APPLICATION NOTE

Solving Low-Power Integrated Circuit IV Test Challenges

With PZ2100 series high-channel density precision SMU solution

KEYSIGHT

Introduction

Performing Current Voltage (IV) characterization is a common challenge for low-power Integrated Circuits (ICs) that incorporate Microcontroller Units (MCUs), sensors, power management ICs, and other components in various applications such as automotive electronics and IoT/mobile devices. These applications often require low power consumption to extend battery life, manage thermal effects, and improve overall efficiency. Furthermore, these circuits must be reliable to deliver the required performance and efficiency in harsh operating environments. Therefore, manufacturers must perform IV characterization under various operating conditions to validate the circuit's design, identify faults or issues, and optimize its performance.

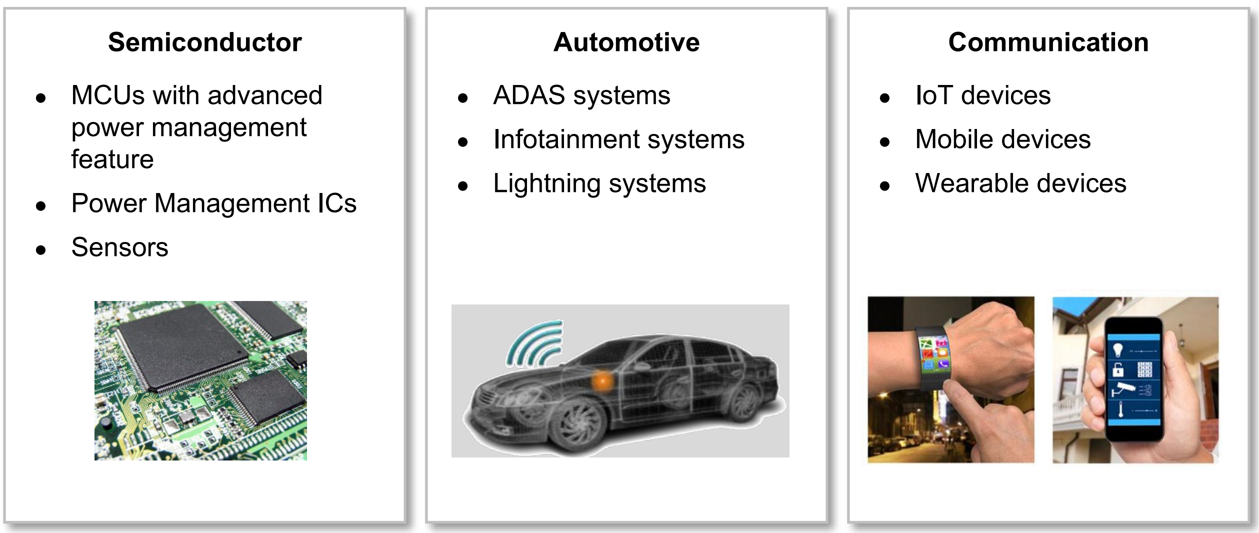

Figure 1. Low-power ICs in a wide range of applications

Low-Power ICs Test Challenges

The demand for smaller, more efficient, and more cost-effective electric devices capable of performing increasingly complex tasks is driving the trend toward highly integrated circuits, which often results in an increase in the number of test ports required. Furthermore, low-power ICs must operate at extremely low current and voltage levels to meet low-power consumption requirements. However, accurate measurement of such small current and voltage levels can be challenging due to limited equipment sensitivity. Additionally, the complex control between sleep and active modes in low-power ICs requires dynamic and static DC IV characterization. As circuits become more complex and used in more critical applications, test sequences become more complicated, necessitating the use of additional test instruments.

Figure 2 shows the conventional test setup for a typical low-power ICs configuration. The conventional test setup requires a variety of basic instruments, including multiple power supplies to supply the required voltage to various test ports with different voltage requirements, digital multimeters (DMMs) for measuring voltage and current, pulse generators for simulating signals, and digitizers for capturing signals in the time domain.

However, the conventional test setup faces several challenges when it comes to meeting recent needs. These challenges include:

- Increasing test cost and footprint due to the higher integration of circuits, which requires more basic instruments such as power supplies and DMMs.
- Lack of precision and speed in basic instruments for characterizing low-power circuits that operate among multiple states, such as sleep and active.
- The emergence of more complex circuit evaluation requirements, necessitating a more complex test sequence that requires the synchronization of a vast amount of equipment.

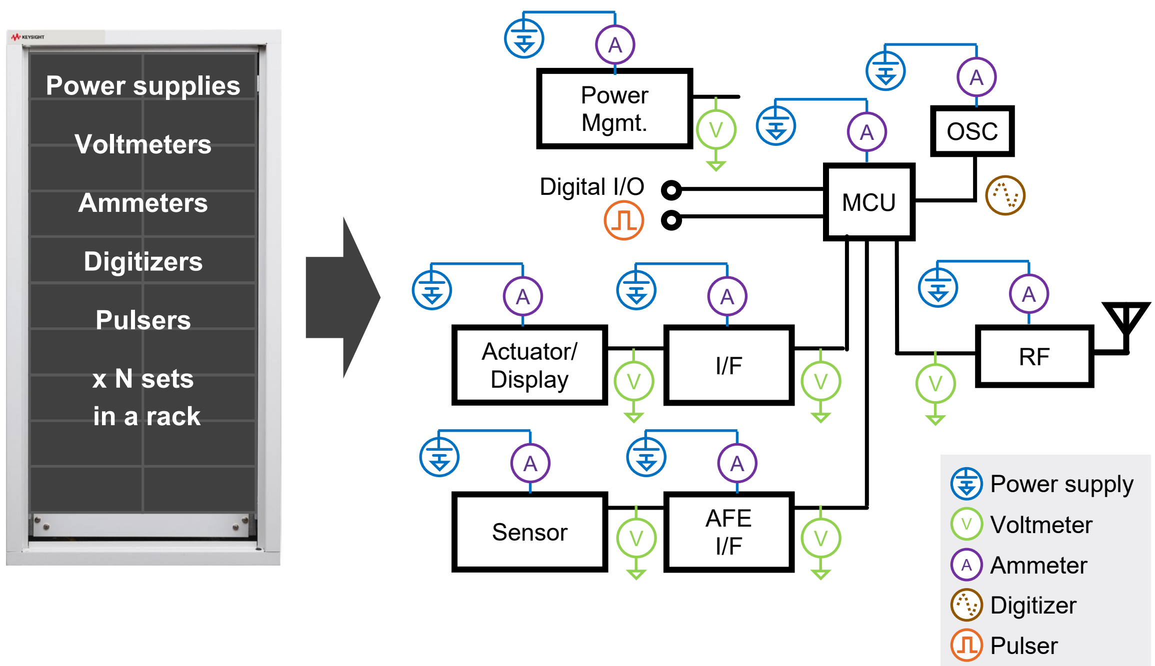

Figure 2. Conventional test setup for testing typical low-power ICs

Solving Low-power ICs Test Challenges

The Keysight PZ2100 series high-channel density source/measure unit (SMU) provides a solution to the challenges of testing low-power integrated circuits, enabling broad IV characterizations of highly integrated low-power circuits that operate among multiple states at a lower cost and with a smaller footprint in semiconductor design, automotive, or communications applications.

Test cost reduction at a small footprint

The Keysight PZ2100 high channel density solution, featuring all-in-one SMUs that integrate pulser/digitizer functionality, effectively reduces the number of required test equipment and the system footprint. It successfully addresses the challenges associated with the increased test cost and footprint in testing highly integrated circuits.

The Keysight PZ2100A is the mainframe that uncompromisingly and densely integrates 20 SMU channels at maximum into valuable 1U-height full-width rack space, with flexible module options at their best performance. It supports a variety of resources, such as the Keysight PZ2110A high-resolution SMU, the Keysight PZ2120 / PZ2121A high-speed SMUs, and the Keysight PZ2130 / PZ2131A high-channel density SMUs.

These resources have multiple functions, including pulser and digitizer, precise voltage / current sourcing and measuring to adapt to various application requirements.

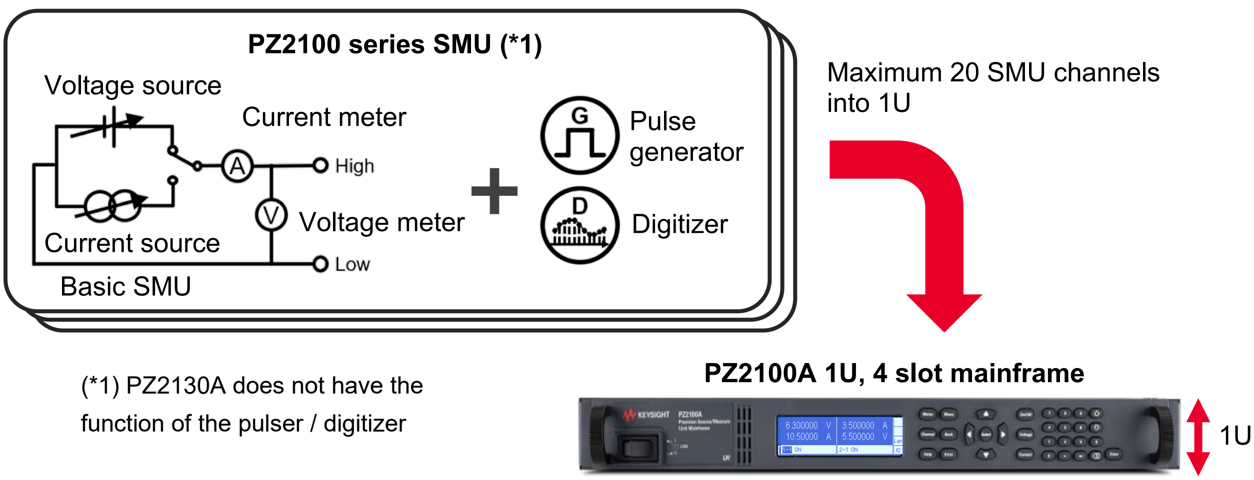

Figure 3. High-channel density solution with all-in-one SMUs

Broad coverage from static to dynamic IV characterizations

PZ2100 SMUs with wide dynamic range enable the characterization of multiple states and their transitions and accurately evaluate the operation of low-power ICs.

The PZ2130 / PZ2131A high-channel density SMUs have five channels per module, each supporting up to 30 V/500 mA, 500 kSa/s, and a minimum 100 µs pulse, making it ideal for multi-channel power supply and multi-channel voltmeter/ammeter applications.

The PZ2120 / PZ2121A high-speed SMUs are suitable for applications requiring a wider output range, faster transient response, and a narrower pulsed bias. It supports up to 60 V/3.5 A DC/10.5 A pulse, 15 MSa/s, and a minimum 10 µs pulse width.

These SMUs with a wide dynamic range enable the characterization of multiple states and their transitions.

Model	High-speed SMU		High-channel density SMU	
	PZ2120A	PZ2121A	PZ2130A	PZ2131A
Density	1 channel /slot		5 channel /slot	
Max. voltage/current	60 V / 3.5 A DC/10.5 A pulse		30 V / 750 mA(ch1/2) or 500 mA (ch3/4/5)	
Max. sampling rate	1 MSa/s	15 MSa/s	250 kSa/s	500 kS/s
Digitizer mode	Yes	Yes	No	Yes
Min. pulse width	50 µs pulse	10 µs pulse	N/A (No support for pulse)	100 µs pulse

Effortlessly Integrate Complex Test Systems and Sequences

The PZ2100 offers a single-box solution with an intelligent trigger system making it effortless to synchronize multiple instruments and characterize circuits under complex sequences.

The PZ2100 series mainframe has six internal trigger lines, enabling synchronization among the channels at less than 50 ns accuracy without any cabling. The external trigger ports on the mainframe and modules are also available, enabling them to synchronize with any external equipment.

The PZ2100 series SMUs also feature an intelligent trigger system that facilitates flexible source and measure sequencing. This system allows for simultaneous voltage application to multiple circuit test ports in a specified sequence, with the option to incorporate wait times or apply arbitrary waveforms. Additionally, the trigger system operates independently of the source and measure function, enabling the observation of current and voltage changes before and after the application of a source in a circuit.

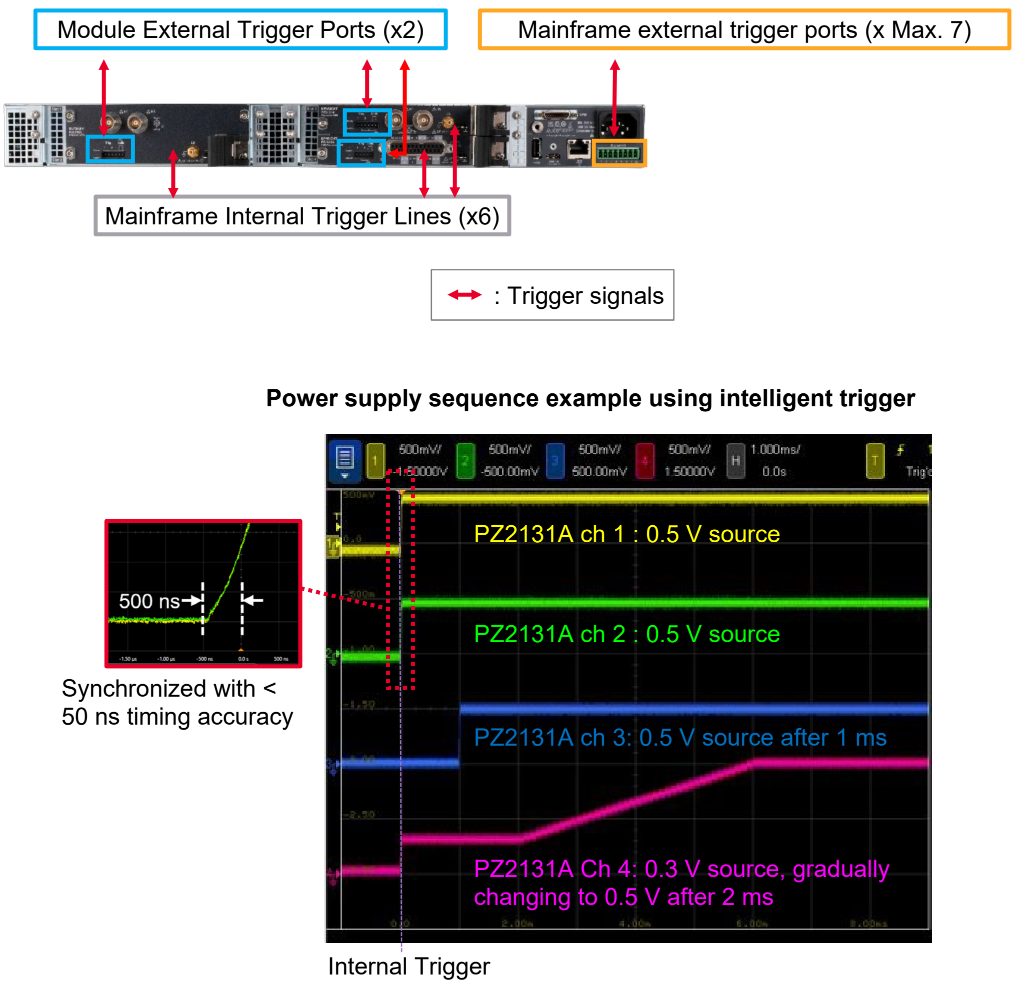

Figure 4. Intelligent trigger system

Getting Started for IV Characterizations of Low-Power ICs

This chapter presents the following measurement examples:

- Multi-channel synchronous IV measurement utilizing an SMU as power supply, ammeter, voltmeter, and digitizer.
- Sleep current measurement under 1 μA with PZ2121A.
- Dynamic IV characterization of the transition from sleep to active state.

Multi-channel synchronous IV measurement utilizing an SMU as power supply, ammeter, voltmeter, and digitizer

Testing ICs typically involves the use of various basic instruments, such as power supplies, voltmeters, ammeters, pulsers, and digitizers. However, employing a multitude of instruments can lead to increased testing costs and larger footprint requirements, and added complexity in synchronization.

Alternatively, a highly versatile instrument known as a Source Measure Unit (SMU) offers a comprehensive solution by combining the functionalities of a voltage source, current source, and simultaneous voltage/current measurement. In particular, the PZ2100 series SMU goes a step further by integrating the pulser/digitizer function directly into the conventional SMUs. This integration allows the PZ2100 series SMU, housed in a single-box, to cater to a wide array of measurements ranging from static DC to dynamic, thereby simplifying the synchronization process significantly.

This chapter presents a measurement of the power-on sequence of a Power Management IC (PMIC) evaluation board as a measurement example of synchronous IV measurement utilizing an SMU as a power supply, ammeter, voltmeter, and digitizer.

Setup

- Figure 5 shows the connection diagram between a PZ2131A and a PMIC evaluation board.
  - PZ2131A Channel 1 – connected to VIN of DUT, supplying voltage to the DUT
  - PZ2131A Channel 2-5 – connected to VOUT1 to 4, measuring the voltage output of the buck converters

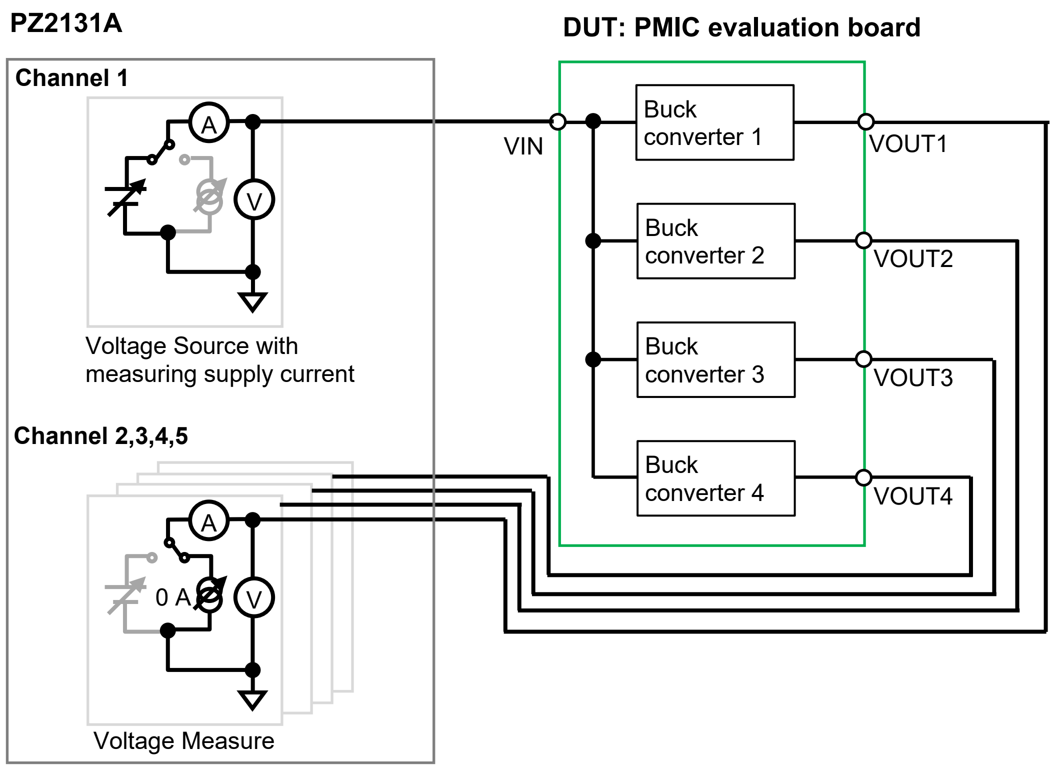

Figure 5. Connection diagram between a PZ2131A and a Power Management IC (PMIC) evaluation board

- PZ2131A channel 1 is set to source 5 V with 750 mA limit current with power supply mode, and simultaneously measure the supply current with seamless current measurement ranging mode using digitizer mode.
- PZ2131A channel 2 to 5 are set to as voltmeter.

Tips for setup

- Limit function – allowing the user to set limits and protect devices from potential damage caused by excessive voltage or current.
- Power supply mode – SMUs usually source voltage or current within a specified limit. However, the voltage slew rate can be slow, particularly when the limit current is small, as it may take time to charge up stray capacitances. The power supply mode allows the inrush current to temporarily exceed the limit to achieve a faster slew rate.
- Use SMU as an ammeter – The internal feedback loop of SMUs allows current measurement with zero burden voltage.
- Seamless current measurement ranging mode – This mode allows for simultaneous measurement of current in multiple ranges, delivering optimal results. By eliminating the need for range changes and enabling measurements at the specified timing, it provides a wider dynamic range for accurate measurements.
- Digitizer mode – This mode allows for multiple measurements at a maximum sampling rate with a single trigger signal.
- Use SMU as a voltmeter – Set 0 A source to be a voltmeter

Result

Figure 6 shows the current and voltage transitions of the power rail and the buck converter when a 5 V is applied to the circuit. The graph lets you observe the voltage level and timing of each buck converter transition and how the supply current changes with these transitions.

Figure 6 also shows the change in supply current from less than 100 μA before power-on to more than 750 mA of inrush current. If you require the capability to measure larger currents, the PZ2120 / PZ2121A high-speed SMU can handle up to 3.5 A DC.

A single PZ2131A can cover this measurement, whereas a conventional setup typically requires one power supply and four voltmeters. This leads to a smaller footprint and simpler configuration.

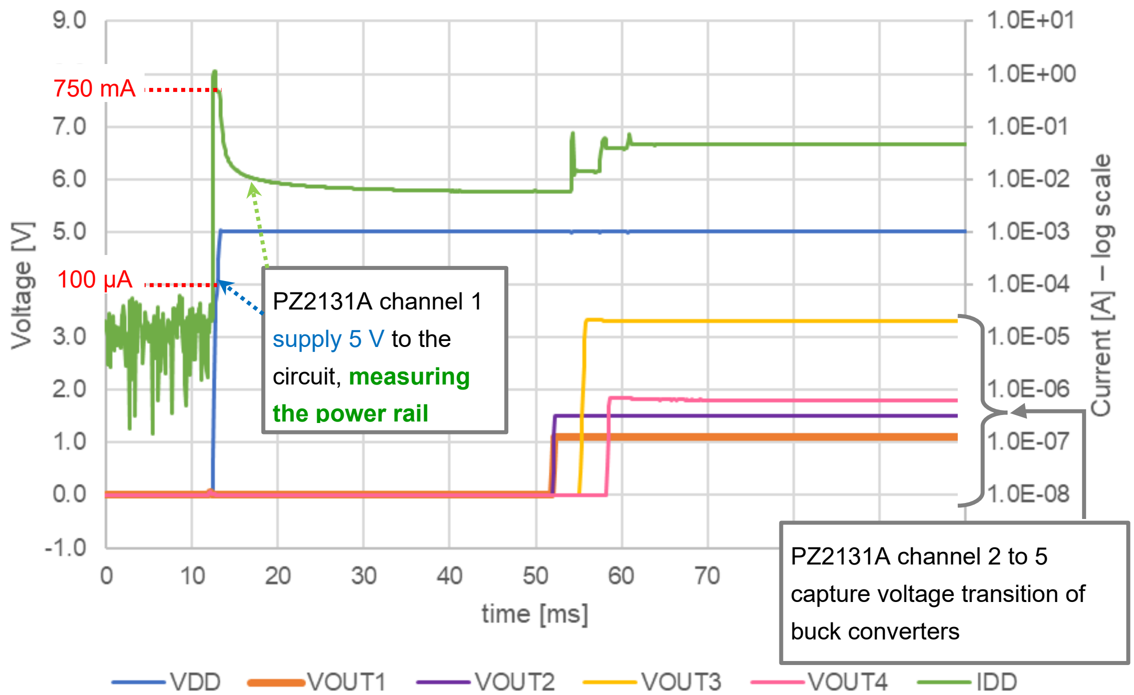

Figure 6. Transient current and voltage of a PMIC evaluation board at power-on

Sleep current measurement under 1 μA with PZ2121A

Accurately measuring the sleep currents is also crucial due to extended battery life and power supply constraints. Low-power ICs have reduced their sleep current to microamperes or less. Measuring such low currents can be challenging.

The PZ2100 series SMU has precise voltage and current resolution, enabling accurate sleep current measurement.

This chapter presents a real-time clock (RTC) evaluation board measurement as an example of a sleep current measurement of less than 1 μA.

Setup

- Figure 7 shows the connection diagram between a PZ2131A and an RTC evaluation board.
  - PZ2131A Channel 1 – connected to VDD of DUT, supplying voltage to the DUT
  - PZ2131A Channel 2 – connected to CLKOE of DUT, enable or disable the clock out

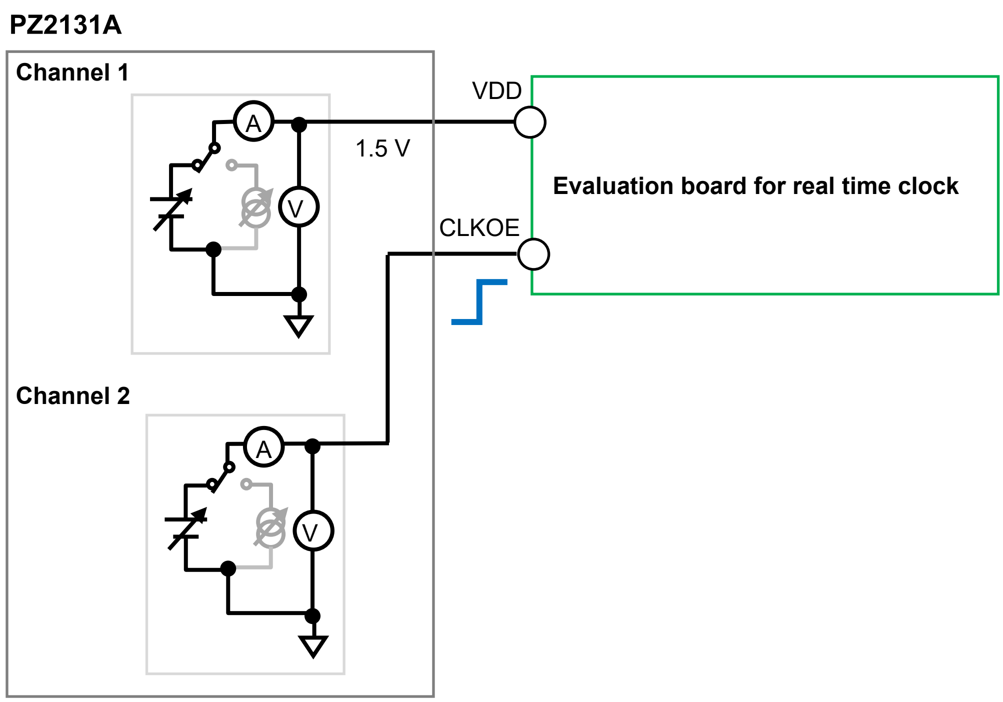

Figure 7. Test setup of a measurement example of the RTC evaluation board

- PZ2131A channel 1 is set to source 1.5 V with 10 mA limit current with power supply mode and simultaneously measures the supply current with seamless current measurement ranging using digitizer mode.
- PZ2131A channel 2 is set to source 1.5 V after a specified delay to enable clocking out

Tips for setup

- To measure sleep current around sub-micro amps accurately:
  - Properly perform self-calibration to minimize instrument offset current.
  - Set appropriate measurement ranges and recommend using auto-ranging mode for static DC measurements, which automatically selects the appropriate range. It is advisable to use a seamless current measurement ranging mode for dynamic measurement, which allows for a wide dynamic range measurement while keeping the specified measurement timing.
- How to set delay – The PZ2100 series trigger system features independent triggers for the source and measure functions, allowing for separate settings of trigger source, count, and delay. By setting a longer delay for the source and a shorter delay for the measure function, users can observe changes in current and voltage before and after the application of a source in a circuit.

Result

Figure 8 shows the current transitions when the circuit's power supply is turned on, and the CLKOE signal is activated after 1 second to start the clock out. The PZ2131A SMUs have a minimum current resolution of 10 pA, which is sufficient to accurately measure currents in the hundreds of nA range.

If you require even lower current measurement capabilities, the PZ2120 / PZ2121A high-speed SMU that provides a resolution of 100 fA is also available.

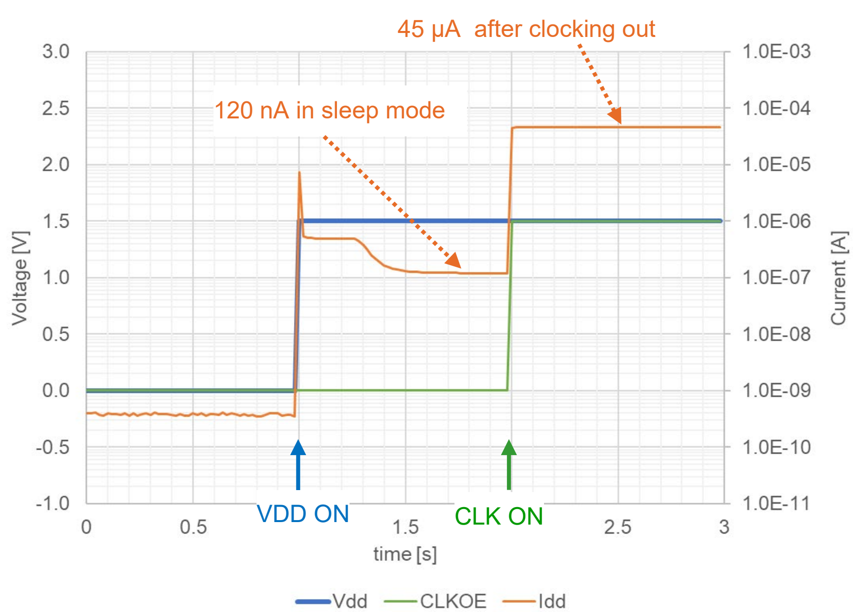

Figure 8. A sleep current measurement example of an RTC evaluation board

Dynamic IV characterization of the transition from sleep to active state

To obtain accurate dynamic characteristics, measurement instruments must have a sampling rate sufficient to capture high-speed signals. However, conventional SMUs or DMMs are limited in their sampling rate, which typically ranges from tens to hundreds of kSa/s. Additionally, while they may offer a good resolution for static DC current measurements, they are often limited in their ability to accurately capture currents that vary widely between sleep and active modes during dynamic measurements.

The PZ2100 series SMUs support digitizer mode with fast sampling rates, 15 MSa/s with the PZ2121A high-speed SMUs, 1 MSas/s with the PZ2120A high-speed SMU, and 500 kSa/s with the PZ2131A high-channel density SMU. Moreover, both the PZ2120 / PZ2121A high-speed SMUs and PZ2130 / PZ2131A high-channel density SMUs offer seamless current measurement ranging, allowing precise and reliable dynamic measurement.

This chapter presents a dynamic IV characterization of the MCU evaluation board, which is programmed to wake up from sleep to active every 1 second to send temperature data through UART.

Setup

- Figure 9 shows the connection diagram between a PZ2120A and an MCU evaluation board.
  - PZ2120A – connected to VDD of DUT, supplying voltage to the DUT
  - PZ2100A Digital IO Port 1 – connected to UART pin as a trigger in

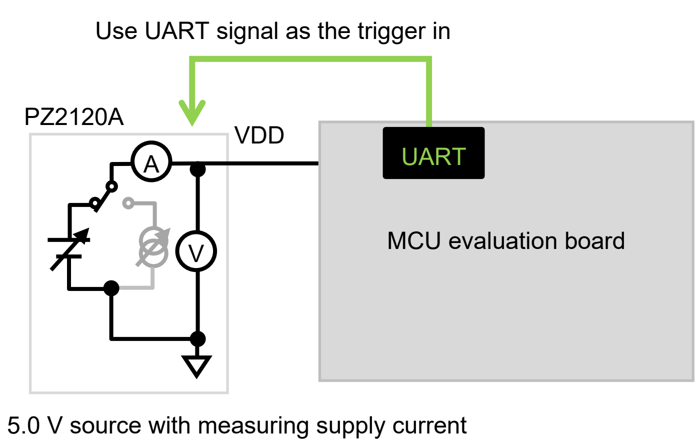

Figure 9. Test setup of a measurement example of low-power ICs

- PZ2120A is set to source 5 V with 500 mA limit current and starts capturing the power rail current with seamless current measurement ranging using digitizer mode with 1 MSa/s by getting a trigger.
- PZ2100A Digital IO Port 1 is to be set as trigger in.

Result

Figure 10 shows the current and voltage transition waveforms captured by the PZ2120A triggered by a UART signal. After getting a trigger, the PZ2100 series SMUs can start measurement immediately. It can capture the current changes in active states within 1 ms and 10 mA and transient currents from active to sleep by the 1 MSa/s and seamless current measurement range.

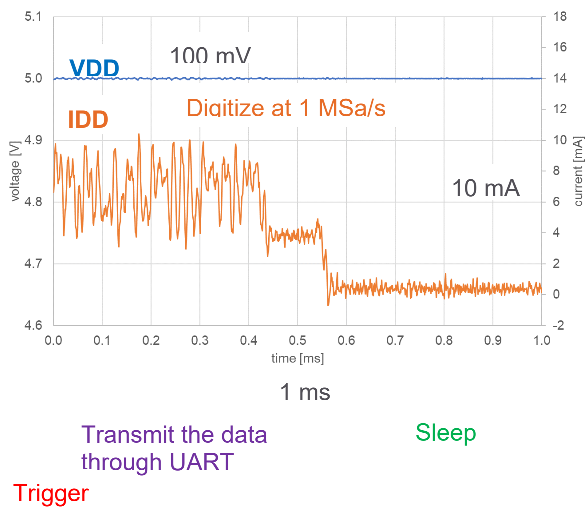

Figure 10. A transient current and voltage measurement example of low-power ICs

Sampling rate considerations

Conventional SMUs or DMMs typically have sampling rates ranging from tens to hundreds of kSa/s. In contrast, the PZ2120A features a much higher sampling rate of 1 MSa/s. Figure 11 shows the significant difference in waveform by the sampling rate. Note that to capture the entire active waveform, it starts the measurement with a certain delay after acquiring the trigger. With its high sampling rate of 1 MSa/s, the PZ2120A can capture high-speed transient characteristics such as inrush currents and changes in the activity state that cannot be captured with a sampling rate of 20 kSa/s. If you require a higher sampling rate, we also offer the PZ2121A, which provides 15 MSa/s.

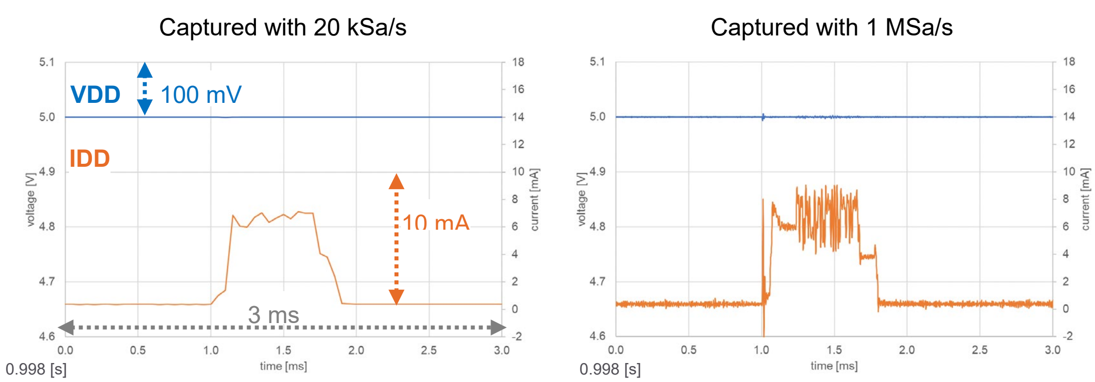

Figure 11. A transient current differences resulting sampling rates

Conclusion

As demand for low-power ICs continues to grow in a wide range of applications, IC manufacturers face the following challenges:

- Increasing test cost and footprint due to the higher integration of circuits, which requires more basic instruments such as power supplies and DMMs.
- Lack of precision and speed in basic instruments for characterizing low-power circuits that operate among multiple states, such as sleep and active.
- The emergence of more complex circuit evaluation requirements, necessitating a more complex test sequence that requires the synchronization of a vast amount of equipment.

The PZ2100 series high-channel density SMU solution offers a way to overcome these challenges with the following key features and gain a competitive edge in the growing low-power ICs market.

PZ2100A 1U, 4 slot mainframe
with PZ2120 / 21A and PZ2130 / 31A

Key benefits	Key features
Test cost reduction at a small footprint	High-channel density solution of all-in-one SMUs minimizes the number of test equipment and system footprint ◦ High-channel density (20 channels at max. in 1U small footprint) at a lower cost/channel ◦ All-in-one SMU integrating pulser/digitizer as well as precision IV sourcing and measurement eliminates the need for additional instruments
Broad coverage from static to dynamic IV characterizations from sleep to active states	High-speed SMUs with wide dynamic range enable the characterization of multiple states and their transitions ◦ Wide supply current coverage from 100 fA to 3.5 A ◦ Fast sampling rate up to 15 MSa/s and seamless current measurement ranging for dynamic characterization
Easy and efficient integration of complex test systems and sequence	Single box solution with an intelligent trigger system makes it easy to characterize circuits under complex sequences among enormous equipment ◦ Single box solution simplifies synchronization with multiple SMUs at <50 ns accuracy ◦ An intelligent trigger system enables complex test sequences among SMU channels and external equipment

Discover how Keysight solutions can empower you to conquer Low-Power Integrated Circuit IV Test challenges. Visit www.keysight.com/find/pz2100 to learn more.