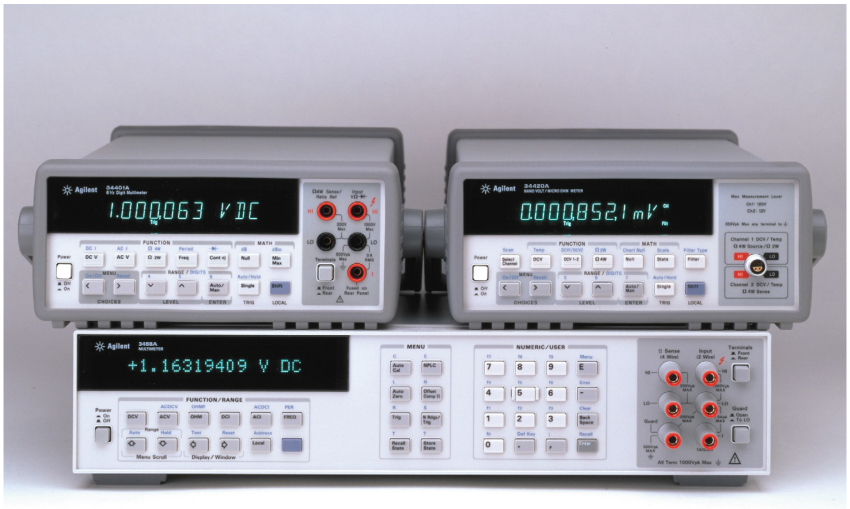
Instrument Design Validation and Recommended Calibration Policy

White Paper

Introduction

What are Agilent's policies regarding the design of the recommended performance test published in our Service Manuals? Why should users have confidence in the overall performance of the instrument, even for functions and ranges that don't seem to be included in the calibration procedure? Although the following article addresses these questions from the perspective of the manufacturing division responsible for digital multimeters, the general principles also apply to other product-types.



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Digital Multimeter Adjustment and Verification Procedures

From time to time, customers or calibration laboratories may inquire about why specific adjustment and verification points or procedures are selected for a given instrument model. This discussion is intended to provide general background information with respect to the methods and philosophies that Agilent Technologies utilizes when specifying these aspects of individual product service procedures.

Calibration and verification procedures documented in the Agilent Service Guide are created and reviewed by design, service, and quality engineers and incorporate our detailed, proprietary knowledge of the DMM's internal hardware and software design and sources of measurement error. Development of procedures and selection of verification test points is based upon our extensive statistical analysis of both characterization data gathered during design verification testing and through on-going monitoring of production processes. During Agilent manufacturing, significantly more verification data are gathered and used to monitor product performance and to assure our outgoing product quality. The documented user procedures completely describe all steps required to fully adjust an instrument to conform to its published accuracy specifications. Philosophically, Agilent verification procedures are designed to achieve > 99% confidence that the instrument conforms to all published measurement specifications and that it is fully functional for use. This high level of user verification confidence is achieved by a multi-tiered approach as described below.

First, all accuracy verification procedures are preceded by checking basic operational readiness through executing the instruments internal Self-Test procedure. This checks internal circuit paths for functional operation and is intended to assure, with > 90% confidence, that the instrument has not experienced a hardware failure and "should be expected" to meet all published measurement specifications — if the specified adjustment procedures have been followed previously. Some non-measurement, user accessible, functionality (e.g. display, keyboard, computer interface, etc.) cannot be completely verified by Self-Test and are generally not addressed by measurement verification procedures. Certain instrument models utilize internal, auto-calibration procedures that should be executed before any performance verification checks are performed. auto-calibration, when employed, automatically compensates for numerous measurement gains and offset drifts due to operating temperature variation and component aging effects. Auto-calibration utilizes internal transfer measurements, relative to the instruments primary voltage and resistance reference standards, to eliminate these measurement errors. Second, all zero offset calibration points are verified including both front and rear input terminals, where present, since separate offset values are stored for each during adjustment.

The third tier of performance verification confidence comes from verifying the linear gain terms of each unique measurement path. For example, while two-wire ohms and 4-wire ohms appear to the user as two independent measuring functions, they in fact share near 100% of the same measuring circuits, differing only in the offset portion of the measurement. The ohms current source, responsible for the linear gain term of the measurement is shared in both functions. Generically, gain verification is performed near the full range points using the nearest commonly available value. For example, ohms full range values are in multiples of 1.2 (e.g. 120 Ω, 1.2 kΩ, 12 kΩ, etc.) while Agilent specified adjustment and verification values are chosen in standard multiples of 1.0 (e.g. 100 Ω, 1 kΩ, 10 kΩ, etc.) for ease of user support. The verification test points and methods specified by Agilent are selected to achieve maximum performance verification confidence while not requiring undue support or cost of ownership burden on our customers.

The fourth element of the verification procedures is aimed at validating the performance of other circuit paths not specifically addressed by the linear offset and gain terms previously discussed. For example, this includes verification checks of the analog-to-digital converter (ADC) linearity (guaranteed by design and not adjusted) and of the ac signal conditioning path frequency response which may be either wholly guaranteed by design or may be adjusted at a single cross-over frequency. Since the same ADC is employed for all measuring functions and ranges, its characteristic is verified in a single configuration where the signal conditioning circuits have the least effect on the overall measurement result. The ADC integral linearity characteristic can be verified using several measurements across the complete scale (i.e. positive full scale to negative full scale). Similarly, the frequency response of the ac section can be verified at the accuracy band edges on a subset of the measuring ranges based upon specific knowledge of the instrument's circuit topologies. In addition, some ac measuring characteristics are determined by fixed, digital signal processing algorithms (DSP) and therefore do not require user verification. These behaviors have been verified earlier through extensive product design validation testing.

In summary, modern instruments such as DMM's employ closed-box electronic calibration methods to store and digitally process measurement correction constants for linear error terms. High quality instrument designs minimize non-linear error terms by design such that no user corrections are necessary to compensate for these non-ideal behaviors. In addition, many traditionally analog behaviors of instruments have been replaced by digital circuits, software algorithms and digital signal processing techniques whose characteristics do not change with time, temperature, etc. Therefore, many of the historical beliefs and experiences of users and calibration laboratories that developed with past generations of measuring instruments are becoming increasingly obsolete and outdated; particularly when inferring sources of measurement error in modern instrument designs. Since independent verification of every possible measured value is, and always will be, impractical by end users, one must rely on the guidance and integrity of the instrument manufacturer to specify appropriate adjustment and verification procedures for the instrument given their detailed knowledge of design limitations and instrument failure modes. As always, users may augment the manufacturer's verification procedures, as they deem necessary, to achieve higher verification confidence at application-critical measurement points.

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