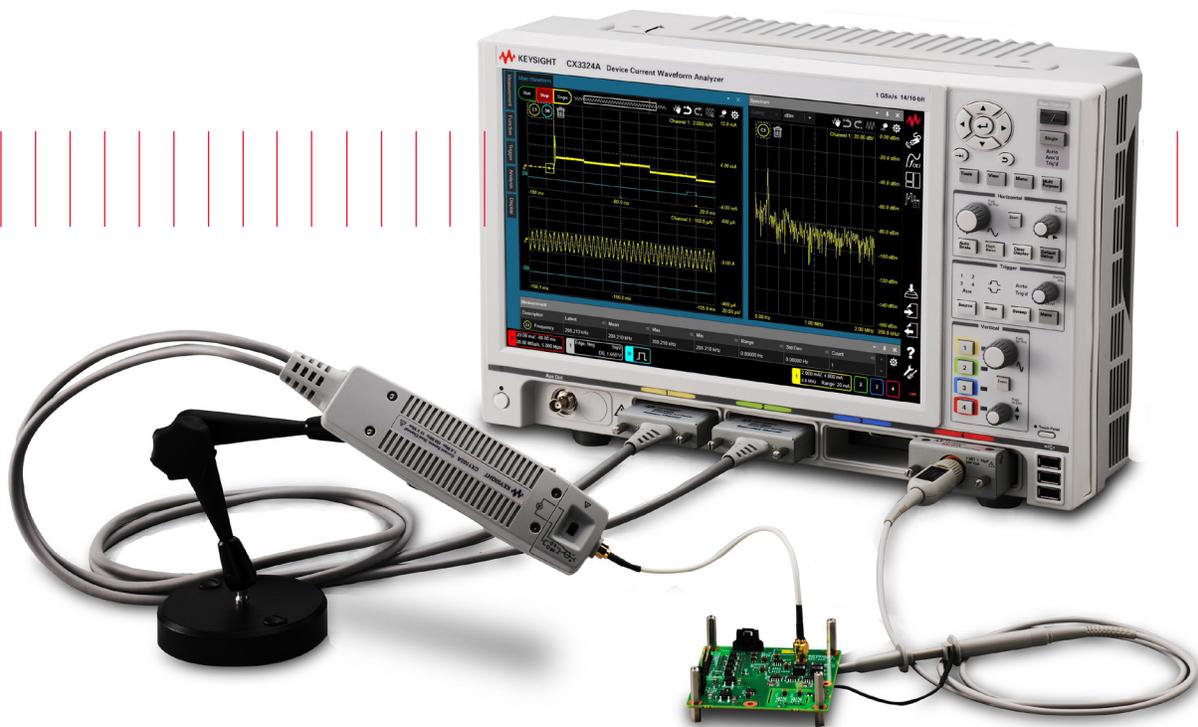


Keysight Technologies

# Precise Current Measurements of MCU Power-Saving Mode Transition using the CX3300

Application Brief





## Introduction

The microcontroller (MCU) is at the heart of a low-power device, and the MCU offers various power-saving modes to meet the demands of long battery life. However, engineers are required to carefully study the behavior of a low-power device and often perform complex debugging operations in order to realize the device's appropriate performance while power saving at the same time,

The CX3300 series of Device Current Waveform Analyzers allows you to visualize wideband low-level, previously unmeasurable or undetectable, current waveforms. The mainframe has either 2 or 4 channels to receive signals from the Current Sensors and digitize them by a maximum of 1 GSa/s and a 14-bit or 16-bit wide dynamic range. There are three types of Current Sensors that can detect a wide range of dynamic currents from 150 pA level up to 10 A, with a maximum of 200 MHz bandwidth.

The CX3300 series also features useful analysis capabilities such as an Automatic Power and Current Profiler, a Power Measurement Wizard, FFT Analyzer and Statistical Analysis functions, which accelerate the analysis of the measurement data without the need to use external analysis utilities.

With this new and powerful analyzer, you can achieve critical mission on power and current consumption reductions by precisely measuring, previously unmeasurable or undetectable, wideband low-level current waveforms.

## Problems with Present Solutions

In order to meet the demands for power consumption reduction, precise dynamic current waveform measurement improvements are required. However, there are a number of difficulties to be resolved as follows:

- Limited dynamic range  
For example, most of the battery-powered devices have low power sleep mode that consumes very little supply current such as less than 1  $\mu\text{A}$ , while the active mode usually requires more than 10 mA current. It is difficult to measure such a wide dynamic range of currents with a single measurement.
- Large measurement noise  
Clamp-on type current probes are widely used, but measuring low-level current less than 1 mA is always difficult due to the large noise floor. Using a shunt resistor and an oscilloscope is very useful, but the minimum measurable current is limited due to the noise floor and the voltage drop across the resistor.
- Limited bandwidth  
Low-level current waveform measurements with a certain level of resolution need a tradeoff with bandwidth, otherwise wideband measurements may degrade the resolution. Using a multimeter or an ammeter is popular for high resolution measurements, but not appropriate for wideband current measurements due to the lower bandwidth.
- Multiple instruments required  
A multimeter is commonly used to measure the averaged sleep current, while the active current can be captured using an oscilloscope. The total power and current consumptions must be manually estimated from these results, but the data is not always reliable and it can be time consuming to validate it.

## Solution

The CX3300 Series of Device Current Waveform Analyzers can solve the problems that engineers can be faced with when measuring the precise dynamic current of MCU power-saving mode transition. Table 1 shows the summary of CX3300's key features.

- A single measurement covers sleep to active mode with a 14 or 16-bit wide dynamic measurement range which clearly visualize even low-level current waveforms.
- The dynamic current waveform in sleep mode is now clearly visible by using the ultra-low noise current sensors.
- The narrow and sharp peak or spike current is captured by the wide bandwidth up to 200 MHz max bandwidth, 1 GHz max sampling rate and 256 MB memory depth so that you can easily eliminate any unexpected noise or other interferences.
- As well as capturing current waveform, the voltage passive probe can simultaneously capture voltage waveform, enabling you to precisely estimate the power consumption.
- Long learning periods for the user are eliminated thanks to intuitive touch screen based GUI and familiar functionalities.

Table 1 Key Features of the CX3300

Key Features	Specification
Current measurement range	150 pA to 10 A
Power measurement range	10 pW to 400 W
Maximum measurement bandwidth	200 MHz
Maximum sampling rate	1 GSa/s
Measurement dynamic range	14 or 16-bit <sup>1</sup>
Maximum memory size	256 Mpts/ch

1. 14-bit (High speed mode) or 16-bit (High resolution mode)

## Measurement Setup Example

Figure.1 shows the block diagram of the  $I_{DD}$  measurement of a MCU power-saving mode transition. The CX1101A Single Channel Current Sensor, which is one of the current sensors of the CX3300 and has maximum 100 MHz bandwidth, a current measurement range from 40 nA to 10 A and 40 V maximum voltage, is connected between the power supply and the DUT for current measurement.

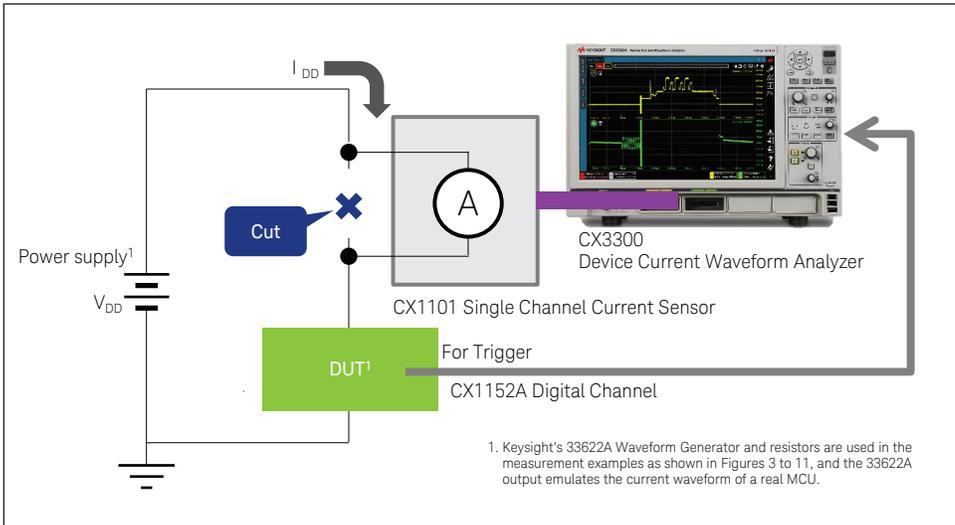


Figure 1. The block diagram of the  $I_{DD}$  measurement of a MCU power-saving mode transition

You can find the best connection interface for your DUT from the six sensor head adapters that can be easily and safely attached to and detached from the CX1101A current sensor as shown in Figure 2. The SMA connector type adapters enable wideband measurements, while twisted pair and test lead adapters are useful for quick current waveform measurements that do not necessarily need a wide bandwidth.

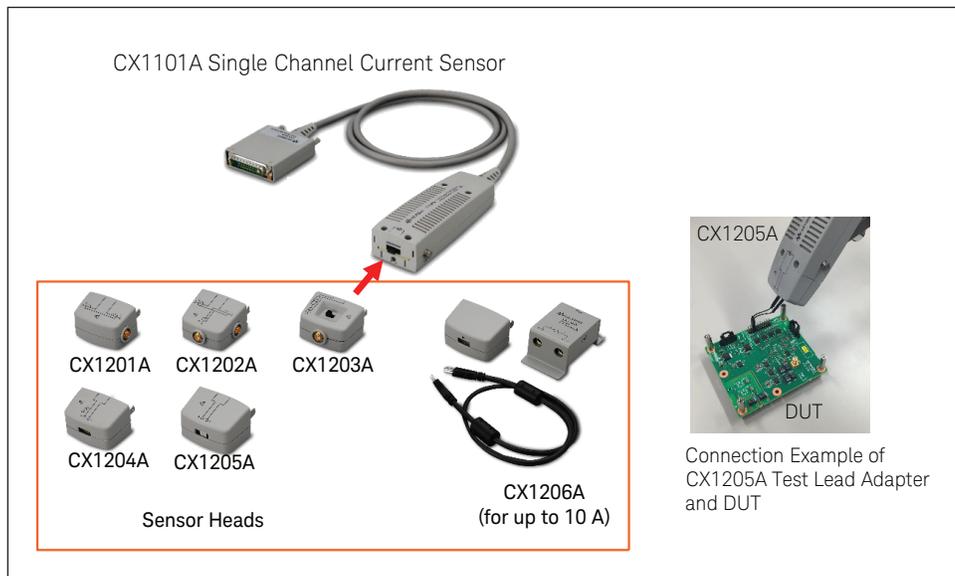


Figure 2. A wide variety of sensor head adapters provides the best connection interface for your DUT.

## Measurement Examples

Figure 3 shows current waveform measured using a CX1101A for transition from the several levels of sleep mode to active mode. The channel 1 of Figure 3, yellow line, is the measured current. Up to ten milli-amperes flows during the active mode, but little current flows during the sleep modes. The current during a sleep mode is small, but the device is in sleep mode most of the time, impacting on the total power consumption. There are several low-power modes from light sleep or standby mode, through to deep-sleep mode, to off. The CPU, memory, interrupt controller, or peripheral blocks are switched off in each mode. As shown in the Figure 3, the sleep current depends on the sleep level, the deeper the sleep level, the lower the power consumption. The current measurement during each sleep mode, and the transition between each mode is one of the key parameters when evaluating a MCU power-saving mode transition.



Figure 3. Current waveform at the transition between several operating modes

The D0 of Figure 3, the blue line, is a digital channel input of the CX3300, connected to the signal of the GP-IO line of the DUT, and it is used as the trigger for this measurement. The CX1152A Digital Channel is the dedicated cable for the digital channel input of the CX3300, it is useful when you need digital triggers to measure current synchronized with digital signals such as controller's I/O or data bus up to 8 channels. Unlike conventional digital probes, each probe for the CX1152A has a large 10 M $\Omega$  input resistance, which enables you to make accurate low power measurements by minimizing the load current.

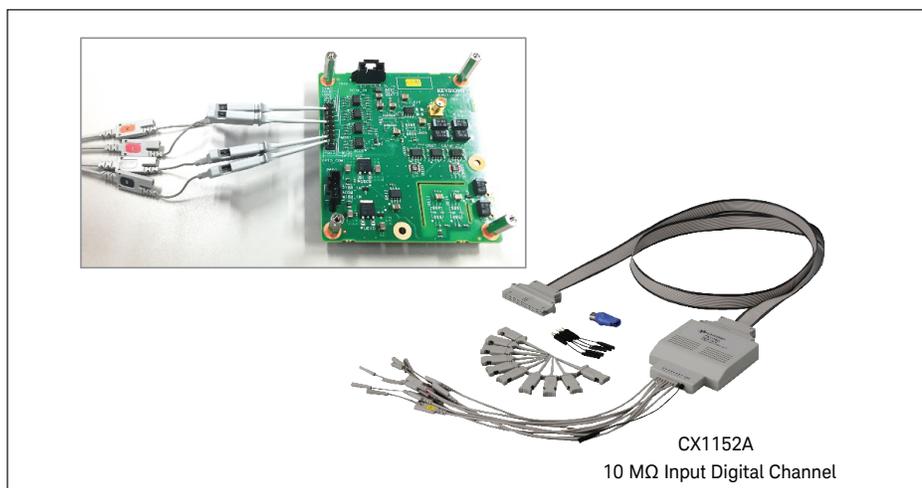


Figure 4. CX1152A and its connection example

## Measurement Examples continued

As shown in the Fig. 5, due to the wide dynamic range, the CX3300 can cover from sleep to active mode with a single measurement. Fig. 5 shows in more detail, the current waveform of Fig.3 for both horizontal and vertical axis during a sleep mode. This detail is possible to obtain by using the powerful zoom function of the CX3300 called the “Anywhere” zoom which allows you to zoom in on any area shown with a rectangular mark.

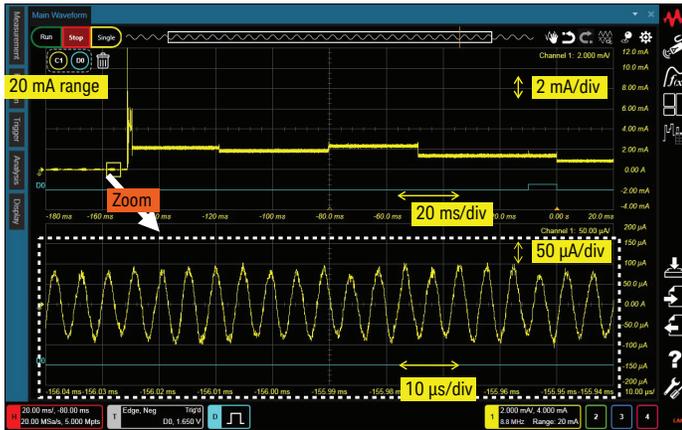


Figure 5. Zoomed waveform at the sleep mode of Figure 3

In this sleep mode, almost all functions stop working, and only a small current is flowed to maintain minimum operating functions. As shown in Figure 5, approximately 200  $\mu\text{A}$  peak-to-peak periodic current flows. At one time, it was difficult to observe such current because no instruments were available with enough bandwidth, dynamic range and noise floor. Using the CX3300 it is possible to identify such characteristics because of its wider bandwidth, wider dynamic range and ultra-low noise floor. The CX1101, Single Channel Current Sensor has several ranges from a 20  $\mu\text{A}$  range up to a 10 A range, and you can easily switch ranges on the current sensor settings. In this example, the 20 mA range is used in order to cover from sleep to active current with a single measurement, but for further analysis, you can obtain lower noise floor if you run another measurement with lower range.

The actual  $I_{\text{dd}}$  line would include many noises or an expected current spikes other than the target current caused by the noises from the power source, operation of other peripheral circuits, and so on. As shown in Figure 6, the CX3300 features various analysis functions such as FFT, histogram or post-filters, that help to obtain the target current waveform and isolate the cause of the noise or spikes.

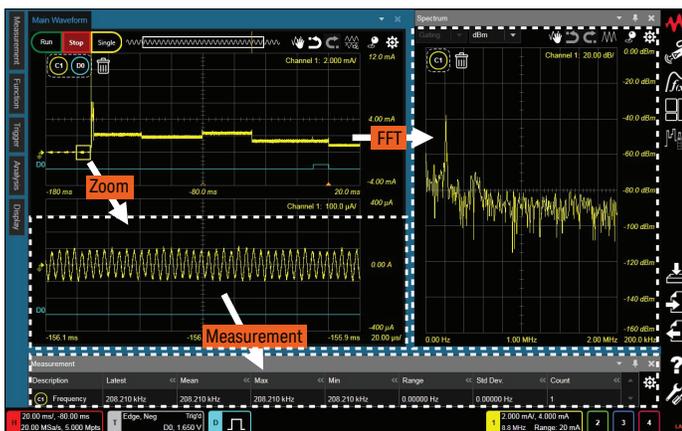


Figure 6. An example of Measurement and Analysis functions

## Measurement Examples continued

Figure 7 shows the zoomed current waveform of Fig.3 at the wake-up area. The current level in active mode depends on the MCU activities and the I/O activities. In this example, the LED is blinking twice in active mode. As shown in Fig.7, the transition waveform from sleep to active mode is complex including spikes. The precise transition measurement is useful for precise power consumption measurement, and is also useful for the debugging of the operation on the circuit. At one time, it was difficult to precisely observe this kind of transition because of the limitations of the bandwidth and the resolution, however, the CX3300 has the capability to observe crisp detailed spike waveform due to its wide bandwidth and low noise front end.



Figure 7. Zoomed waveform at the wake-up area of Figure 3

In actual measurement, it is required to observe the waveform over tens of seconds, while to observe the detailed waveform in a certain events at the same time, for example, to check the behavior from power on to steady state through a complex processes. CX3300 has up to 256 Mpts/ch memory depth. As an example, 25 seconds long term behavior can be observed with 10 MSa/s shown in Figure 8. The Bandwidth is still high enough 4.4MHz with 10 MSa/s, you can see a clear wake-up process from a deep sleep mode as shown in the lower display of Figure 8.

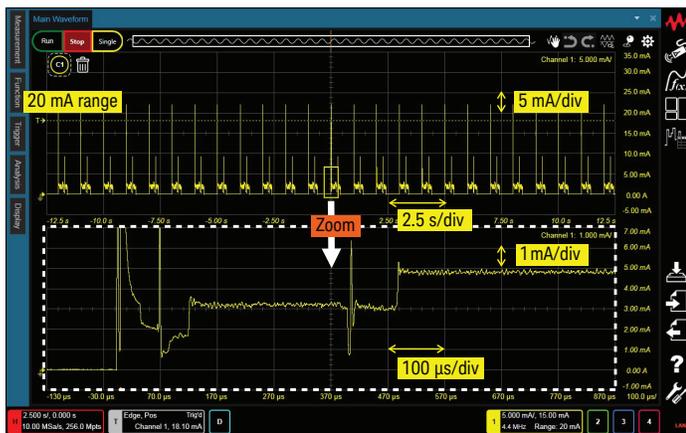


Figure 8. A long-term, 25 sec, measurement with 10 MSa/s

## Measurement Examples continued

As shown in Figure 3, the CX1101A Single Channel Current Sensor has wide dynamic range that allows you to observe the current waveform from sleep to active mode. Furthermore, if wider dynamic range is required, the CX1102A Dual Channel Current Sensor is available. The CX1102A Dual Channel Current Sensor enables simultaneous measurements under two different measurement ranges. For example, the primary channel is set to a 200 mA range, while the secondary channel is set to a 2 mA range (primary channel range is 100 times more than secondary channel range). This current sensor is very useful for low-power applications that periodically operate in both sleep and active mode. Figure 8 shows the concept of the Dual Channel Current Sensor, it has two channel outs to provide simultaneous low- and high-gain views for wider dynamic range measurements.

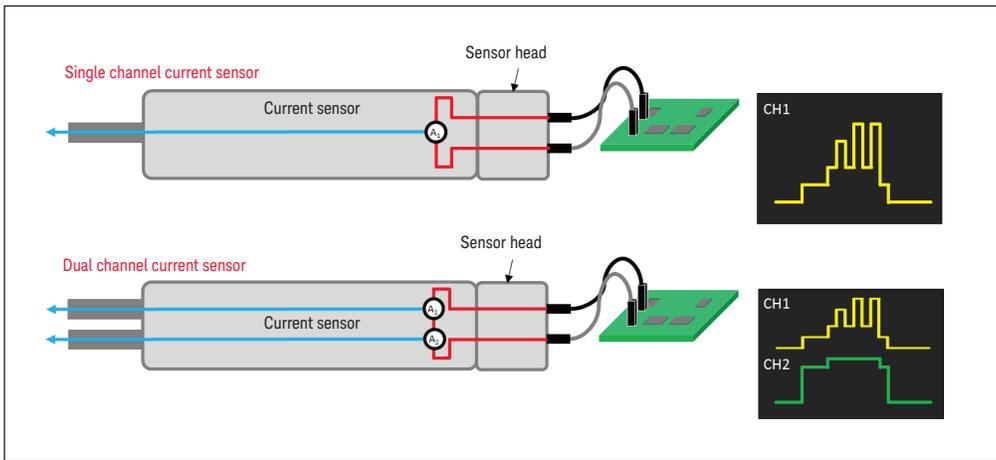


Figure 9. The concept of the Dual Channel Current Sensor

Figure 10 shows the same measurement as Figure 5 with the CX1102A. As shown in Figure 10, the CX1102A enables you to simultaneously measure a current waveform for both sleep and active mode.

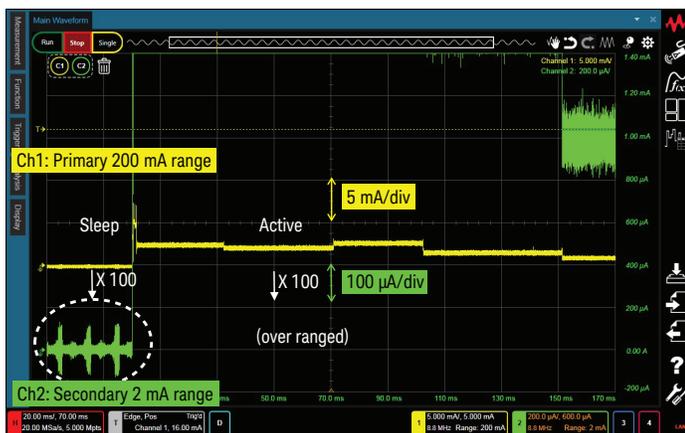


Figure 10. Current waveform at the transitions between several operating modes with CX1102A Dual Channel Current Sensor

## Measurement Examples continued

The analysis of power or current profile is essential in order to know how much current is consumed at a certain event or status, but it is time-consuming process. As shown in Figure 11, the Automatic Power and Current Profiler functions can eliminate time-consuming power and current profile analysis. This profiler automatically draws lines in the time scale by the vertical level difference and instantly calculates key parameters such as average current, max. /min. current, accumulated charge, etc. for each segment in the adjacent table. You can also manually adjust the segment according to your measured profile.



Figure 11. Automatic Power and Current Profiler

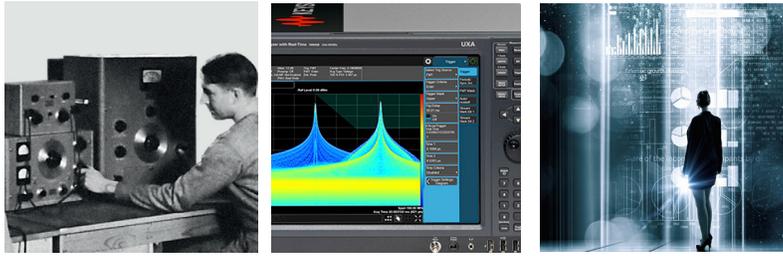
## Conclusion

The CX3300 enables you to easily and accurately visualize wide-band and low-level current waveforms of the MCU power-saving mode transition.

Useful analysis capabilities such as an Automatic Power and Current Profiler, a Power Measurement Wizard, a FFT Analyzer and Statistical Analysis functions, accelerate the analysis of the measurement data without the need for external analysis utilities.

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