2016太克科技
春季創新論壇
Power Consumption Measurement Techniques

Maximize the Battery Life of Your Internet of Things Device

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Internet of Things
IoT: Internet of Things: Disruption & Potential for high growth

Source: Raymond James research
IoT applications

Health

Home automation

Farming / Smart metering / ...

Automotive

Source: Raymond James research
Device development is accelerated by new low cost IoT modules (sensors, RF modules, MCUs)

- Explosion of sensor systems and components. Several physical/chemical parameters can be sensed (temperature, pressure, movements, etc.)
- Wireless connectivity made simpler with wider offering of high performance RF modules
- MCUs offering higher performances (low power, computation speed, DSP, etc.)

Source: Raymond James research
IoT wireless, portable device architecture and Power Budget

Power Budget: **80uW** (6months)

- Accelerometer 14uW
- Bluetooth SMART Tx/Rx 12uW
- Power Management Unit 20uW
- Processing 34uW
  - (MCU 100uA/MHz + memory + peripheral + oscillator)
Low Power Modules & Components

- Sensor
- Power Management
- Radio
- Power Source
- Microprocessor/Microcontroller

Brands:
- Texas Instruments
- Silicon Labs
- Microchip
- NXP
- Analog Devices
- Microsoft
- Freescale
- STMicroelectronics
- Dialog Semiconductor
- Nordic Semiconductor
- Broadcom
- Qualcomm
- Samsung
- Panasonic
- Energizer

Antenna
Low Power Devices & End Products

Enables statistical data analysis

Microprocessor Microcontroller

Sensor

Power Management

Radio

Power Source

Antenna
Typical IoT device power profile

**Common Characteristics**

- A wide dynamic range of current
- High current > 1A
- Low current < 1uA
- Complex multilevel current load profile
- Fast transients from 100us to 100ms
- Long periods of operation
Characterizing low power consumption is not a trivial matter

Test Challenges

• Accurately capturing a wide dynamic range of current, over 8 decades
  • Sleep mode load currents down to $10^{-9}$A
  • Transmit mode currents from $10^{-3}$A to 1A

• Capturing complex and fast transmit mode load current waveforms
  • Ensuring sufficient sampling rate, bandwidth, and record length
  • Triggering on a short duration, fast rise time waveform
  • Analyzing power consumption from complex waveforms

• Ensuring stable, clean, and accurate power to the device-under-test (DUT)

- Peak power consumption
  Data Transmission
  ~29mA

- Active mode consumption
  Data acquisition
  ~2mA

- Ultra Low Power Consumption
  Sleep Mode
  ~70nA

- Fast Transient Event Capture
  Pulse Width
  ~4ms

- Long datalogging
  Device operation > 10s, >10 million data points need to be saved
Traditional Test Solutions

Scope + Current Probe + Regular Power Supply

- High Sampling Rate
- Low Accuracy – High Noise, Hard to capture signal
- Few to support long term recording

Regular DMM + Regular Power Supply

- Hi Accuracy
- Low Sampling Rate – High Noise, Hard to capture signal
- High Burden Voltage
- No high level trigger function
- Slow transient response
- Poor Source Accuracy
Measuring power relies on accurate current measurement

- Auto-range on most ammeters and DMMs may introduce latency and glitch
  - produce an inaccurate or even incorrect result
- Almost all ammeters and DMMs use either the shunt ammeter or the feedback ammeter technique

**Shunt Ammeter**

- Built-in current sensing resistor
- Higher voltage burden reducing the actual voltage applied to the device
- Lower sensitivity
- Smaller resistor means smaller voltage burden and
  - faster instrument response time
  - degrade the signal-to-noise
  - significantly impacts the accuracy and sensitivity

**Feedback Ammeter**

- Virtually no voltage burden
- Higher sensitivity
- Large signal to noise ratio
- Bandwidth limited
  - More sensitive to capacitance and susceptible to oscillation and unstable readings.
Effect of shunt/sense resistor and other sources of error on low sleep mode current

- Burden voltage from the internal series resistance that can be as high as 500mV
  - Effectively reducing 3 V power source to 2.5 V
- Reduced signal to noise ratio (SNR)
  - Need sensitivity ≤100pA to measure 10's of nA
- Measurement accuracy
- Connections between the device and the instrument
- Ammeter input bias current
- Source resistance of the device under test
- Leakage current from cables and fixtures
- Currents generated by triboelectric or piezoelectric effects

**Much more difficult task!**

<table>
<thead>
<tr>
<th>Sensitivity</th>
<th>DMM7510</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOW</td>
<td>HIGH (1pA)</td>
</tr>
</tbody>
</table>

**Voltage Burden**

- Technique
  - Hall effect
  - Sense resistor
  - Shunt
  - Shunt
  - Hybrid (Feedback + Shunt)

**Magnitude**

- 0V
- HIGH
- LOW
- HIGH
- 15mV all ranges ≤1mA

**Accuracy**

- LOW
- LOW
- HIGH
- LOW
- HIGH

**DMM7510 Example ~70nA**

![Image of DMM7510 measurement result]
Effect of shunt/sense resistor on high transmit/receive current

- Burden voltage from the internal series resistance that can be as high as 500mV
  - Effectively reducing 3 V power source to 2.5 V
- Can choose smaller resistance value with smaller burden voltage and faster response time and better accuracy because of the large test signal

Much easier measurement to make!
Capturing complex transient current waveform is a significant undertaking

- Slow reading rates (nplc) and large processing overhead on conventional ammeters and DMMs
- Oscilloscopes are perfect for capturing fast transients, but lacks the sensitivity for low level measurement
  - Small signal is lost in scope and probe noise
- Analog bandwidth combined with sample rate determines the smallest fast transient
  - Higher sample rate can better reconstruct the original waveform
  - Small bandwidth will not resolve high-frequency changes such as a “wave-up” profile. Amplitude will be distorted. Edges will slow down.
  - Details lost due to the 10kHz bandwidth are not recoverable at 200kSamples/s sample rate
  - High speed DMM7510 has sufficient performance and sensitivity for IoT device operation
- Monitoring power consumption over an extended period
  - Small internal data storage on conventional DMMs and other instruments makes trending impossible
  - Scopes are not ideal for trending data over time
  - Streaming data or transferring to an external storage device is a huge benefit

DMM7510 Internal Data Buffer Capacity > 27 million
Built-in triggering simplifies the task to locate the waveform of interest

- No trigger capability on conventional current measuring instruments
- Low current (microampere) edge trigger accuracy relies on the sensitivity the trigger acquisition system in the instrument.
- Advanced triggering, such as pulse width, logic trigger, A-B sequence trigger, and synchronous external trigger are ideal for challenging waveforms.

A variety of triggering available on DMM7510

✓ Edge, Pulse, Timeout, Logic, Time, Sequence (A->B Event), Boolean Logic/State, Pattern, Window
Graphical display for quicker insight into power profile

- Instruments with a graphical display are ideal for capturing IoT device operation and let user immediately “see” device operation
  - Conventional instruments can only acquire current readings
  - Some specialized instruments provide basic statistics such as min, max, and average.
  - Oscilloscope offers more sophisticated numerical calculation tools such as RMS calculations, duty cycle, and other math operations
- Pinch-and-zoom touchscreen interface allow for quick analysis of waveforms
- Measurement “gating” using cursors enable quicker and deeper insight into device operation
- Intuitive UI design is a large part of the ‘time-to-answer’ calculation
Automated tools for analyzing power consumption from complex waveforms

DMM7510’s Touchscreen Graphical User Interface

Cursor Analysis

“Gated” Cursor Statistics

Buffer Statistics

Reading Table

Average current = battery life
DMM7510 meets the low current and the waveform capture needs in a single box solution

Common current measurement solutions today

<table>
<thead>
<tr>
<th></th>
<th>Scope + Voltage Probe + Sense Resistor</th>
<th>Scope + Current Probe</th>
<th>Picoammeter</th>
<th>Broad Purpose DMM</th>
<th>DMM7510 Graphical Sampling DMM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dynamic Range</td>
<td>×</td>
<td>×</td>
<td>×</td>
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<td>×</td>
<td>×</td>
<td>✓</td>
</tr>
</tbody>
</table>

DMM7510 Summary

- High sensitivity
- Minimal voltage burden
- Fast waveform capture
- Long Data Memory
- Solution oriented waveform analysis
- Ease to use UI

Common current measurement solutions today

- Scope + Voltage Probe + Sense Resistor
- Scope + Current Probe
- Picoammeter
- Broad Purpose DMM
- DMM7510 Graphical Sampling DMM
Use a high quality supply to provide clean, stable and accurate DC power

- Look for good setting and readback accuracy when powering IOT devices that operate on low voltages
  - Ensures accurate determination of shut-off threshold voltage
- Use a supply with remote sensing to ensure the voltage is accurately applied to the load
- Use a low noise output supply to minimize disturbance to the DUT
- Use a power supply with a fast response to maintain a stable output during large load current transitions
  - Transitions from sleep mode/standby mode to a transmitting mode can be from milliamps to amps, in microseconds

![Diagram of power supply circuit](image)

- Fast response to load change
- Poor response to load change
Enhancement to the Power Consumption Analysis Solution – Dynamically Simulate the Battery

- Test the DUT under the most realistic sourcing conditions
- Simulate different types of batteries based on battery models
- Simulate different battery conditions
  - Avoid waiting for a battery to reach a specific condition
  - Precisely replicate a test condition
2281S Builds Up a Battery Model based on Charging Cycle Data

After a full charge cycle, the 2281S builds up a battery model automatically and can simulate the battery based on that model.

Battery model includes the parameters: State of Charge (SOC), Open Circuit Voltage (Voc) and Equivalent Series Resistance (ESR).

Battery testing ➔ Build battery model ➔ Battery simulation

Battery charging data ➔ Generate battery model

Battery model includes the parameters: State of Charge (SOC), Open Circuit Voltage (Voc) and Equivalent Series Resistance (ESR).
Power Sourcing for Battery-Powered Devices and Products

- Parameters automatically adjust based on the model and power consumed by the device
- Customize battery “State of Charge” and “Open Voltage” point

Select a model
Test at any battery voltage
Test at any capacity
IoT device power consumption analysis solution

- Voltage setting and measurement accuracy of 0.02% of reading +3mV - superior to most power supplies
- Low noise; it is a linear supply: < 1mVRms output ripple and noise
- 4-wire remote sensing to ensure that the programmed value is accurately delivered to the load
- High resolution TFT display and soft-key/icon-based user interface simplify power supply operation

- 1pA resolution, 0.006% basic 1 year DC current accuracy
- 15mV burden voltage
- Precisely analyze current and voltage waveforms and transients with 1MS/sec, 18-bit digitizer
- Capture signal with advanced analog triggering features
- Large reading memory (27.5 million compact and 11 million standard) to capture more of your signal
- Display more with five-inch, high resolution touchscreen interface
Example
Smartwatch Power Consumption
Example

Analyzing Smart Watch Overall Power Consumption

Notice the Repeating Spikes

- Power Saving OFF
  - Standby Mode (Screen On)
- Finger Presses Touchscreen to initiate commend
- Sleeping Mode (Screen Off)
Example

Analyzing Smart Watch Overall Power Consumption

We can zoom in to the graph with the touchscreen, seems like a power-up transient.
Example

Analyzing Smart Watch Overall Power Consumption
Demo - BLE Pedometer
CR2032 BATTERY OPERATED

Power-Up & Sensor On
Data Transmission

Data Sync to Phone & Sensor Off
Data Transmission

Graph
Data
Scale
Trigger
MAN

Buffer Stats
Min: -724.5429μA
Max: OverflowA
Avg: +824.5633μA
Std: +2.378556mA

Buffer Stats
Min: -93.02517μA
Max: OverflowA
Avg: +270.8808μA
Std: +1.266486mA
Demo – BLE Anti-loss Tracker

FOLLOW-ALONG

Find each other (iTag and smart phones) within range

Graph Data Scale Trigger MAN

Active

Paring

Alert
What is SourceMeter?

Well, it works.

It works well.
A fully-integrated combination of multiple instruments

- A Source Measure Unit instrument can simultaneously source or sink voltage while measuring current, and source or sink current while measuring voltage.
SourceMeter make your test much easier!

- **Precision Power Supply**
  - 5.0000V

- **DMM (measure I, V, and R)**
  - 1.99999V

- **Current Source**
  - 1.000e-6

- **Electronic Load**
  - 2.00V 0.01A

**SMU**
- 4 Quadrant – Source and Sink

**Materials**
- Resistive devices
- Semiconductors
- IR testing

**Reverse leakage tests**

**Solar cells**

**Batteries**
SMU Compared to Power Supply: What are the differences?

Power Supply

Versus

Source Measure Unit (SMU)
Advantage of 4 Quadrant Operation – Fast Discharge

- **Source + Sink**
- **Source Only**

4 Quadrant SMU

2 Quadrant Power Supply

Using a Model 2657A
- Time Scale = 2 msec/div
- Total discharge time = 5 msec

Using a Power Supply
- Time Scale = 2 sec/div
- Total discharge time > 6 sec
Keithley 2461 - 1000 Watts, 10 Amps Pulse, 7 Amps DC
Go to the Main menu and tap the Sweep icon under Source.

Configure the Sweep Settings:
- Type: Linear
- Start: 1.0 mA
- Stop: 0.1 mA
- Definition: Number of Points or Step Size

Tap the Generate button to configure the SMU.

Analyze your results.
Viewing the source and digitize waveforms simultaneously on the front panel (2461 only)

Source readback to capture the current source waveform and the voltage digitize waveform. Plot the two waveforms together on the same graph to examine time dependencies between the two waveforms.
Visualizing IV Data

Go to the main menu and tap the Graph or Histogram icon under Views.

Data is plotted on the graph as it is collected.
Use pinch-and-zoom gestures to zoom in on the data.

View real time statistical data

Analyze with scope-like cursors.
Saving the Data

1. Go to the Main menu and tap the Data Buffers icon under Measure.

2. Tap the name of the buffer where the sweep data was collected, defbuffer1.

3. Tap the Save to USB button.

4. Give the file a name then tap OK.
TSP®-Link for Test System Scaling

*Channel expansion without needing a mainframe*

- Connect up to 32 Model 2450’s for multi-point or multi-channel parallel testing
- Unlike mainframe-based systems, there are no power or channel limitations
- Only requires one GPIB, USB, or LAN/LXI connection
Battery Test with a SourceMeter (TSP enabled)

**VOC**

![Graph of VOC](image)

**ESR**

![Graph of ESR](image)

**Battery Capacity / SOC**

- **VOC = 1.397 V, ESR = 0.083 ohm**
- **66.139 mAh**
- **Range: 2V, Source: +1.4000V, Limit: 100.00mA**
Charging or Discharging Curves
Thank You!