Keysight Technologies
Optimizing *Bluetooth*® Device Battery Drain Measurements in Manufacturing

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Introduction

Battery operating time is a critical parameter for portable devices. It is a key factor that consumers weigh heavily in their purchasing decision. Reducing battery drain to improve operating time is a top priority for early *Bluetooth®* designs. To assure meeting specified operating time, the manufacturing test engineer must select appropriate *Bluetooth* operating states for making battery drain measurements while still meeting tight cost and throughput goals. In addition, the wide range of levels and the pulsed nature of the battery drain for *Bluetooth* devices dictate using specialized test equipment for optimum test accuracy, throughput, and lowest cost in manufacturing.

Key Representative Operating States for Manufacturing Test

Bluetooth devices feature many operating states, each providing a certain capability with a corresponding power drain. This enhances performance as a networked device, while still optimizing battery-operating time. Key representative operating states need to be identified for making battery drain measurements to assure specified operating time while minimizing testing. Due to the wide potential diversity of *Bluetooth* applications, key operating states will depend largely on the intended application of the particular device and its dynamic range of operation, making their identification challenging. Most key operating states fall into four broad categories, including battery charging for rechargeable devices.

These categories are:

1. Active call state operation
2. Standby/scan state operation
3. Low power modes of operation
4. Battery charging (when applicable)

Active Call State Operation

The highest level of power drain is when the *Bluetooth* device is linked and actively communicating with the host network. A large portion of the power is drawn by the respective *Bluetooth* RF and baseband circuitry. Its power consumption will depend on transmit power and rate. For example, power class 1 devices output up to 100 mW (20 dBm), having a range of up to 100 meters. At the low-end, power class 3 devices output only up to 1 mW (0 dBm) of RF power for close proximity operation. Regarding rate, a headset is an example of a device that transmits at a continuous rate with a corresponding continuous high power drain. In comparison, a room thermostat may transmit for only a few milliseconds, once every minute, using much less power.

A second potentially large portion of the power is unique to the function of the particular device, which is over and above the *Bluetooth* RF and baseband circuitry. One higher power example is an illuminated color display, which can consume up to several watts of power.

Bluetooth is a digital time-multiplexed transmission format. As a result most battery-powered *Bluetooth* devices in active call state operation typically draw pulsed current with the following characteristics:

– Average and high level current from tens of milliamps up to amps.
– A low-level current from milliamps up to hundreds of milliamps.
– Crest factors on the order of 10X.
– Waveform periods with multiples of the 1.25 millisecond frame rate.

Primary measurements for the active call state current drain in manufacturing test include:

– The DC current as it is the most fundamental measurement verifying battery operating time.
– Peak and high-level currents as they can cause excess battery voltage droop and are an indicator of device faults.

Measurement system needs for performing such measurements include:

– Ability to handle high crest factor signals.
– Accuracy of 0.5% or better for the DC level of interest.

– Adjustable integration time for fast and accurate averaging over waveform periods.

– Ability to track and capture maximum and high level waveform values.

These characteristics and their measurement needs pose challenges to most test equipment. Most system DC sources have very basic measurement capabilities and are usually not adequate for pulsed load currents. Most DMMs do not have the necessary integration time control, which is the key to accurate measurement with good throughput. Likewise, most general-purpose equipment does not have the ability to capture peak and maximum values of the active call state current.

Figure 1 illustrates an actual current drain waveform measurement taken on a *Bluetooth* headset device operating in an active call state.
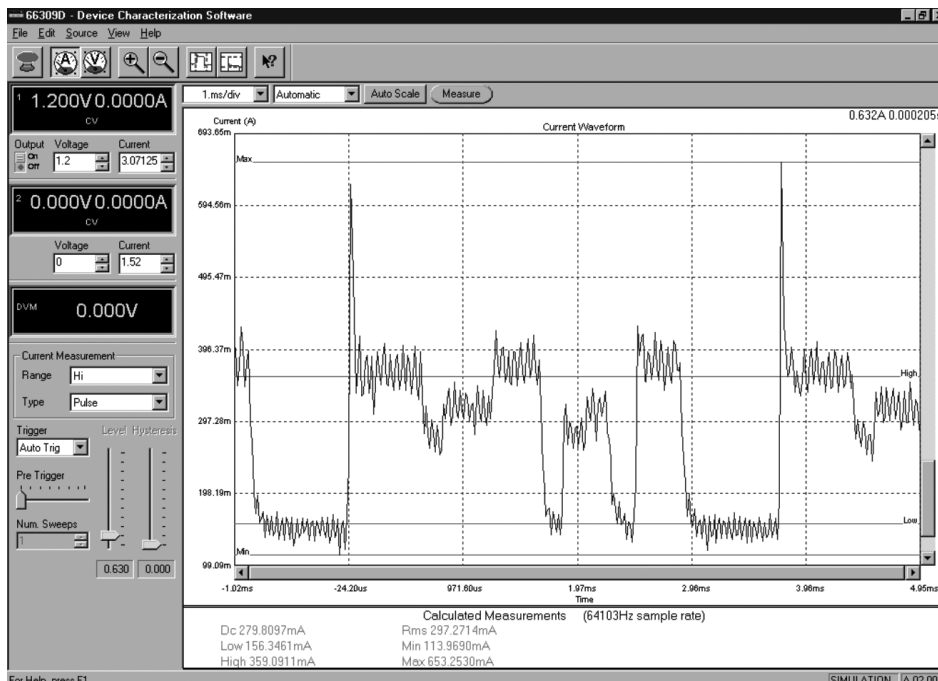

Figure 1 Example *Bluetooth* Headset Device Active Call Current Drain Waveform

Standby/Scan State Operation
Acting as a Slave Device

When not networked, a *Bluetooth* device acting as a slave will be operating in standby, at an intermediate to low power level. During each scan period the device wakes up to receive and check for pages and/or inquiries. This produces a pulsed current drain with the following typical characteristics:

– One or two 11.25 msec pulses within a 1.28-second scan period.

– High levels from tens to hundreds of milliamps.

– DC levels from single to tens of milliamps.

– Low levels from tens of microamps to tens of milliamps.

– Crest factors from 10 to 1000X.

Next to active call, standby/scan state DC current drain is the second most common measurement made in manufacturing to assure meeting the specified battery- operating time of the device. Long standby time is a critical end-user requirement. The measurement system needs for standby/scan state include:

– Ability to handle very high crest factors.

– Accuracy of 0.5% or better for average levels from single to tens of milliamps.

– A settable integration time for accurate averaging over long (>1 second) waveform periods.

Figure 2 illustrates the current drain of the example *Bluetooth* headset device in the standby/ scan state.
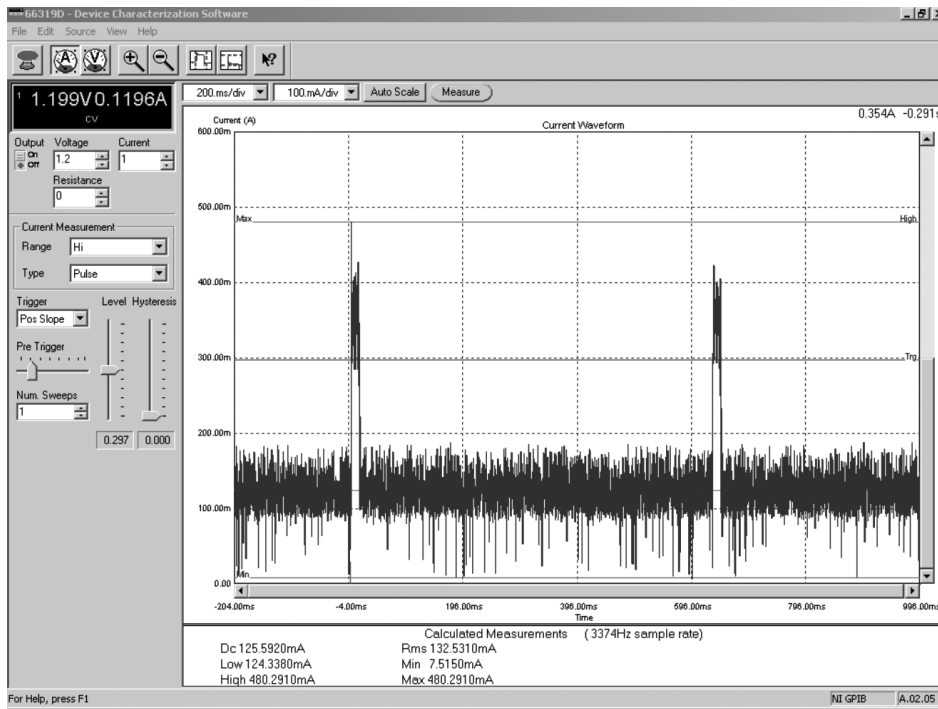

Figure 2 Example *Bluetooth* Headset Device Standby/Scan State Current Drain Waveform

Standby/scan state measurements are even more challenging than active call state due to the lower current levels and long signal period. As a result most general-purpose test equipment and system DC sources do not adequately address these measurement needs for optimum test throughput and accuracy.

Acting as a Master Device

Conversely, a *Bluetooth* device acting as a master during the standby/scan period trans-mits a series of pages or inquiries in an effort to contact a slave device. For this situation the device's current drain characteristics and measurement needs are basically the same as that for the active call state operation.

Low Power Modes of Operation

During periods of inactivity the *Bluetooth* device can be placed into low power modes of operation, such as PARK, HOLD, and SNIFF, for extended time periods to conserve power. During these periods the device enters into sleep mode drawing as little as only tens to hundreds of microamps of current.

To further conserve power many *Bluetooth* devices can be placed in off-mode, where they likewise draw as little as only tens to hundreds of microamps of current. The example *Bluetooth* headset device was found to draw 121 microamps of current in its off-mode.

There is very high value in testing current drain to assure against unexpectedly high battery drain in these low power modes as well as identifying existing and latent manufacturing defects in the device.
Key measurement system needs include:

– A low-level current measurement range of about 10 mA.

– 10 microamp or better measurement accuracy.

– A suitable measurement delay and integration time for obtaining a stable reading.

Most system DC sources do not adequately address the measurement needs for low power modes of operation, not having sufficient accuracy for making microamp level measurements.

Battery Charging Mode of Operation

For higher power *Bluetooth* devices incorporating rechargeable batteries, the charging function will be typically built in. For proper charging function, the battery charge current and voltage needs to be measured and calibrated as part of the manufacturing test process.

Key measurement system needs include:

– Able to measure the charge current (typically up to 1 amp) with 0.5% or better accuracy.
– Able to measure the charge voltage (typically up to 9 volts) with 0.2% or better accuracy.

Additional system needs include:

– The DC source should double as a constant voltage load and sink the charging current to emulate a charging battery.
– A second DC source is needed to provide the charging current.

Most general-purpose DC sources do not have the necessary features to support the battery-charging mode of operation for test and calibration during manufacturing test, not able to operate as a constant voltage load and sink the full level of charging current.

Optimizing Throughput and Accuracy with Minimum Measurement Integration Time

Controlling the measurement integration time is necessary for measuring the DC values of the pulsed current drains for *Bluetooth* active call and standby/scan states. Being able to precisely set the integration time optimizes test throughput and accuracy.
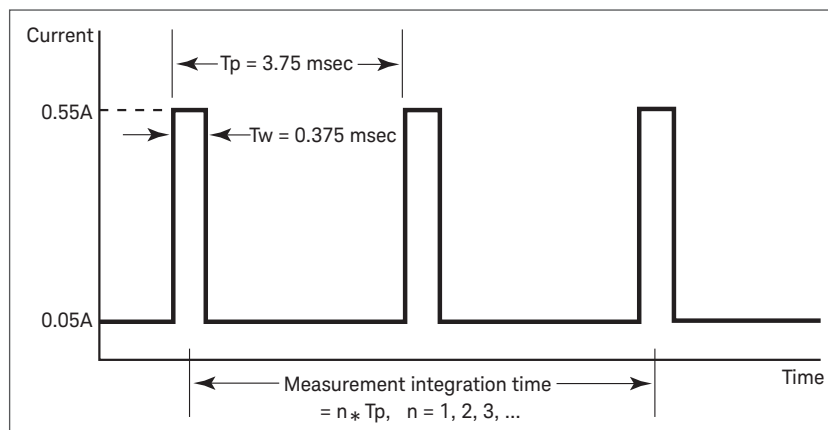

Figure 3 Setting Measurement Integration Time for a Pulsed Signal

A pulsed current drain example is shown in figure 3. When the measurement integration time is precisely set to an integral multiple of the pulse period, the measurement accuracy is predominantly the specified DC accuracy of the test equipment. However, when there is even a small mismatch between the pulse period and integration time, significant

error is encountered. This mismatch usually manifests itself as repeatability error and it occurs when either a part of a pulse is missed or an additional part of another pulse is captured in the integration. The objective is to make this mismatch error a small part of the overall error budget.

As an example, using an integration time that is 10% too long, 4.13 msec instead of 3.75 msec, on the signal in figure 3 will produce about 45% error when a second pulse is captured. The error decreases with longer integration time and number of pulses averaged. A ten-fold longer integration time will have one-tenth the error. The accuracy is improved at the expense of reduced test system throughput. This relationship is summarized in figure 4.
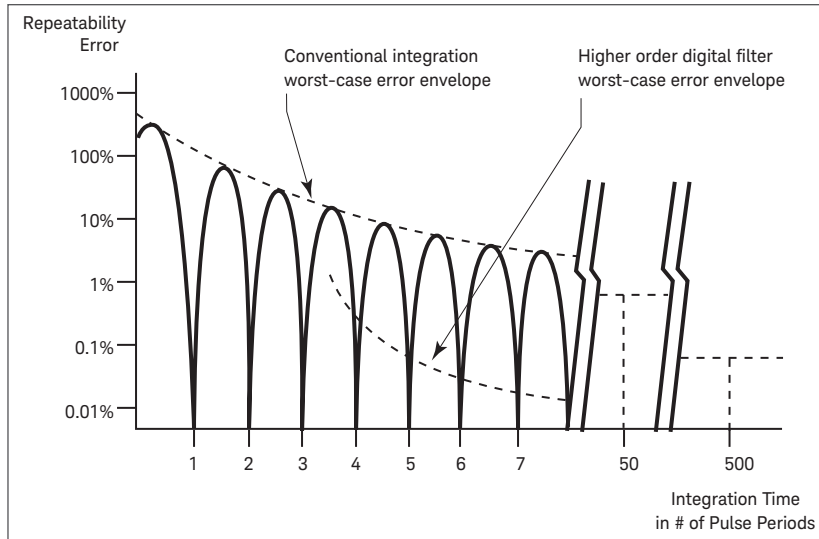

Figure 4 Attenuation and Error vs. Measurement Time for one Example Pulsed, Periodic Signal

The integration time for a typical DMM is set in Power Line Cycles (PLC's). A PLC is 16.7 msec for 60 Hz and 20 msec for 50 Hz. Using PLC's minimizes AC line interference error. However, the limited integration time adjustment of a typical DMM, based on PLC's, is not well suited for measuring non-PLC based pulsed currents. This leads to seconds-long integration time, over hundreds of pulse periods, in order to make the mismatch error a small part of the overall error budget. Making several measurements in active and standby/ scan states with a generalpurpose DMM can add tens of seconds to the test time. Specialized test equipment providing the necessary integration time accuracy and resolution minimizes measurement time, optimizing test throughput and accuracy.

Digital filtering as an Alternate Approach for Optimizing Measurement Throughput and Accuracy

With sampling measurement systems, digital filter signal processing can be used to significant advantage, as an alternative to conventional measurement integration. By applying weighting factors to the sampled values from the acquisition, very low repeatability error is achieved in a small number of pulse periods, thus providing high throughput and accuracy for DC measurements. The order and shape of the digital filter function determine what the weighting factors are. An example of a higher order digital filtering worstcase error envelope is shown by the lower curve in figure 4. In this case the repeatability error becomes negligible within 6 pulse periods. Being the envelope, the low level of error is achieved independent of exact matching of the pulse period. This is a major advantage when the pulse period is not precisely known or controlled, as well as when there is another signal to reject, such as AC line frequency interference. Some specialized sampling measurement test equipment provide such capabilities as standard.

Summary

Accurate DC current measurements for battery powered *Bluetooth* devices are fundamental in assuring specified battery operating time, calibration, and quality. Table 1 summarizes these key test parameters and system measurement needs. In optimizing manufacturing test it is important for the test engineer to appropriately select these key operating states to best assure the specified batteryoperating time is met while still minimizing the amount of testing.

Table 1 Summary of *Bluetooth* Device Tests and Measurement Needs for Manufacturing

Operating Mode & Test Parameter	Test Rationale	Measurement System Needs
Active Call & Page/Inquiry States – DC current	– Assure meeting specified battery operating time when active	– Handles high crest factors. – Accuracy of 0.5% or better for DC average level (typically from tens of milliamps up to amps). – Integration system suited for fast & accurate averaging over millisecond waveform periods.
Active Call & Page/Inquiry States – high-level current – peak current	– Assure against premature battery minimum voltage shutdown.	– Incorporates high-speed pulse signal high and peak level detect circuitry or algorithms.
Standby/Scan States – DC current	– Assure meeting specified battery operating time when in standby	– Handles very high crest factors. – Accuracy of 0.5% or better for average levels (typically from single to tens of milliamps) – Integration system suited for fast & accurate averaging over long (>1 sec) waveform periods
Low Power & Off Modes – DC current	– Assure against unexpected battery drain when off. – Detect latent defects in components & assembly.	– A low-level current measurement range, around 10 mA. – 10 microamp or better measurement accuracy. – Suitable measurement delay and integration periods for stable value.
Battery Charging Mode – DC voltage – DC current	– Part of device calibration. – Assure of proper battery charging function.	– Measure charge (negative) current (typically up to 1 amp) with 0.5% or better accuracy. – Measure charge voltage (typically up to 9 volts) with 0.2% or better accuracy. Additionally: – The DC source should double as a constant voltage load and sink charging current to emulate a charging battery. – A second DC source to provide charging current.

The wide range of levels and pulsed characteristics for *Bluetooth* device current drains are a challenge to measure in manufacturing. These measurement needs are not adequately addressed by general-purpose system DC sources and measurement equipment. Specialized test equipment providing measurement ranging and pulse signal integration are key to optimizing test accuracy, throughput, and cost.

Keysight Technologies, Inc's 66319B/D and 66321B/D DC Sources are ideal solutions for manufacturing test of battery-powered *Bluetooth* devices. They incorporate a specialized high-speed sampling measurement system with Digital Signal Processing to address test needs specifically for such digital devices drawing pulsed current. Due to this advanced measurement system these DC sources provide both accuracy and throughput for optimum test results, at a low cost.

Key features include:
  – Current ranging for high accuracy measurement from amps, down to microamp levels, for testing high and low power modes of operation.
  – High-speed sampling digitizes pulsed current waveform and its parameters, including peak and high levels, for active call state testing, to guard against premature low battery shutdown.
  – 15.6 µsec integration time resolution for fast and accurate conventional integrating measurements of pulsed currents, for optimizing test throughput.
  – Alternate DSP-based digital filtering setting for fast and accurate DC measurement of pulse currents, independent of exact period, for optimizing test throughput.
  – CV load operation (current sinking) for testing and calibrating battery-charging circuits
  – Second output available for replacing battery charger during test.

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