WHITE PAPER

Five Essentials for Trusted Device Characterization

KEYSIGHT

Introduction

As electronic devices become more complex and embedded across industries such as wireless telecommunications, medical and healthcare, automotive, and consumer electronics, the need for precise electronic device characterization has never been greater. Characterization enables engineers to understand physical and electronic device behavior under various operating conditions, identifying a device's strengths and weaknesses and guiding design improvements that enhance overall functionality and performance.

Device characterization enhances quality and reliability by analyzing how a product behaves under temperature and physical stresses. It also helps improve manufacturing processes to increase product quality and yield.

This white paper outlines five fundamentals for device characterization so you can uncover trusted test insights.

Configure Your Setup to Produce Precise and Accurate Measurements

Precision and accuracy are key factors in enhancing device characterization. Outlined below are three areas to focus on, using a digital multimeter (DMM) as an example.

Choose the right instruments for the job

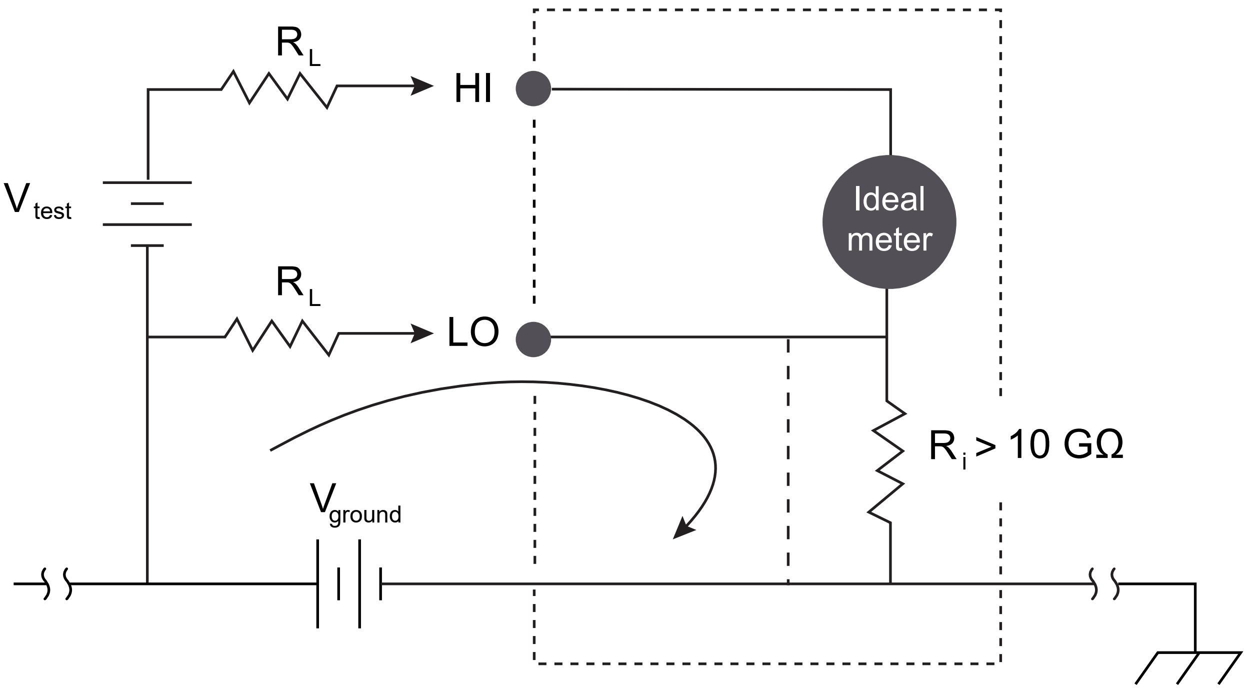
Do not underestimate the importance of selecting the right instruments for the task at hand. Verify that they meet the necessary specifications and performance standards. For example, while many modern DMMs have 6.5 digits, they may lack measurement stability, especially when measuring extremely low voltages or currents. This instability is evident when poor repeatability causes the least significant digits to fluctuate during measurement. The stability of the least significant digit greatly impacts the accuracy of your results, especially when measuring very small signal applications.

The Keysight Smart Bench Essentials Plus 6.5-digit Truevolt DMM provides an accuracy of 35 ppm DC voltage over a year. While many brands claim to meet certain test ranges and accuracies, they may not be rigorously tested against important test and metrology standards such as ISO / IEC 17025 or safety standards such as IEC 61010 and CSA. Check the test instrument company's regulatory website for declaration of conformity documents to verify quality, safety, and metrology standards. Keysight provides such documents on its product environmental and regulatory compliance website.

Reduce measurement errors from the test setup

The test setup and the instruments themselves can introduce measurement errors. Signal interference, unfiltered external noise, and internal current leakages are common errors. Test probes sometimes introduce loading errors.

Figure 1 illustrates a common measurement error caused by the test setup: a finite ground loop connection caused by different ground potentials between the test fixture and the instrument. This discrepancy introduces unwanted noise errors.



R_L	=	Lead resistance
R_i	=	Multimeter isolation resistance
V_{ground}	=	Voltage drop on ground bus

Figure 1. Potential noise error from a ground loop caused by differing ground potentials during setup

To eliminate this ground loop error, maintain the test instrument's isolation from the earth's ground; do not connect the input terminals to the ground. If the test instrument must be earth-referenced, be sure to connect it and the device under test (DUT) using the same common earth ground point. This process will reduce or eliminate any voltage differences between the devices.

Well-designed test instruments, such as the Smart Bench Essentials Plus DMM, provide proper grounding isolations and very high input impedance to prevent such ground loops. For more information on how to reduce measurement errors with a DMM, read this white paper: Eliminate Measurement Errors and Achieve the Greatest Accuracy Using a DMM.

Configure instruments to optimize precision and accuracy

Careful consideration of how you configure your instruments is crucial to obtaining precision and accuracy. For example, there is usually a trade-off between the speed and precision of your measurements. Figure 2 shows a chart of speed versus resolution for a Smart Bench Essentials Plus DMM. The higher your measurement throughput speed, the lower the resolution you get for your measurements. Hence, there is a sweet spot that you need to find as an engineer. Typically, a development engineer characterizing a product will optimize for higher accuracy and precision. A manufacturing engineer, on the other hand, may consider good enough accuracy to prioritize higher test throughput or speed.

Another trade-off that can affect the accuracy of your measurement is averaging — for example, increasing the averaging of your measurements to reduce random noise. This will help you get more accurate measurements but at the expense of speed because of the real-time averaging processing power required.

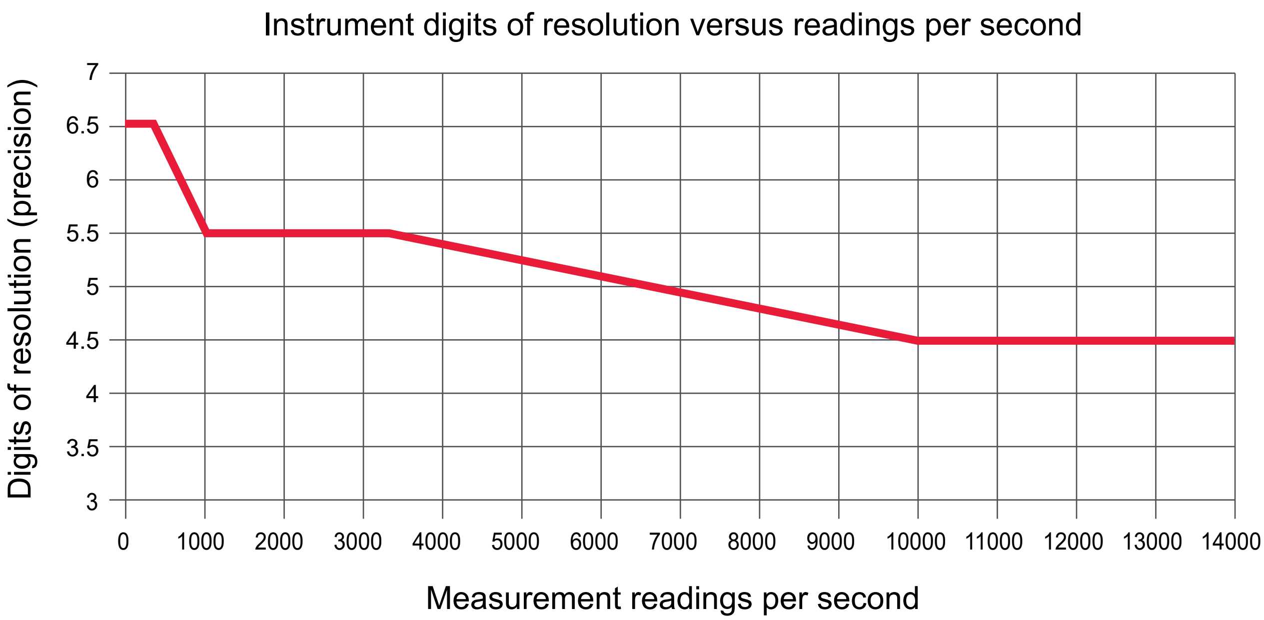
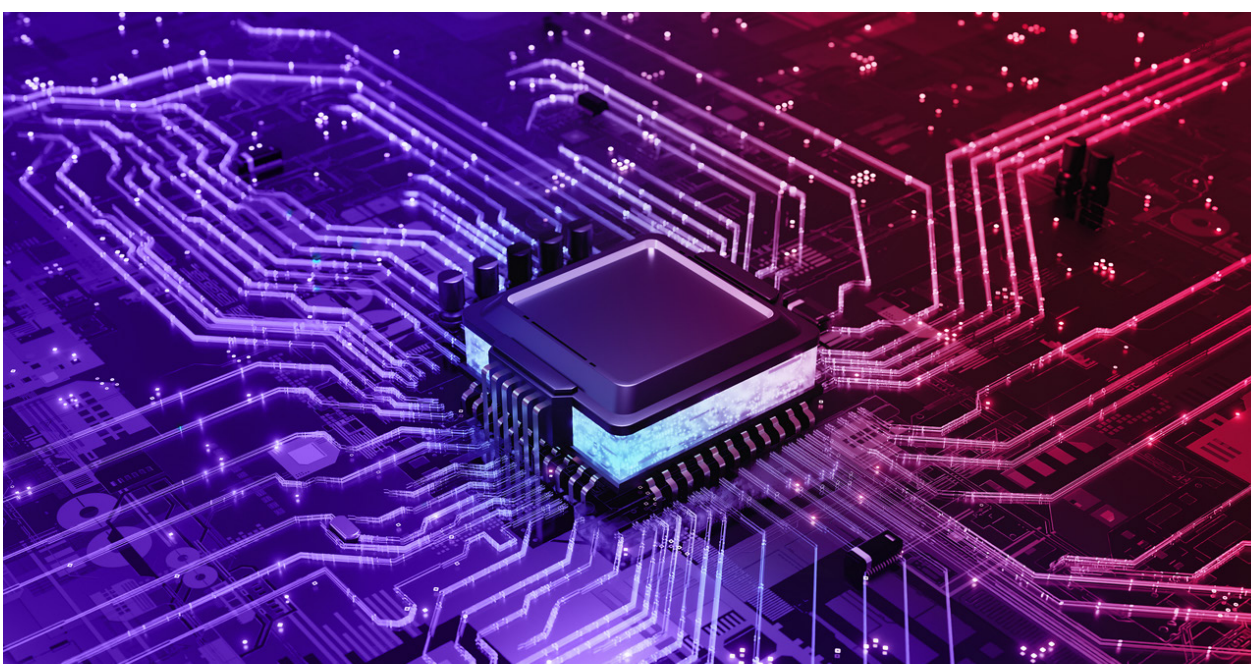


Figure 2. A trade-off between precision and speed of an instrument

If you understand what kind of noise you need to remove, you can selectively remove it using features available in modern instruments. This process is often more effective than using the brute force of high-averaging counts in your configuration. For example, suppose you want to remove power line cycle-induced AC noise that is affecting your measurement. In that case, you can use the Smart Bench Essentials Plus DMM's Truevolt power line cycle (PLC) integration time function with its built-in analog-to-digital converter. Other features, such as AC and DC block filters, also help remove unwanted noise.



Leverage Calibration and Error Correction Techniques to Ensure Accuracy over Time

The performance of all electronic instruments drifts over time because of environmental factors such as shock, temperature, humidity, current, and voltage. This makes periodic calibration necessary to ensure instrument accuracy according to specifications. A properly calibrated instrument will reveal true and accurate information about your DUT.

Besides periodic instrument calibration, which typically occurs annually, there are additional methods to enhance measurement accuracy while performing device characterization.

Auto-zeroing and auto-nulling

Auto-zeroing and auto-nulling are both calibration techniques used in Smart Bench Essentials Plus DMMs to remove unwanted bias signals from your test measurement paths. These bias signals can come from ground loops, cross-channel interferences, and temperature-induced errors. To improve measurement accuracy, you can execute this function frequently, such as during initialization prior to executing your test sequences.

Auto-calibration

Auto-calibration takes auto-zeroing and auto-nulling to the next level. The Smart Bench Essentials Plus DMMs are pre-calibrated in a controlled environment to characterize their temperature and internal drift errors. When this feature is enabled, your instruments will accurately remove drift errors based on their characterized stored data.

De-embedding

The de-embedding technique improves measurement accuracy in the high-frequency component characterization process using vector network analyzers. De-embedding is a post-measurement process that minimizes extraneous errors and reveals information about the device under test. When you perform a composite measurement of a DUT and fixture, de-embedding isolates the fixture's performance and extracts, or de-embeds, the fixture from the measurements. Mathematically de-embedding removes the measurements affected by the fixture, leaving only the DUT's behavior.

Four-wire measurement method

The four-wire measurement, or the Kelvin measurement, uses a pair of sourcing leads and a pair of sensing leads. The measurement separates the lines that supply current to the DUT from the lines that measure the voltage drop across the DUT. Since the sense lines making the voltage measurement do not conduct any current, there is no voltage drop caused by cable resistance. Therefore, you eliminate cable resistance effects. The four-wire measurement method is available in Smart Bench Essentials Plus DMMs and DC power supplies. For DMMs, the method eliminates measurement errors caused by leads and connectors in the measurement path. For DC power supplies, it allows for the accurate sourcing of power to the DUT.

Automate Data Collection to Eliminate User Error

Device characterization usually requires substantial amounts of data collection. Datasets may be multidimensional to capture device operating behavior under various environmental conditions. Depending on the complexity of the device, the process can be lengthy, taking hours or days. Here are the key steps for automating data collection.

Data acquisition and recording

Modern test instruments such as DC power supplies, digital multimeters, and oscilloscopes have some data logging functionality. These instruments can be synchronized for simultaneous data recording. Remote PC instrument control software can be used to synchronize, execute testing, and record results, as shown in Figure 3.

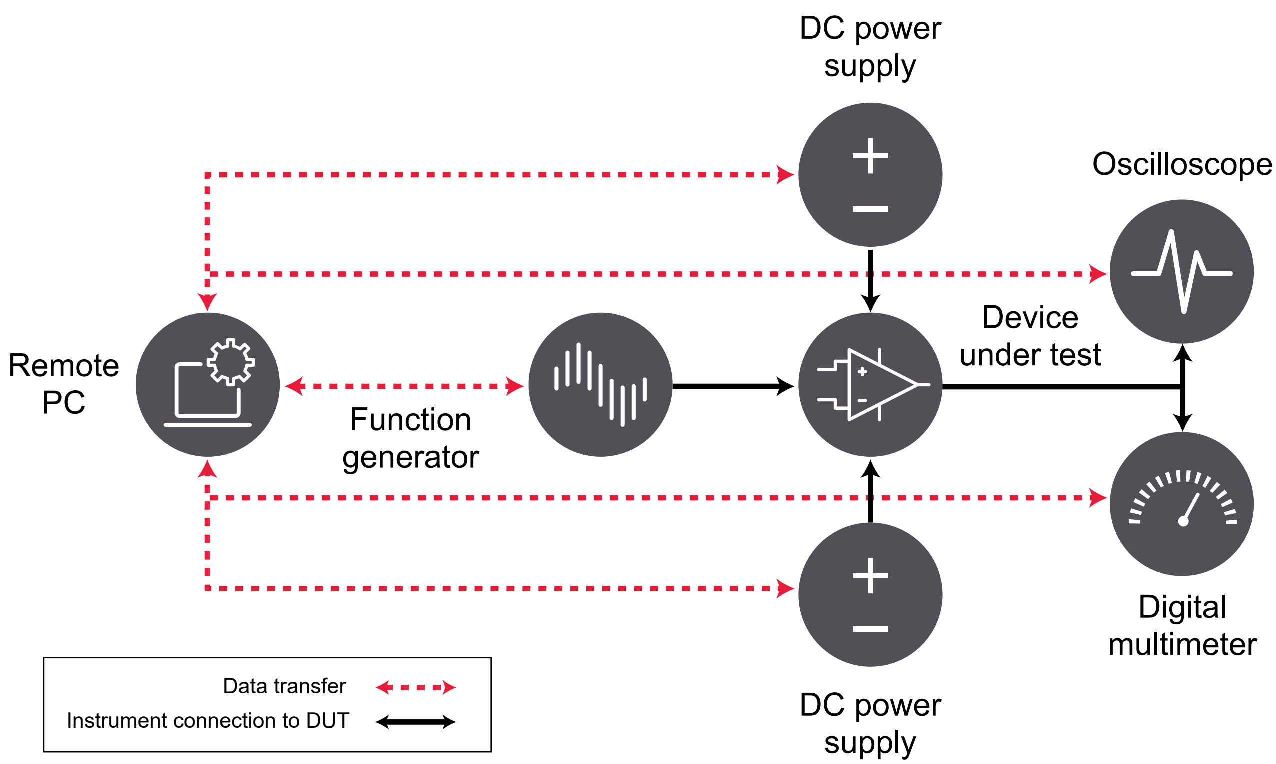


Figure 3. Data acquisition and recording control of test instruments via a remote PC

Data aggregation, correlation, and visualization

After all the data acquisition and recording, the data sources need to be organized and consolidated into a single unified data set. During the consolidation process, multiple data sources must be aggregated based on time stamps from each source. This process is usually automated via a software program such as the Keysight BenchVue TestFlow application.

The outcome of data aggregation provides a simplified and more usable dataset. For example, you can perform data correlation between two sets of information, such as two sensors, to ensure that they are functioning as expected. Another key benefit is that you can display multiple sets of information in a single time-based chart for a comprehensive view of the overall device characterization results. Automating your data collection eliminates tedious work and manual errors.

Use Device Characterization Software to Enhance Your Measurements

Device characterization software complements test instruments by accelerating design test and verification through intuitive graphical interfaces and no-code programming. Such software also enables you to review test results on graphs and tables, streamlining report generation. Figure 4 shows an example of device power characterization software with multiple test results displayed on graphs.

Figure 4. Advanced device power characterization software

This software is usually designed for specific device applications. For example, the Keysight advanced device power characterization software supports a wide range of applications, including component current-voltage (IV), photovoltaic inverter, battery, electric vehicle charging, and cellular and wireless. It can perform tasks such as connecting to key hardware test instruments, configuring the test setup, running test sequences, capturing waveforms, logging data, and graphically charting out the characterization test results. This software may include statistical tools to help analyze the results.

Analyze Test Data and Compare with Simulations

Data analysis is a critical step in the device characterization process, as it determines whether the device meets its design objectives. It also informs product specifications, defines manufacturing test guard bands, and reveals potential issues. Simulated results from the design phase help guide expectations and validate hardware performance throughout each design cycle.

Analyzing test results requires well-organized data, as discussed earlier — data must be aggregated, processed using mathematical or statistical tools, and visualized in 2D or multidimensional plots for effective analysis. Figure 5 shows a 3D plot illustrating sample product output characteristics. In this example, the output is influenced by two input conditions, which may be test signals or environmental factors such as temperature and humidity.

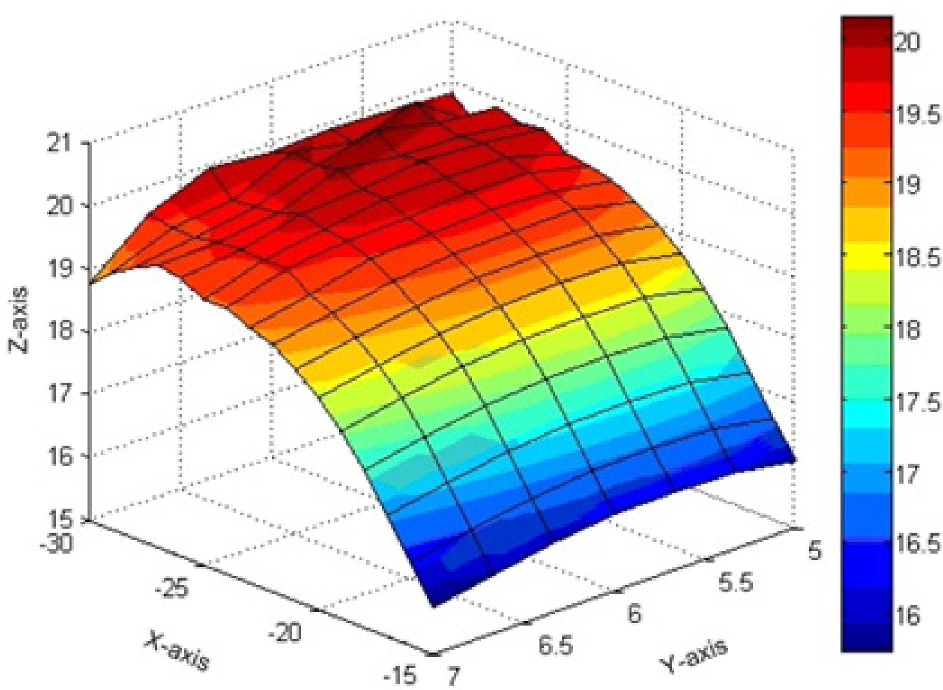


Figure 5. 3D product output characteristics visualization from MATLAB software

Summary

Enhancing device characterization is key to uncovering insights you can trust. Applying the five fundamentals outlined in this white paper will help you reduce errors, improve accuracy, and develop high-quality and reliable products.

But accurate device characterization depends on more than just test procedures — it requires reliable test instruments and performance, effective calibration, and seamless data handling. The quality of your measurements is directly tied to the quality of your tools.

If your older bench instruments are holding you back — introducing errors, slowing down test cycles, or failing to meet evolving standards — it may be time to advance your test bench.

Keysight Smart Bench Essentials Plus delivers an elevated set of basic instruments — power supply, function / waveform generator, DMM, and oscilloscope — equipped with proven pro-level measurement technologies and certified to industry and safety standards.