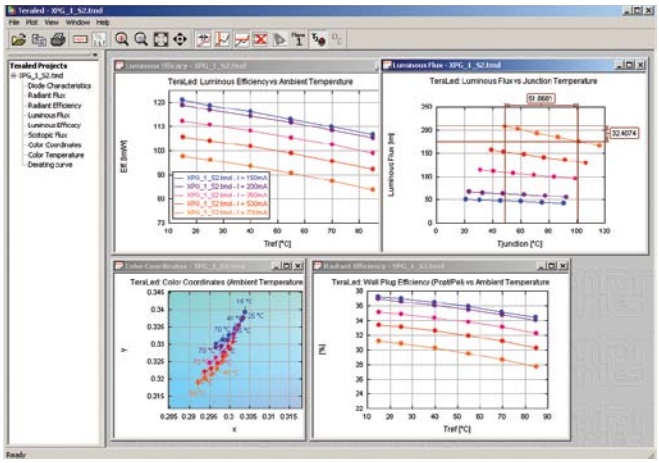
WHY CHOOSE *TERALED*?

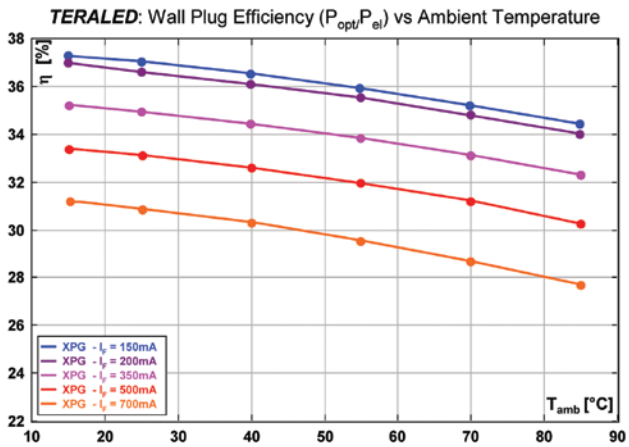
TERALED has been developed specifically in response to demand from leading LED manufacturers, and provides a unique, complete solution for LED testing. This integrated system is scalable with low initial investment. You can start with just a stand-alone *TERALED* system to measure the total radiometric flux as well as luminous flux and chromaticity coordinates. Combining *TERALED* and *T3Ster*, thermal transient measurements produce real thermal metrics considering the emitted light as well as highly accurate structure functions which provide detailed internal information for power LED packages revealing die attach failures and other structural integrity problems.

ADVANCED RESULTS POST-PROCESSING TOOLS

THE *TERALED*VIEW UTILITY

The *TERALED*View utility depicts the measurement results obtained with the *TERALED* hardware as diagrams. The results can be plotted as a function of current and temperature (either ambient or junction), thus enabling you to examine the characteristics of the tested LED.





FUNCTION DIAGRAMS

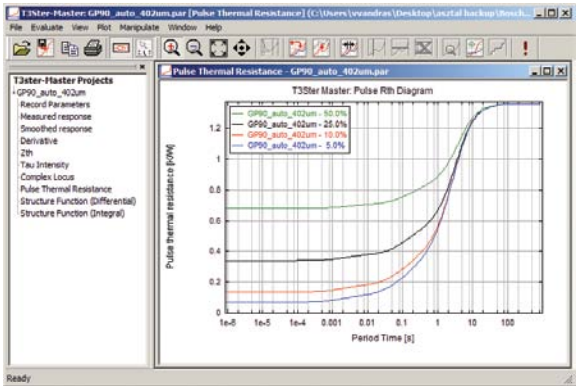
You can view the following as function plots:

- Diode characteristics
- K-factor
- Absolute or relative total radiant flux
- Absolute or relative total luminous flux
- Luminous efficacy
- Energy conversion efficiency
- CIE x-y color coordinates
- Correlated color temperature,
- And furthermore, the utility calculates the derating curve.

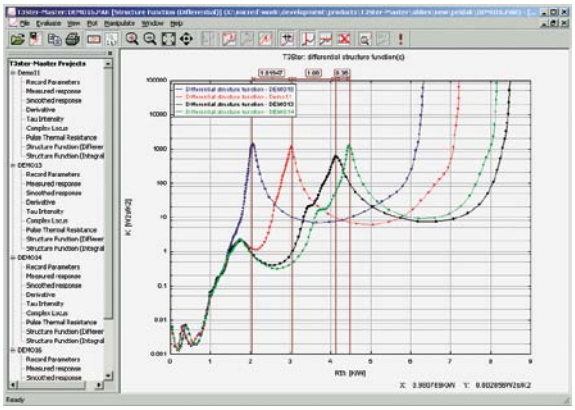
A detailed test report in tabulated format is also available, including real thermal resistance. For further details, please contact your local Mechanical Analysis office .

THE *T3Ster*-MASTER PROGRAM: ADVANCED RESULTS EVALUATION

T3Ster-Master is an optional software tool (available on all types of Windows® operating systems) primarily aimed at post-processing measurement results obtained by the *T3Ster* equipment. Thanks to its import wizard, thermal transient curves from almost any source can also be post-processed with this tool: simulated thermal transient (and all the descriptive functions derived from it) can be easily compared with measured ones (and with the descriptive functions identified from the measured data).



This way one can validate detailed simulation models with test results of packages. By comparing "measured" and "simulated" structure functions it is possible to identify where in the package the simulation model fails to match reality.



Results of multiple *T3Ster* measurement "projects" can be displayed in one single plot allowing one to quantify differences in structure functions e.g. failures in the heat-conduction path or identify junction-to-case thermal resistance according to the JEDEC JESD51-14 standard.

Besides advanced results presentation options, the latest version of *T3Ster*-Master provides dynamic compact models in the form of Cauer-ladders which can be used directly in FloTHERM 9.2.

EVALUATION RESULTS INCLUDE:

- Time-constant spectrum
- Pulse thermal resistance diagrams
- Complex loci of measured thermal impedance
- Cumulative structure function
- Differential structure function
- R_{thJC} value identified according to JEDEC JESD51-14

All results can be viewed as function plots that can be printed or copied into other Windows application programs.

TECHNICAL SUPPORT AND TESTING & MODELING SERVICES, CUSTOMIZED SOLUTIONS

TESTING SERVICES

- Tests in natural and forced convection environments as well as in cold plate setups
- Special test environments for special devices like *TERALED* for power LEDs
- Detailed test reports including advanced results using the *T3Ster* results evaluation technology
- High accuracy and excellent repeatability of tests
- Service at our facilities in the US, Japan and the EU

TECHNICAL SUPPORT

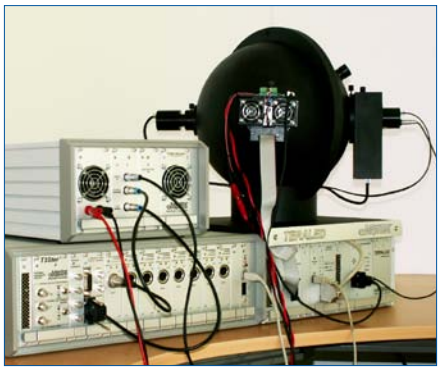
Our global testing services team are available to assist you with your special projects: in our central laboratory in Budapest, Hungary, at the North American Test Facility in Fremont, North California, as well as in the Japan Test Facility in Tokyo. Comprehensive characterization of packaged semiconductor devices as well as simulation with FloTHERM or FloTHERM PCB are available at our Northern California facility. The created simulation models are validated against measured data using the *T3Ster*-Master program.

- Spare parts: should a component of the *T3Ster* hardware fail, the required spare parts can be provided with the shortest possible lead time to assure minimal downtime of the measurements.
- Upgrade: new versions of specific hardware components or new software releases are available to existing customers. Contact us for details.
- SupportNet: our personalized support website offers release and patch downloads, reference materials, technical support and more.

CUSTOMIZED SOLUTIONS FROM STANDARD ELEMENTS

Due to the scalability of the *T3Ster* equipment and its wide range of add-on options versatile testing solutions can be built. With the help of our application engineers our customers can configure a *T3Ster* system to best meet their thermal testing requirements. With its flexibility our hardware can be tailored to the specific needs of our customers. This typically involves:

- Finding the necessary number of the measurement channels and power driving modules or boosters;
- Proper scaling of power boosters for the actual needs of the customer in terms of both current and voltage; up to 280 V and many hundred Amps;
- Choosing the appropriate test environment (cold-plate, still-air chamber, integrating sphere for LEDs) and calibration devices (MicReD thermostat or third-party thermostat).



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