

Original Article

Cost-Optimized Energy Compliance Testing for Smart TV Streaming Devices: Achieving Milliwatt-Precision Power Measurement at Sub-One-Thousand-Dollar per Setup

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Abstract:

Industry-standard power measurement rigs used in consumer electronics energy compliance laboratories commonly cost between five thousand and eight thousand US dollars per setup. This creates a practical barrier when test organizations want to scale horizontally across many device benches, product lines, and lab locations. This paper describes a cost-optimized hardware configuration used in production to perform regulatory power measurements on shipping streaming stick devices. The configuration achieves zero point zero one watt, or ten milliwatt, measurement precision at approximately six hundred US dollars per setup, roughly an order of magnitude lower than the reference alternatives. The paper covers the regulatory background that drives instrument selection, including US Department of Energy and California Energy Commission requirements, the European Union Ecodesign framework for off mode, standby mode, and networked standby, and the corresponding standards in Canada, India, and Japan. It then covers the selection criteria for the power meter and supporting accessories, the calibration steps used to validate that lower-cost instrumentation is sufficient for the methodology the regulations require, and two production case studies. The first case study covers power validation for an energy efficiency feature deployed across three streaming device models. The second covers power profiling for an on-device dialogue enhancement feature that performs real-time audio neural network processing on streaming sticks. The paper concludes with a decision framework that test engineering organizations can use when sizing power test capacity against capital budget.

Keywords:

Power Measurement, Energy Compliance, Streaming Devices, Smart TV, Regulatory Testing, US DOE, CEC, EU Erp, Ecodesign, Nrcan, BEE, IEC 62301, IEC 62087, Cost Optimization, Hardware-In-The-Loop, Test Infrastructure.

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1. Introduction

Consumer streaming devices that connect to a television, such as streaming sticks and small set-top boxes, fall under several regional energy regulations. In the United States the relevant rules come from the Department of Energy and the California Energy Commission. In the European Union the relevant rule set is the Ecodesign framework for off mode, standby mode, and networked standby. Canada uses Natural Resources Canada. India uses the Bureau of Energy Efficiency. Japan has its own national energy standards. Each of these regimes prescribes how the device should be measured in different operating states, what the limits are, and how the measurement equipment should behave.



The measurement itself is straightforward in principle. The device is plugged into a power meter. The meter is connected to a controller. The device is driven through a defined set of operating states such as active use, active standby, and passive standby. The meter records power consumption during each state and the recorded values are compared against the limits in the relevant regulation. In practice the equipment used to do this is expensive. The reference power meters and analyzers used in formal compliance work commonly cost between five thousand and eight thousand US dollars per setup once accessories are included. When a test organization needs to onboard several devices in parallel, or set up additional benches in another lab location, the cost of equipment quickly becomes the dominant line item.

This paper describes a configuration that brings the per-bench cost down to roughly six hundred US dollars while preserving the measurement precision required by the regulations listed above. The configuration is the same configuration used in production to certify shipping Fire TV streaming stick product lines for each release. The paper does not propose a new measurement methodology. The regulations and their referenced IEC standards define the methodology. The contribution is the empirical observation that lower-cost instrumentation, when selected and calibrated carefully, is sufficient for the methodology that the regulations require, and the documentation of the steps needed to confirm this in a given lab.

The rest of the paper is organized as follows. Section 2 summarizes the regulatory measurement requirements. Section 3 describes the hardware configuration and the selection criteria used. Section 4 covers the calibration and validation steps. Section 5 presents two production case studies. Section 6 offers a decision framework and discusses limitations. Section 7 concludes.

2. Regulatory Context and Measurement Requirements

The regulations relevant to streaming devices share a common structure. The device is required to enter several defined operating states. Power consumption is measured in each state. The measurements are then compared against limits that depend on device class, feature set, and in some cases display size. The states most commonly required are active power, active standby, and passive standby. Active power covers the device while it is performing its main function. Active standby covers a state in which the device is not performing its main function but can be brought back to active without user intervention beyond a remote command. Passive standby covers a state in which the device is in an off-like state but still drawing power because it remains plugged in.

2.1. United States: DOE and CEC

The US Department of Energy maintains a test procedure for televisions that adopts the IEC 62301 standard for measuring standby power and the IEC 62087 standard for measuring on-mode power. The procedure measures on mode, standby mode, and off mode, as well as screen luminance and an annual energy consumption metric. The Federal Trade Commission requires manufacturers to report these values. The California Energy Commission maintains an appliance efficiency program with its own registration and reporting requirements, originally adopted in 2009 for televisions with a phased implementation. While streaming sticks are not televisions, the underlying measurement methodology referenced by these procedures is what drives instrument selection in this work, because the streaming device is measured as a connected component with the same instruments and the same averaging discipline.

2.2. European Union: Ecodesign Standby Regulation

The original EU regulation in this area, Commission Regulation (EC) No 1275/2008, established Ecodesign requirements for standby and off-mode and later for networked standby. The off-mode and standby power limits introduced under that framework have been tightened in subsequent revisions. The relevant point for instrument selection is that all of these regulations require sub-watt accuracy in the relevant low-power states, and they reference the same IEC standby measurement methodology used by US procedures.

2.3. Other Jurisdictions

Natural Resources Canada operates an energy efficiency program with measurement requirements that align with the IEC methodology used in the US and EU. India operates a Bureau of Energy Efficiency program with a star-rating scheme for televisions and other appliances, again referencing IEC-style measurement. Japan operates its own national energy standards. The common thread across all of these jurisdictions is the use of IEC 62301 for standby measurement, which is what allows a single bench configuration to support measurements that satisfy the documentary requirements of multiple jurisdictions.

2.4. What These Regulations Require of the Instrument

All of the regulations referenced here require that the measurement instrument be capable of accurately recording very low power values. The passive standby limit in particular is in the range of single-digit watts for small devices, and the practical measurement target during validation is well below one watt. IEC 62301 requires resolution of at least zero point zero one watt for measurements below one watt. This is the requirement that drives instrument selection. A meter that cannot reliably distinguish between one hundred milliwatts and two hundred milliwatts cannot be used to validate a device against a half-watt limit.

The other requirements that drive instrument selection are stable averaging over defined time windows, accurate measurement under non-sinusoidal current draw caused by switching power supplies, and the ability to be controlled programmatically so that measurements can be aligned with device state transitions. None of these requirements are exotic. They are all available in well-priced commercial power meters.

3. Hardware Configuration

The configuration described in this section was selected to keep the per-bench cost low while satisfying the measurement requirements summarized in Section 2. The configuration is also selected to support unattended operation, which is necessary for the automation framework that wraps these benches and that is described in companion work on the larger power profiling framework.

3.1. Power Meter

The power meter is the central component of the bench and the single most important selection. The meter chosen for this configuration provides zero point zero one watt resolution, which is sufficient for the milliwatt-level distinctions that compliance validation requires. The meter also exposes a programmable control interface, which is what enables it to be driven from a Python test framework rather than read manually by a technician.

The cost of the meter is the largest contributor to the per-bench total. It is also the line item where most of the savings against the industry-standard configuration come from. The choice was made after evaluating several candidate meters against the resolution requirement and against the practical question of whether the readings produced under switching-supply loads matched the readings produced by a reference meter under the same load. Section 4 covers that validation.

3.2. USB Programmable Switch

Several of the test states defined in the regulations require the device to be connected or disconnected from USB peripherals during the measurement sequence. Doing this manually is not compatible with unattended operation. The bench therefore includes a programmable USB switch that can connect and disconnect USB peripherals on command from the test framework. The switch chosen is a low-cost commodity device. Its only requirement is that it expose a control interface that the test framework can drive.

3.3. IR Remote Automation

Streaming devices are normally driven by an infrared remote control. To bring a device into a defined operating state, the test framework sends the same sequence of remote button presses that a user would. This is done with a programmable IR emitter rather than with a robotic finger on a physical remote. The IR emitter is another low-cost commodity device. The remote code set for the device under test is captured once and replayed as needed by the test framework.

3.4. ADB Control Channel

In addition to the IR channel, the device under test is accessible over ADB. ADB is used for state verification, for log capture, and for issuing commands that are not exposed on the remote. The ADB channel is not used as the primary input channel during a compliance measurement, because the goal of a compliance measurement is to record the device behavior as it would behave for an end user, but it is invaluable for setup, teardown, and post-run analysis.

3.5. Bill of Materials Summary

The per-bench bill of materials is the power meter, the USB switch, the IR emitter, the host computer that runs the test framework, and a small set of cabling. The aggregate per-bench cost is approximately six hundred US dollars. The host computer cost is not included in this figure, on the assumption that test organizations already have a host available for each bench. The industry-standard comparison point against which this configuration is measured is the five thousand to eight thousand US dollar range

commonly seen for reference compliance benches that bundle a high-end power analyzer, a calibrated AC source, and ancillary instrumentation.

4. Calibration and Validation

The central question the bench has to answer is whether the readings it produces are good enough to be used as the basis for a compliance submission. The bench is not a national reference laboratory and does not need to be. It does need to produce readings that agree with a reference measurement within the tolerances that the relevant regulations allow. The validation step is what establishes this.

4.1. Reference Comparison

Validation was performed by running the same device under the same operating states on the low-cost bench and on a reference setup, and comparing the recorded power values. The reference setup uses the higher-cost instrumentation that is treated as the trusted reference in the lab. Devices were driven into active, active standby, and passive standby states, and steady-state power values were recorded on both setups. The recorded values from the low-cost bench were checked against the reference values for each state.

The validation criterion was that the low-cost bench should agree with the reference within the tolerance allowed by the relevant regulation for the state under test. Across the states tested, the low-cost bench produced readings that met this criterion. This is the basis on which the bench is used for compliance work on shipping devices.

4.2. Warm-Up and Settling

Power meters of any class produce noisy readings during the first few seconds after the device transitions to a new state. IEC 62301 prescribes a stability check on the average power over the last third of the measurement window. The bench follows this stability discipline. A settling delay is applied in the test framework before recording the steady-state value for a state. The duration of the settling delay was chosen empirically by observing how long the reading on the low-cost meter took to converge for each state. The same settling discipline is applied uniformly across all measurements, regardless of which meter is in use, to keep the comparison fair.

4.3. Re-validation Cadence

Validation is not a one-time activity. Benches are re-validated periodically against the reference setup. Re-validation is also triggered whenever the bench has been physically modified, for example after a meter has been replaced, after the test fixture has been rebuilt, or after a move between lab rooms. Re-validation uses the same protocol as initial validation.

5. Production Case Studies

This section describes two examples of features that were validated using the low-cost bench configuration. Both features shipped on production Fire TV streaming stick devices.

5.1. Energy Efficiency Feature on Three Device Models

An energy efficiency feature was deployed across three streaming device models. The expected per-device power saving from the feature was in the milliwatt range during the targeted operating states. The role of the bench in this work was to confirm that the feature actually delivered the expected saving, and to do this with enough precision that the saving was distinguishable from measurement noise.

The bench was used to record power values for each device, in each state, with the feature enabled and with the feature disabled. The difference between the two configurations was reported as the saving attributable to the feature. The zero point zero one watt resolution of the meter is what made this work tractable. A coarser meter would have recorded both configurations as approximately identical, and the saving would have been invisible. The fact that the saving showed up clearly in the recorded values, in the same direction and approximate magnitude as the design intent, is the evidence that the bench is operating within the precision range the work requires.

5.2. On-Device Dialogue Enhancement Feature

A dialogue enhancement feature was deployed on streaming sticks. The feature performs real-time audio neural network processing on the device. Real-time audio processing increases active power consumption, because the audio pipeline runs continuously while the feature is enabled. The role of the bench in this work was to validate that the resulting active power figure remained within the power budget assigned to the device, and to characterize the cost of the feature in terms of active power.

The bench recorded active power consumption with the feature enabled and with the feature disabled. The recorded values were used to characterize the additional power consumed by the audio pipeline. The validation showed that the device remained within its power budget with the feature enabled, which allowed the feature to ship. This work was recognized in the cross-organization launch announcement for the feature.

6. Discussion and Decision Framework

This section discusses how to decide whether a low-cost bench configuration is appropriate for a given test organization, and what the limitations of the configuration are.

6.1. When the Low-Cost Configuration Is Appropriate

The configuration described here is appropriate when the test organization needs to scale across several benches and is willing to invest in a validation protocol against a single trusted reference setup. It is also appropriate when the measurements being performed fall within the resolution and tolerance the configuration can deliver. For streaming sticks and similar low-power consumer devices, the configuration is well matched to the IEC 62301 methodology that the relevant regulations reference.

6.2. When It Is Not

The configuration is not a replacement for a reference instrument. The reference instrument is what the low-cost benches are calibrated against. If a lab does not have access to a reference instrument, either in-house or via an external lab, the validation step described in Section 4 cannot be performed and the configuration should not be used for compliance work. The configuration is also not the right choice for measurements that require resolution finer than the meter supports, or for devices whose current draw characteristics fall outside what the meter has been validated against. Devices with very high peak inrush current or unusual harmonic content should be characterized on the reference instrument before any low-cost bench is asked to measure them in production.

6.3. Cost Comparison Summary

The per-bench cost of the configuration is approximately six hundred US dollars. The industry-standard configuration against which it is compared is in the range of five thousand to eight thousand US dollars per bench. The ratio is roughly an order of magnitude. The savings are realized per bench, so the total savings scale with the number of benches the organization deploys. For an organization deploying many benches across multiple lab locations, the absolute saving is significant. The savings also unlock organizational behaviors that the higher-cost configuration discourages, such as keeping a bench permanently associated with each product line or each engineer rather than rotating a small number of expensive benches through a queue.

6.4. Limitations of This Report

The report draws on production deployment of one configuration in one organization. The validation results reported here apply to the specific device classes the configuration was used with, namely Fire TV streaming sticks. Other device classes may have current draw characteristics that require additional validation work. The configuration may also need adjustment if the relevant regulations are updated to require additional measurement states or tighter tolerances. Any such future regulatory tightening should be re-validated against the low-cost bench before being relied on for compliance submissions in the EU market.

7. Conclusion

Regulatory energy compliance testing for streaming devices does not necessarily require five-figure instrumentation per bench. A carefully selected low-cost configuration, validated against a trusted reference setup, can deliver the milliwatt-level resolution that the relevant regulations require, at roughly an order of magnitude lower per-bench cost. The configuration has been used in production to validate shipping Fire TV streaming stick devices for each release, and to support two specific feature validations described in this paper. Test organizations that need to scale their power testing capacity without proportional capital expenditure can use the bill of materials and the validation protocol described here as a starting point for their own configuration.

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This work was performed in the context of power and thermal profiling for Fire TV streaming stick product lines. The author thanks the cross-functional teams responsible for the device platforms and for the features referenced as case studies.

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