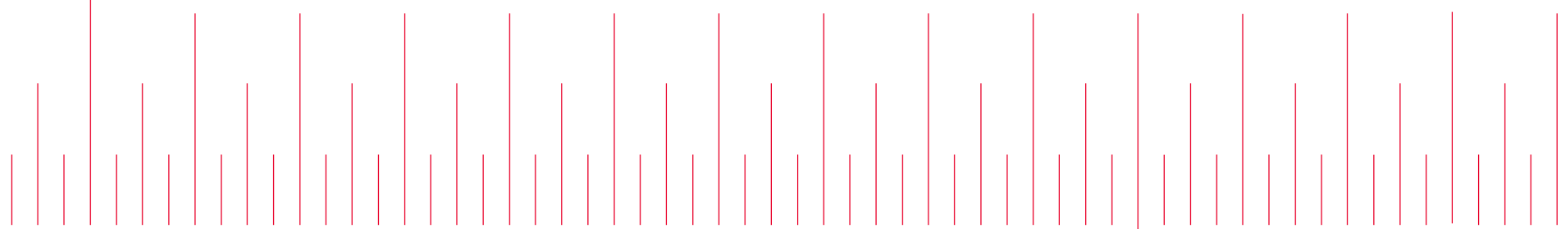


Low Current Measurement Challenges for IoT and Keysight Solutions

Dec, 2016

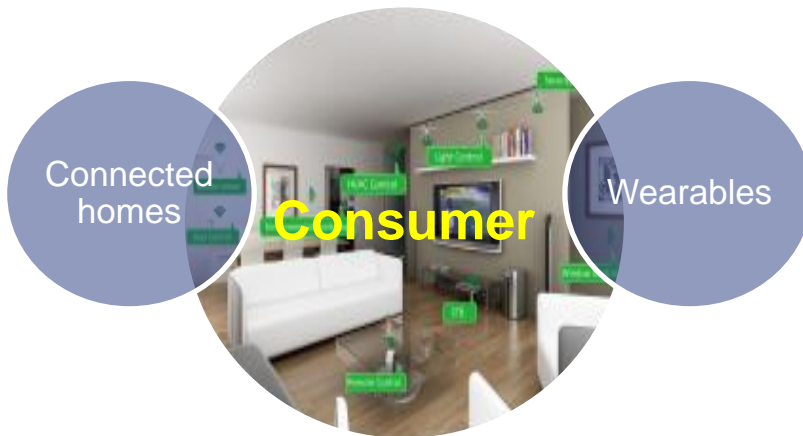


DOHO KIM
Keysight Technologies

What is IoT?

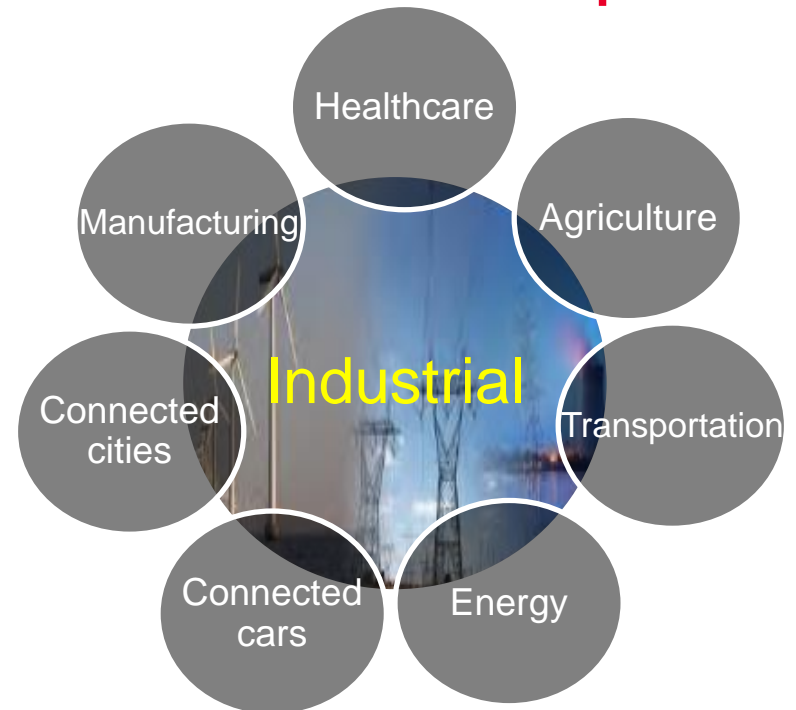
- *Definition: “Sensors and actuators embedded in physical objects are linked through wired and wireless networks, often using the same Internet Protocol (IP) that connects the Internet.” (source: McKinsey)*

Consumer IoT



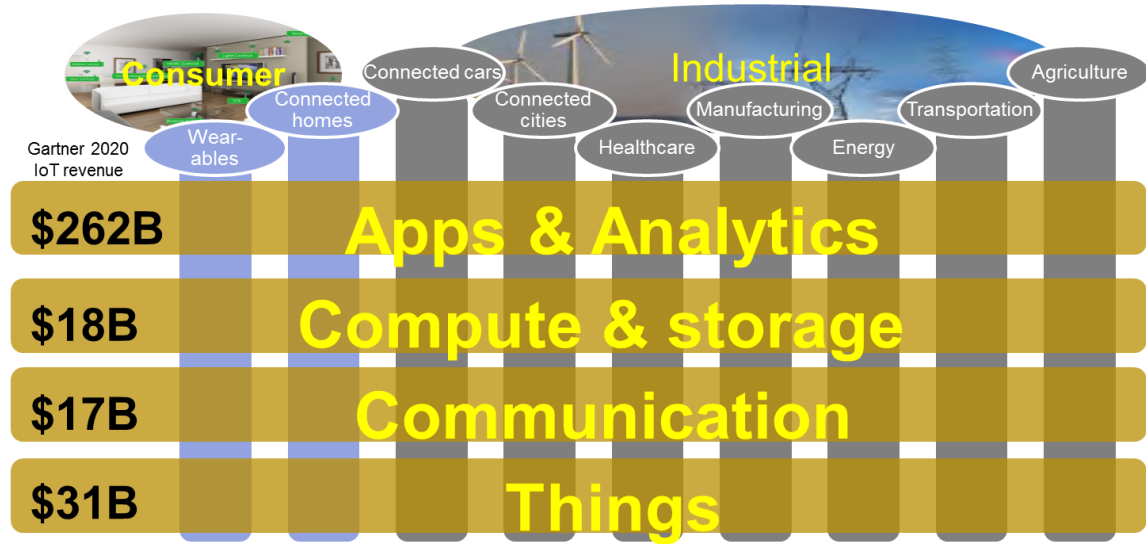
Low cost, low energy are major factors

Industrial & business/ enterprise IoT



Security, reliability and higher functionality are major factors

IoT market and trend

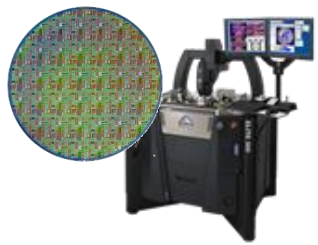


Low power design

Low power device

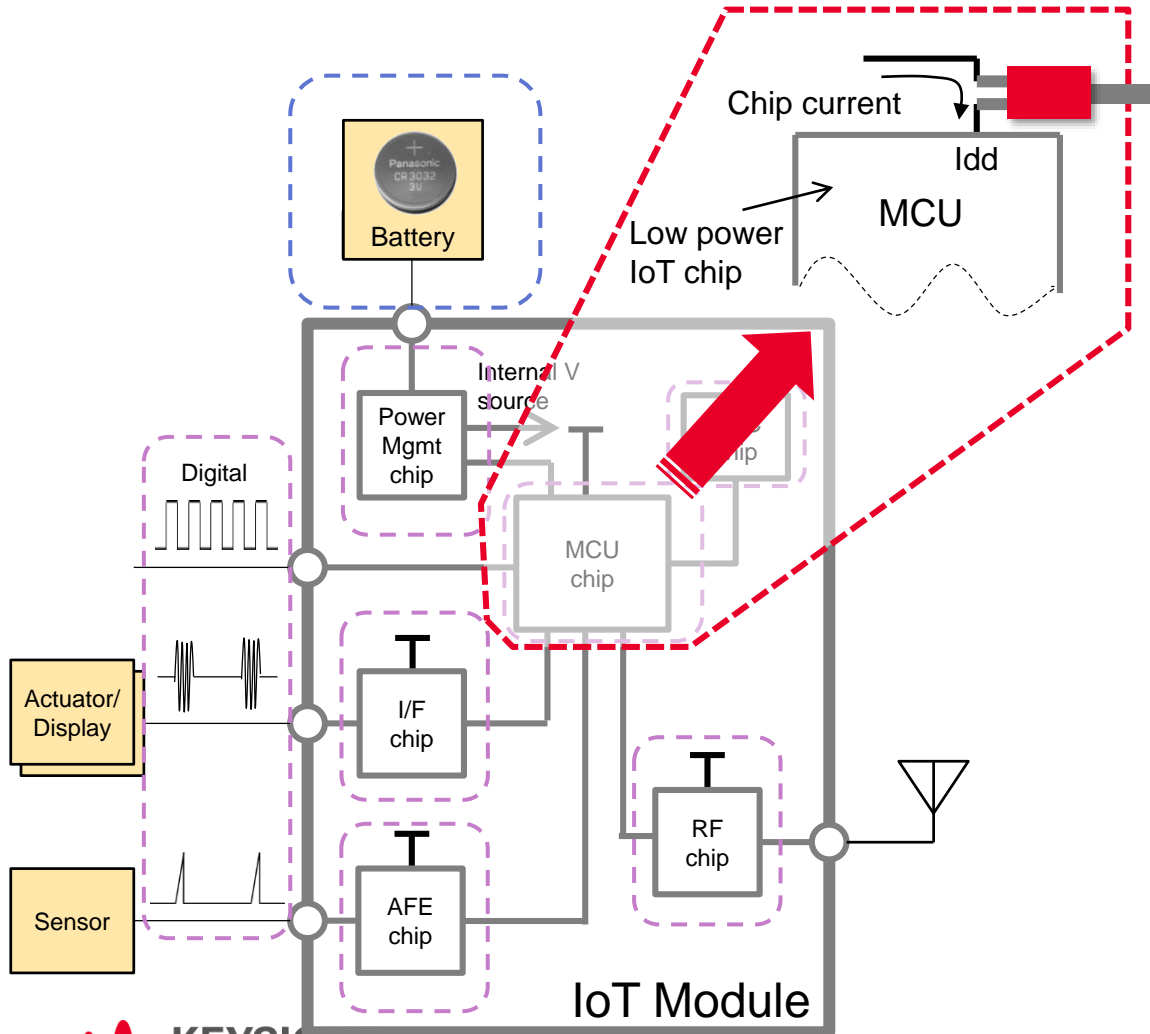
Technology trend 1:
How to reduce current consumption

Technology trend 2:
How to fully study device operation



IoT Device Measurement Needs

IoT Sensor Configuration



General Circuit Engineer:

Use inductive current probe for gross power consumption measurements. Total current consumption is measured by DMM that cannot show transient behavior. Only verifies correlation with typical values on product data sheets.

Power Consumption Circuit Engineer:

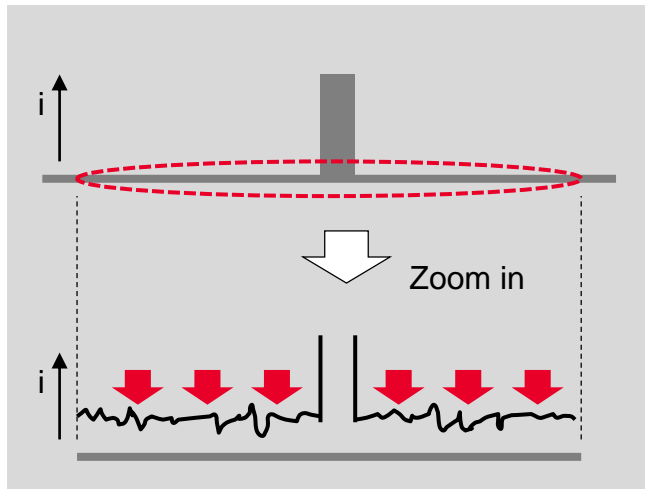
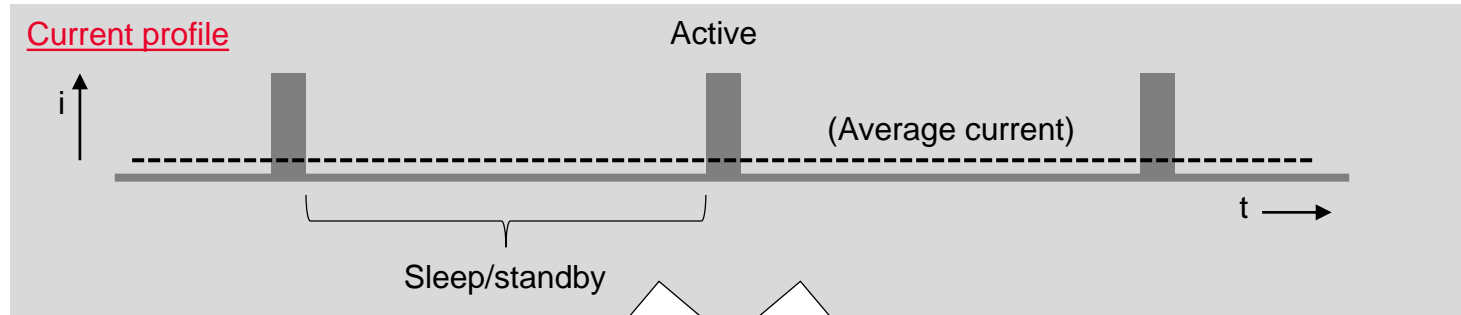
Measure dynamic power consumption of module using DC Power Analyzer

Advanced Circuit Engineer:

Measuring current using conventional techniques, but looking for a better solution that can display “meaningful current waveforms”

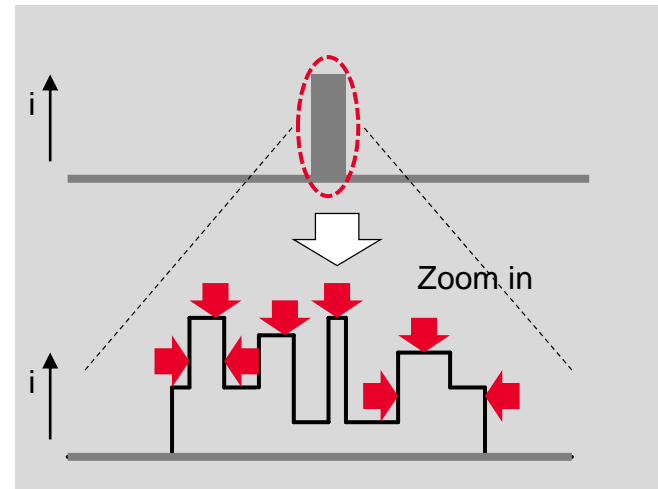
Trend 1: How to reduce current consumption?

Further reduction of low power devices operating intermittently



Reduce sleep/standby current
($< 1 \mu\text{A}$ level)

When more current
consumption
reduction is required



Reduce active current and duration
($> 10 \text{ mA}$ level)

How small is the low current for IoT application?

Microchip Technology PIC18FXX2

- < 1.6 mA typical @ 5V, 4 MHz
- 25 μ A typical @ 3V, 32 kHz
- < 0.2 μ A typical stand-by current

8,000:1

13 bits

ST Micro STM32L0xx

- 11 modes: Stand by, Stop, Low Power & Sleep mode
- Current Range from 290 nA to 41 μ A
- 5.6 mA @32 MHz @1.8 V_{CORE} ~3.6 V_{DD}

20,000:1

15 bits

Zolertia RE-Mote platform

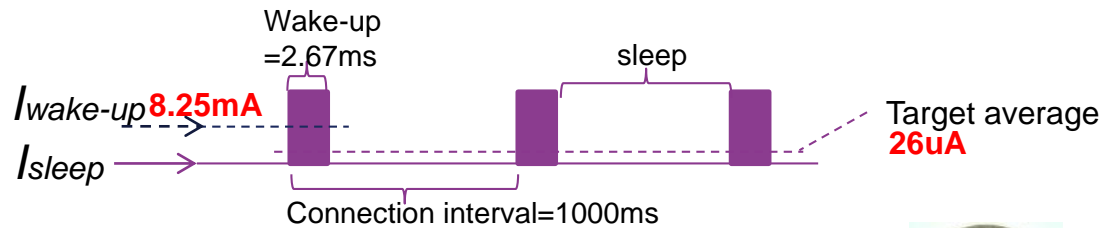
- Turn off mode (150 nA)
- Active Mode (2.4 GHz Rx, CPU idle) 20 mA
- Active Mode (2.4 GHz Tx, 0 dBm, CPU idle) 24 mA

160,000:1

18 bits

Why uA-level sleep current is required?

Rough calculation for 1 year operation with a coin battery



- Target average current for 1 year operation
= 225 mAh / 8760 h(1 year) = **26uA**



CR2032, Capacity:225 mAh

- Allowable I_{sleep} for 1 year operation

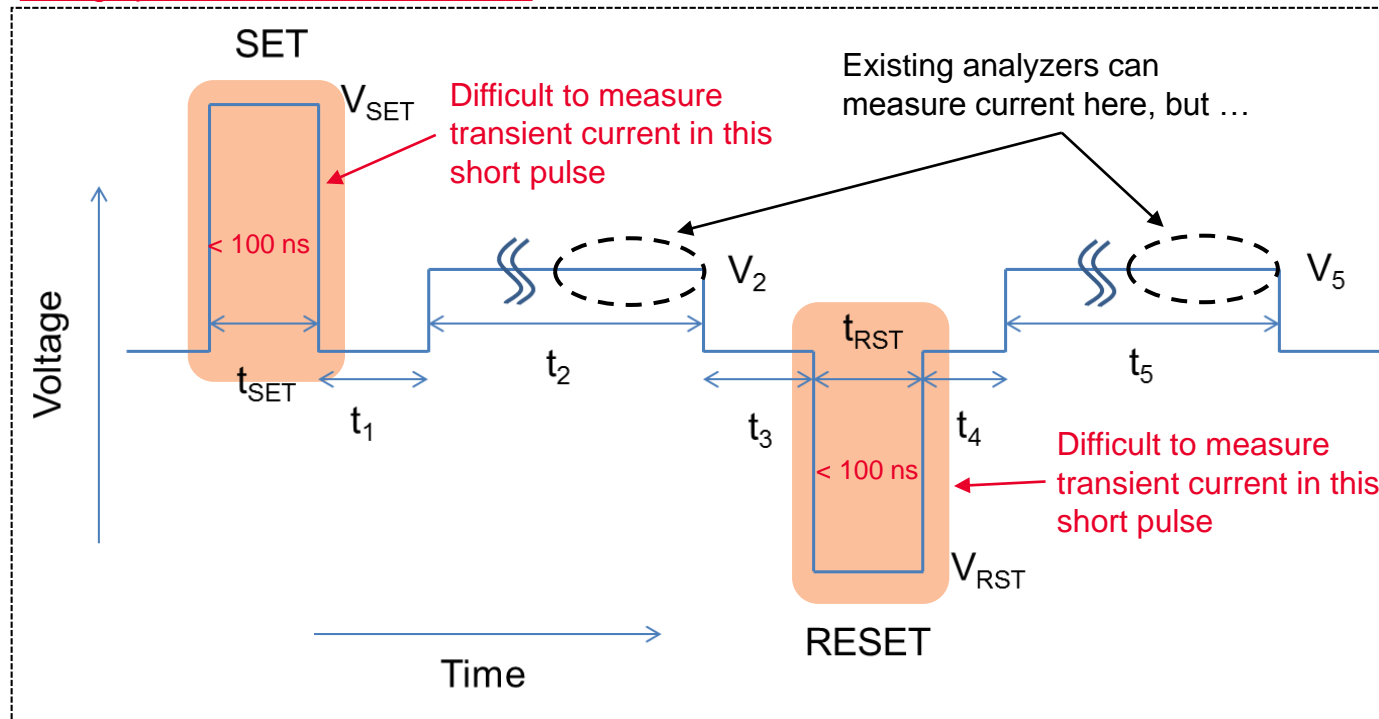
$$8.25\text{mA} \times 0.267\% + I_{sleep} \times 99.733\% \leq 225 \text{ mAh} / 8780 \text{ h (1 year)}$$

$$\Rightarrow I_{sleep} = < 4\text{uA}$$

Trend 2: How to fully study device operation?

Measuring transient current when a short pulse is applied

Voltage pulse for ReRAM evaluation



Current transients in a short pulse provide customers with deeper insights on the device or material.

Issues: Advanced Device Characterization

ReRAM, PRAM, Image sensors, Semiconductor devices, etc.

Background

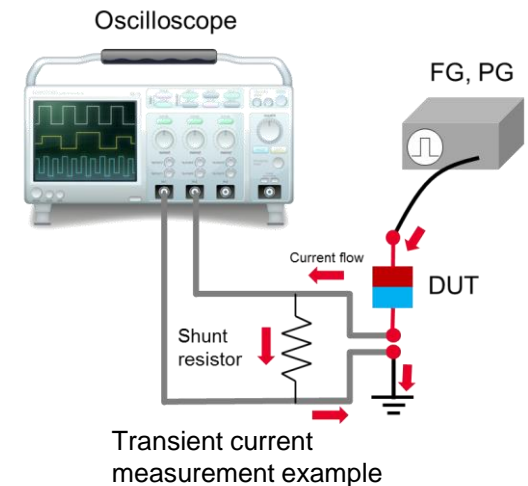
Due to ongoing device scaling and the adoption of new materials, wide bandwidth low-level current measurements are required to **fully study device operation**.

Measurement

Transient current measurements are made with a shunt resistor after applying a short voltage pulse (< 100 ns) to the device to reveal device and the materials characteristics.

Issues customers are facing

- **Measurement noise:** Noise limits low-level current sensing
- **Limited dynamic range:** Even 12-bit oscilloscopes insufficient
- **Bandwidth:** Insufficient bandwidth to detect transients



Low level current waveform measurement challenges

Measurement Challenges

1. Limited Dynamic Range

- E.g.. Sleep mode (nA) – Doze mode (uA) – Active mode (mA)

2. Large Noise

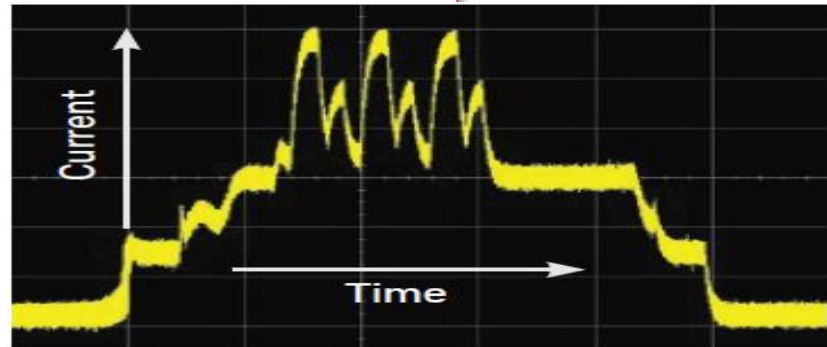
- Clamp-on current probe may have >1mA noise.

3. Limited Bandwidth

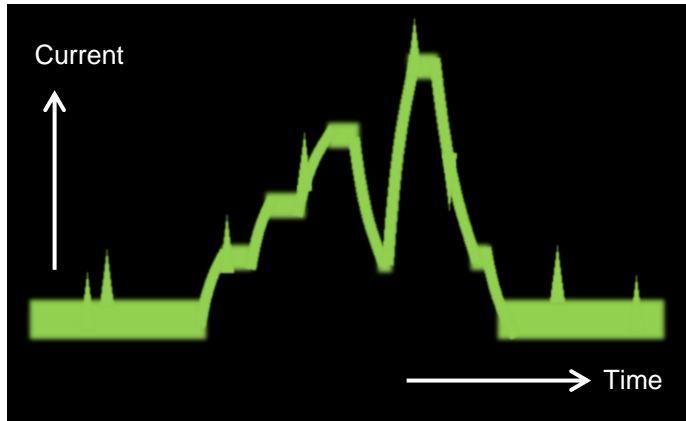
- High resolutions will need to tradeoff bandwidth (e.g.. Multimeter / ammeter)

4. Need more than 1 instruments

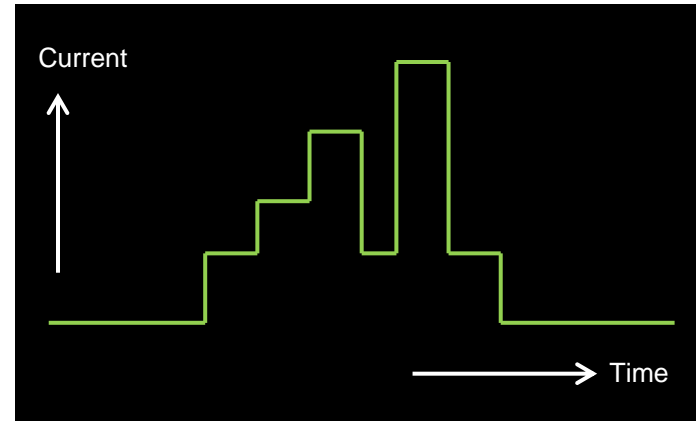
- Need multimeter, oscilloscope, current sensor for on-off mode measurements.



The dilemma can be solved by the CX3300 Series



Previous waveforms



CX3300 series

The CX3300 series allows:

- Engineers to quantitatively evaluate the current and power consumption waveforms for low power device development.
- Researchers and engineers to measure fast transient currents required for further study on advanced devices/materials.

CX3300 Series Device Current Waveform Analyzer

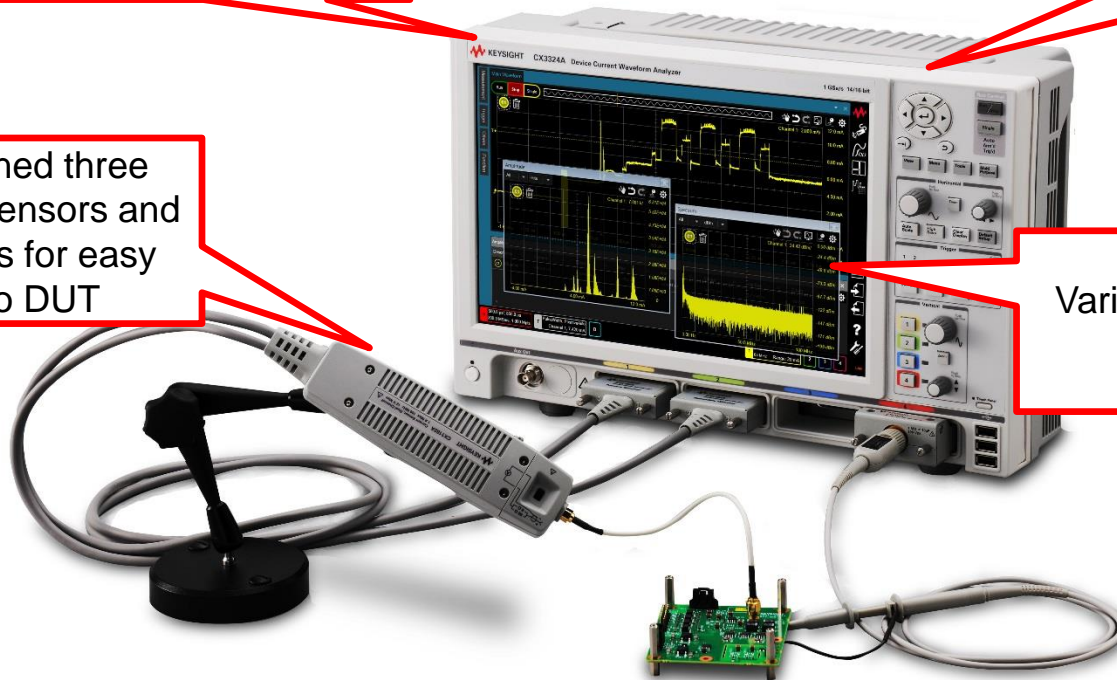
Precisely visualize device current waveforms you've never seen before.

From 150 pA to 10 A, wide current range with 16 bits resolution

Max 200 MHz wide dynamic range with 1 GSa/s fast sampling

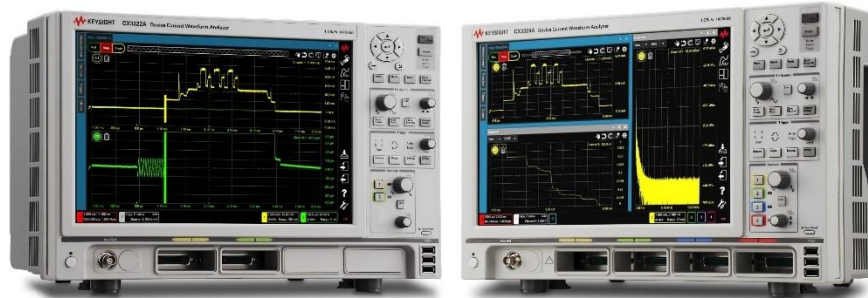
Specially designed three types of current sensors and six sensor heads for easy connection to DUT

Variety of current waveform analysis function



CX3300 series Device Current Waveform Analyzer

- Measure low level current waveform that you never seen before.
- Main frame and accessories was optimized for large bandwidth, small current and wide dynamic range measurement.

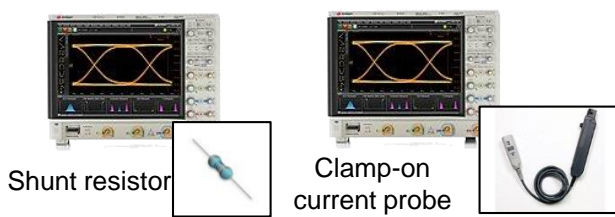

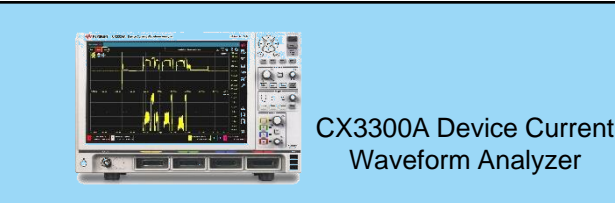



CX3322A (2 Channel)

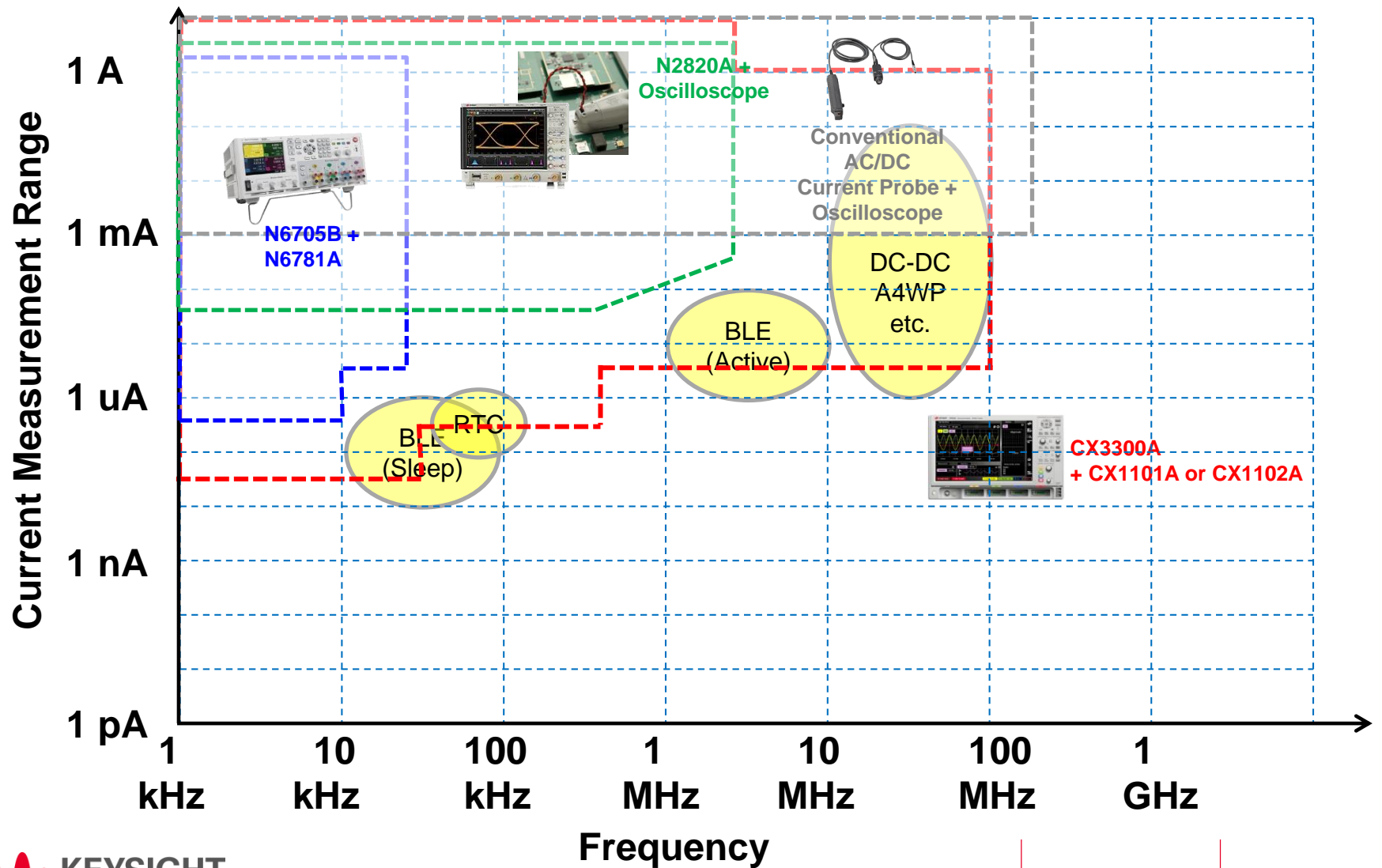
CX3324A (4 Channel)

Specification	Range
Current Measurement Range	150 pA to 10 A
Maximum measurement bandwidth (current, voltage)	200 MHz
Maximum sampling rate (current, voltage)	1 GSa/s
Measurement dynamic range (current, voltage)	14-bit (Normal Mode) 16-bit (High-Res. mode)
Maximum memory size	256 Mpts/ch
Channel	2 or 4

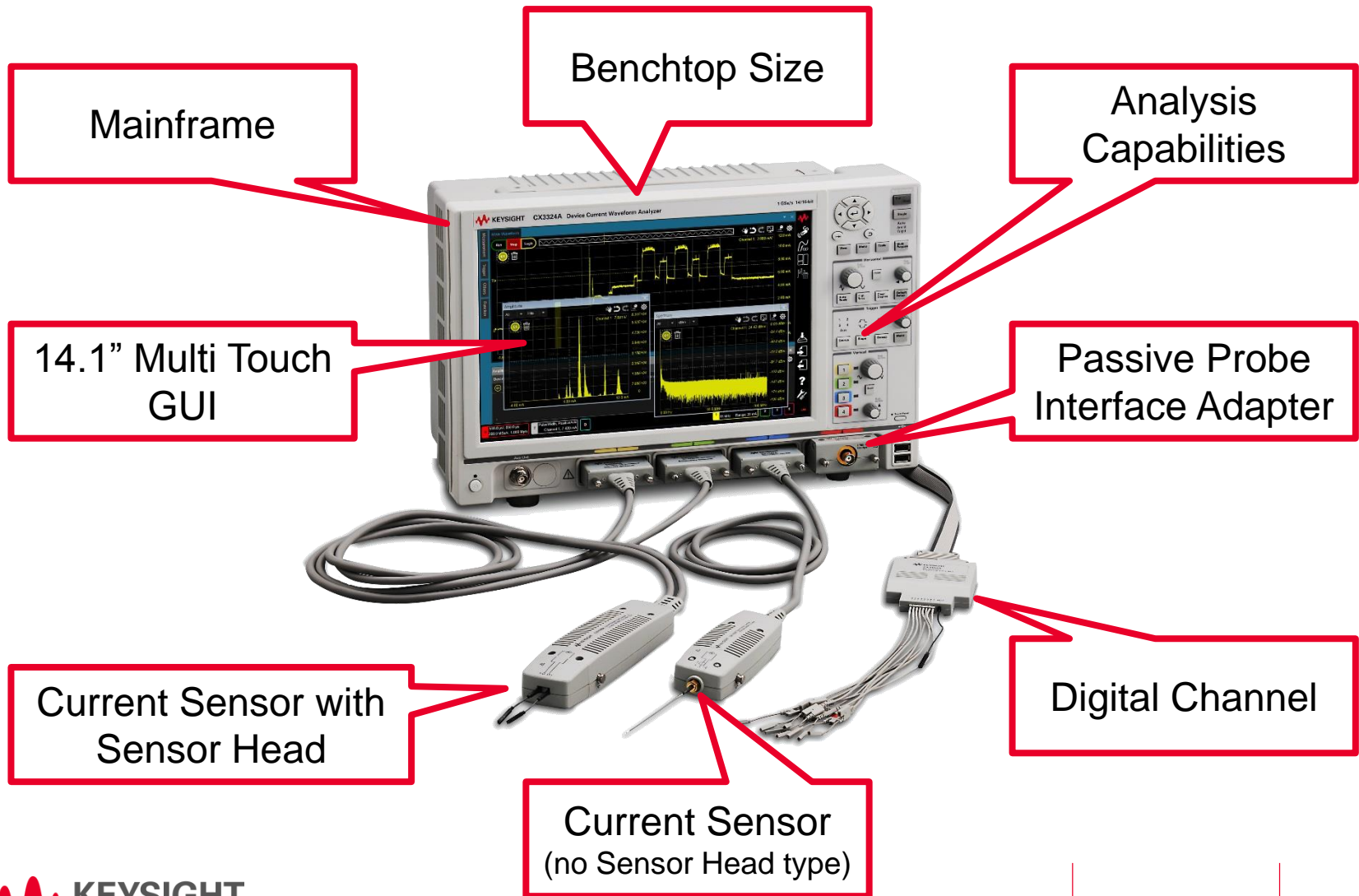
Current Waveform Measurement Positioning:

Positioning	Precision	Accuracy	Bandwidth	Product	Price range
Measure Only	$> 1 \text{ mA}$	2%	Widest	 <p>Shunt resistor</p> <p>Clamp-on current probe</p>	Scope price + 500\$ to \$1k\$
Measure Only	$> 50 \mu\text{A}$	2%	Wide (3 MHz)	 <p>N2820A High Sensitivity Current Probe</p>	Scope price + 3k\$ to 4k\$
Measure Only	$> 150 \text{ pA}$	$< 1\%$	Wider (200 MHz)	 <p>CX3300A Device Current Waveform Analyzer</p>	50k\$ to 90k\$
Source + Measurement	$> 20 \text{ nA}$		Narrow $< 30 \text{ kHz}$	 <p>N6705B DC power analyzer N6781A SMUs</p>	20k\$ to 40k\$

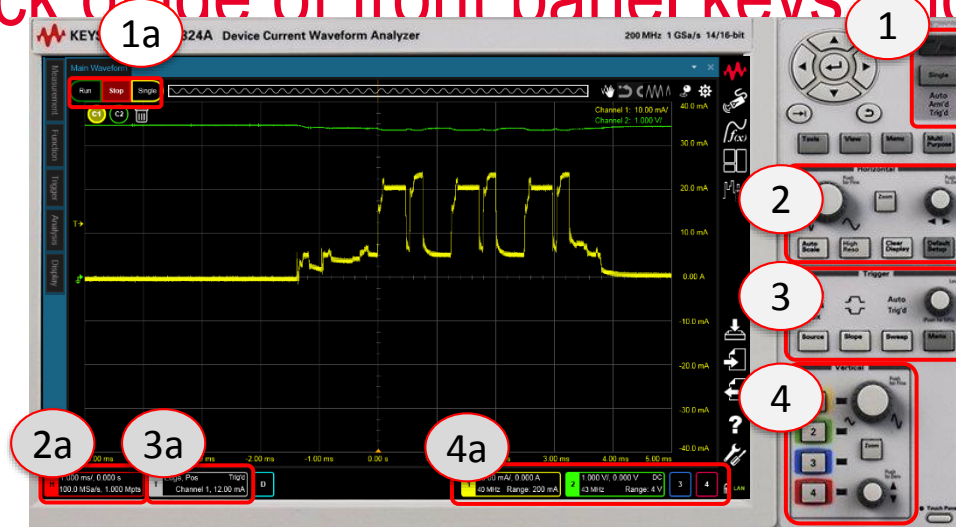
CX3300A Coverage



Solution components



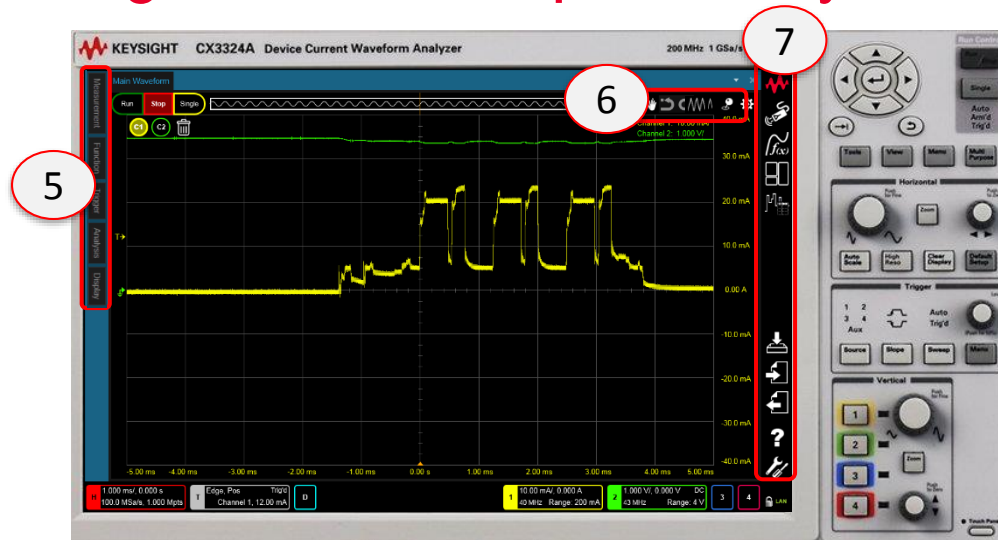
➤ Quick guide of front panel keys and GUI



1. Run control buttons: Set Run/Stop/Single measurement.
1a. The same control can be made by the touch screen icon box.
2. Horizontal parameter control
2a. Displays the Horizontal parameter setup summary.
3. Trigger control
3a. Displays the trigger parameter setup summary.
4. Vertical parameter control
4a. Displays the Vertical channel setup summary.

2a/3a/4a: Clicking the box enables to change the related measurement parameters.

➤ Quick guide of front panel keys and GUI (cont'd)

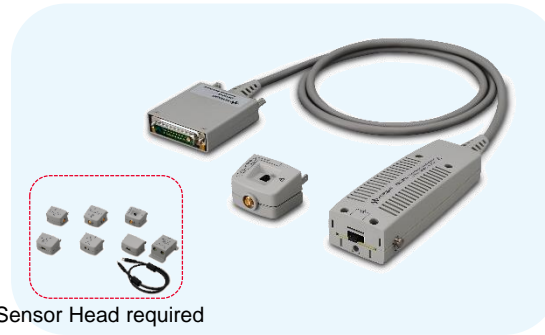


5. Tool Palette: Apply Measurement, Function, Trigger, Analysis to waveform by drag & drop the icon.
6. Zoom, Display control
7. Side Bar: Can access almost all settings from here & Load/Save/Help/Utilities(User calibration etc.)

Current Sensors

HF noise suppression with low-burden current sensing

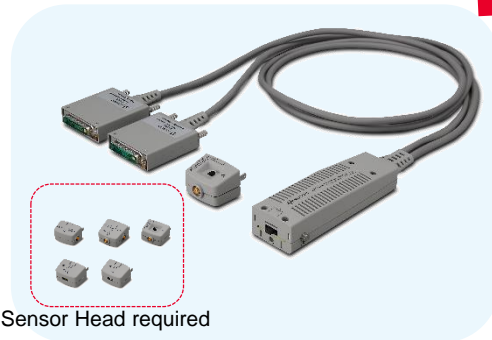
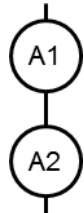
Basic current sensor



Sensor Head required

- CX1101A**
Current Sensor,
Single Channel
- ✓ 100 MHz max bandwidth
 - ✓ 40 nA to 10 A
 - ✓ +/- 40 V Common mode voltage

More dynamic range



Sensor Head required

- CX1102A**
Current Sensor,
Dual Channel
- ✓ 100 MHz max bandwidth
 - ✓ 40 nA to 1 A
 - ✓ +/- 12 V Common mode voltage

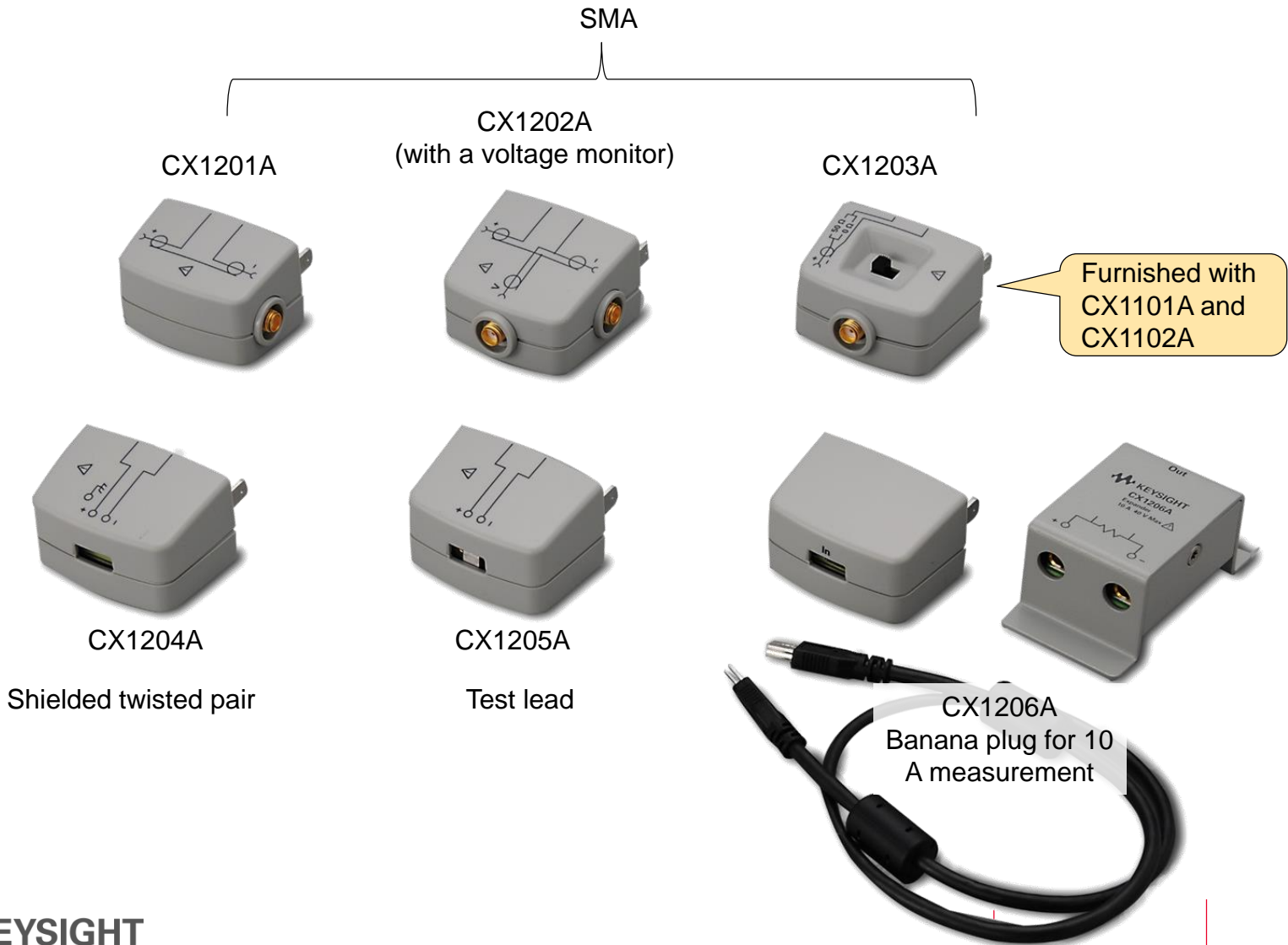


More BW & lower noise

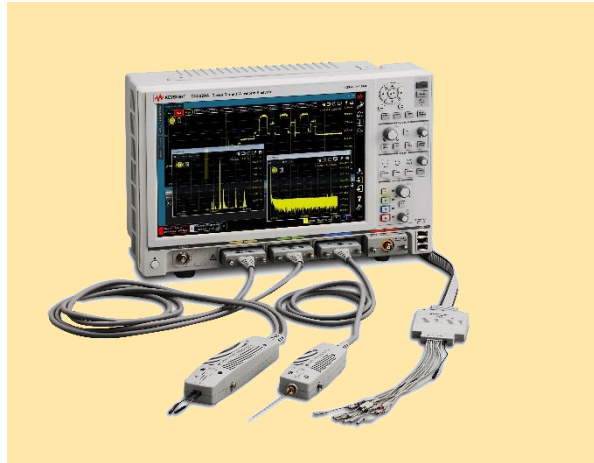


- CX1103A**
Current Sensor,
Low Side
- ✓ 200 MHz max bandwidth
 - ✓ 150 pA to 20 mA
 - ✓ +/- 0.5 V Common mode voltage

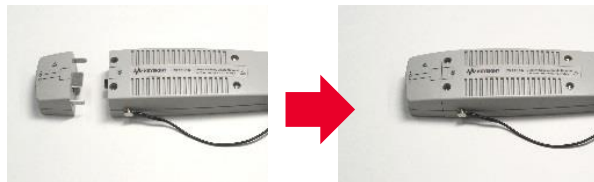
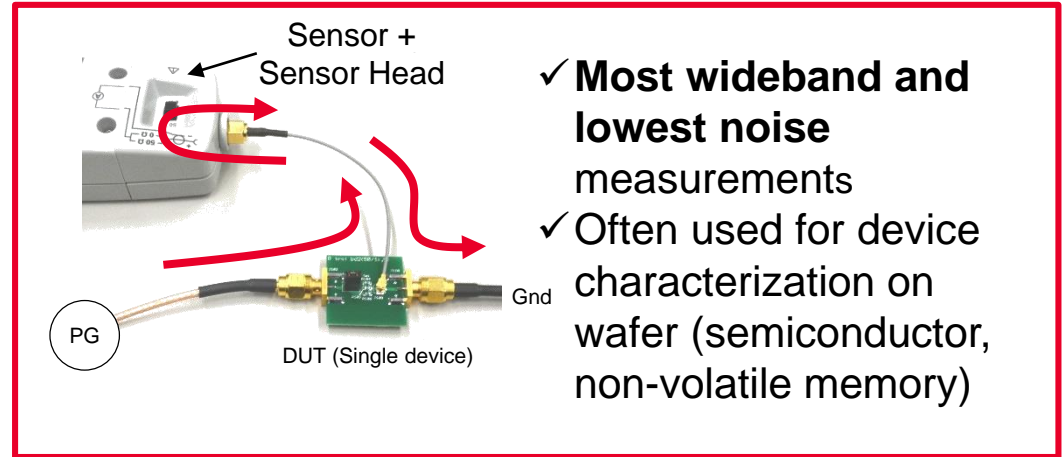
Sensor Head and the connector type



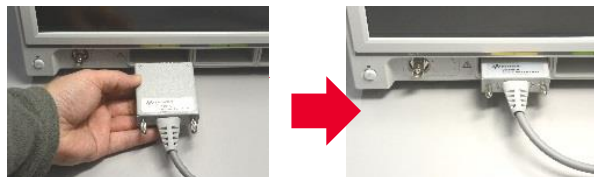
DUT connection examples



SMA type connection

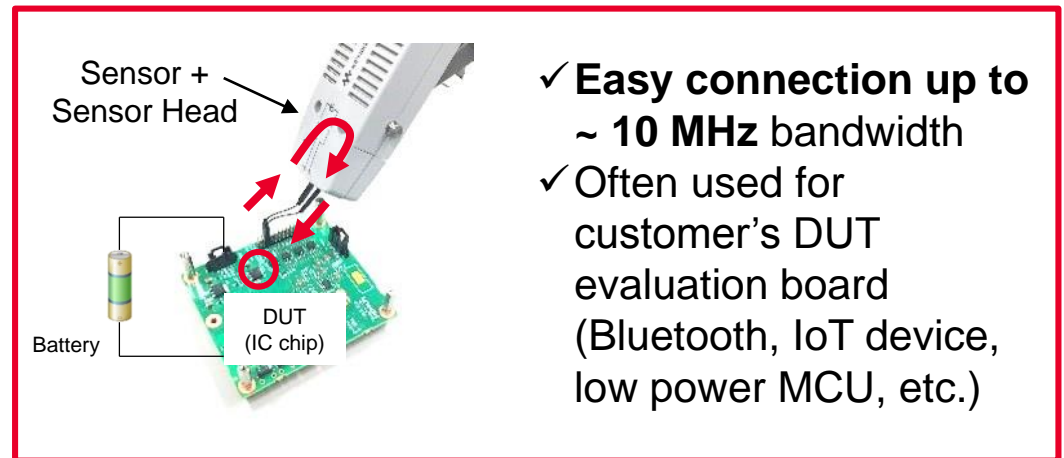


Attach a Sensor Head to Current Sensors



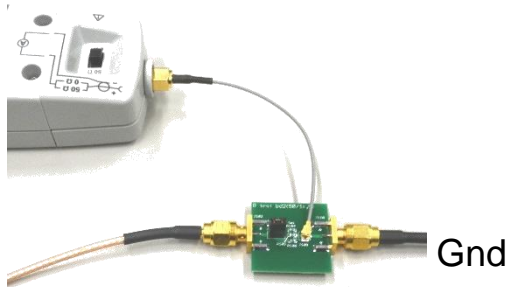
Attach a Current Sensor to Mainframes

Test lead connection

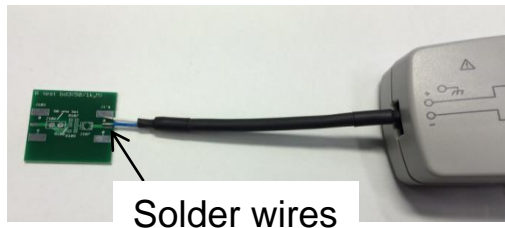


Tips: Connection example to customer's DUT

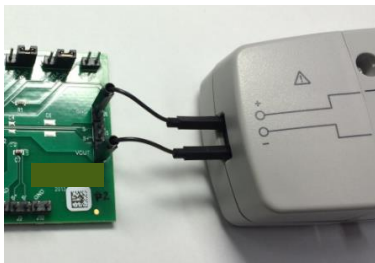
CX1203A Coaxial Termination



CX1204A Twisted Pair Adapter



CX1205A Test Lead Adapter



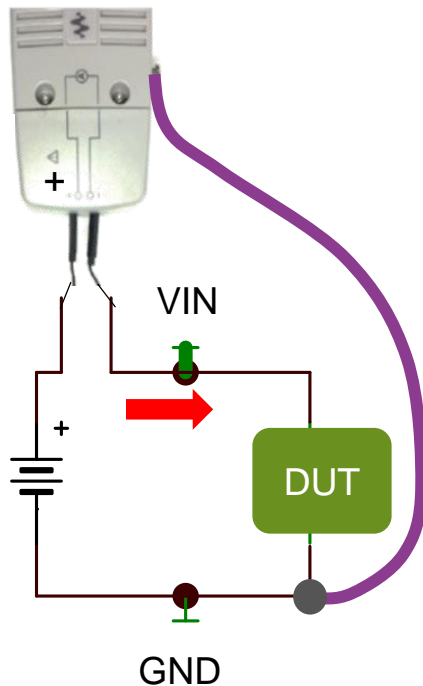
Applicable Current Sensors: CX1101A, CX1102A

Sensor Head	Connection type	Max. standalone bandwidth [MHz]
CX1201A Coaxial Through	Coaxial (SMA)	≤ 100
CX1202A Coaxial Through with V Monitor		
CX1203A Coaxial Termination		
CX1204A Twisted Pair Adapter	Twisted pair	$\ll 10$
CX1205A Test Lead Adapter	Test lead	$\ll 10$
CX1206A High Current Adapter with Expander, 10 A	Banana plug	≤ 3

Tips: Ground lead connection

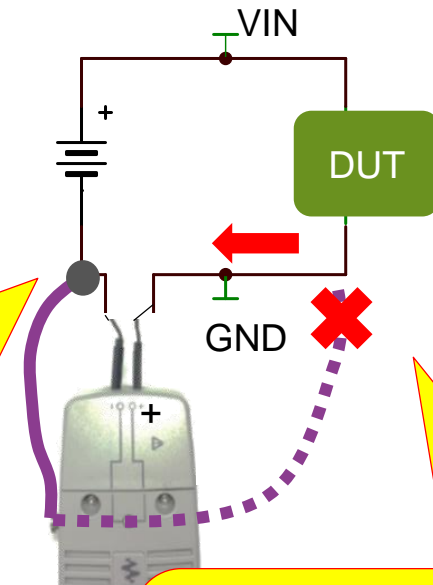
Where to connect the ground lead in a floating device?

When measuring current from source to DUT at high side



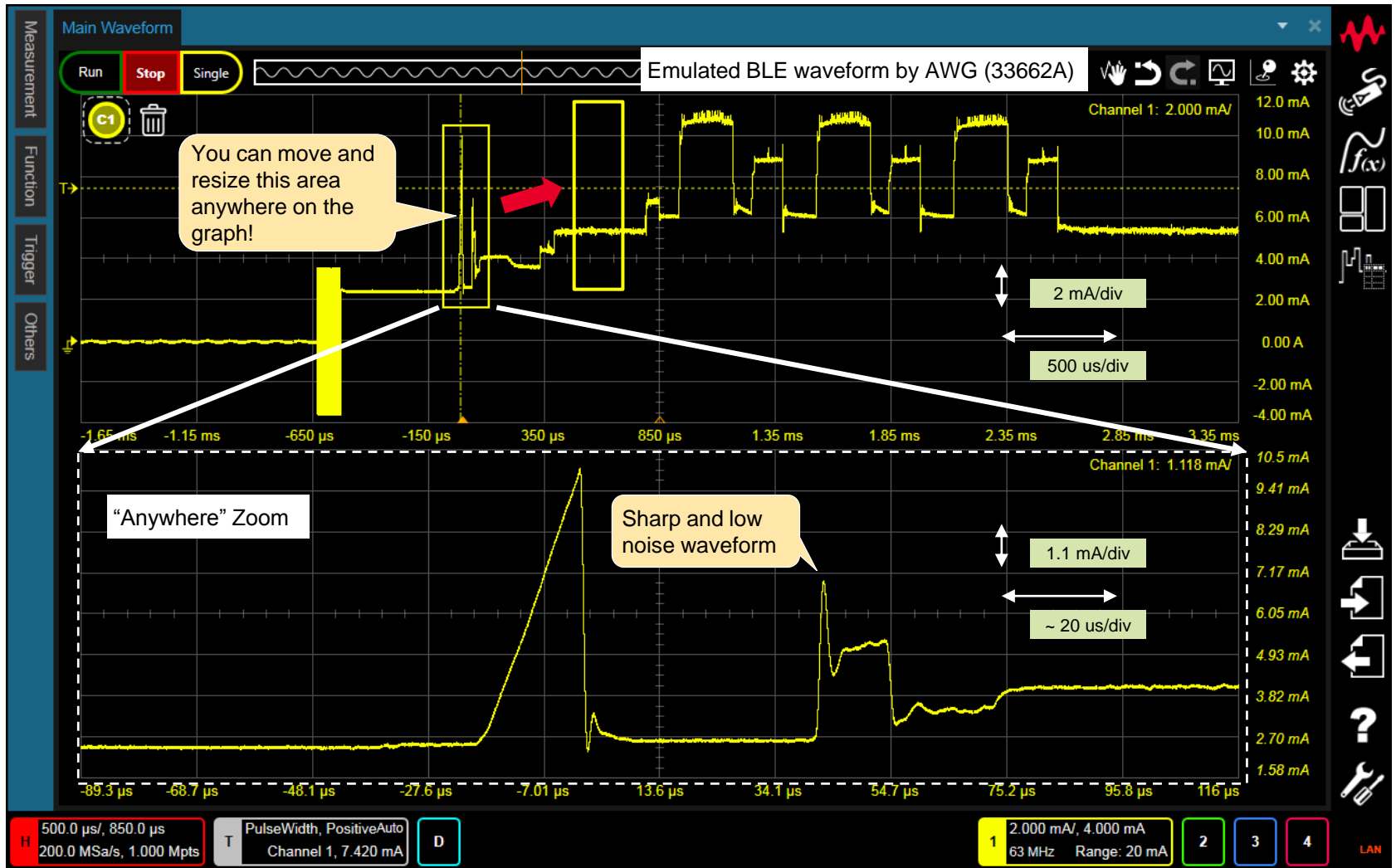
Note: Connect ground lead to the negative electrode of the battery, not to GND terminal (= + terminal of the current sensor) of the board.

When measuring current from DUT to source at low side

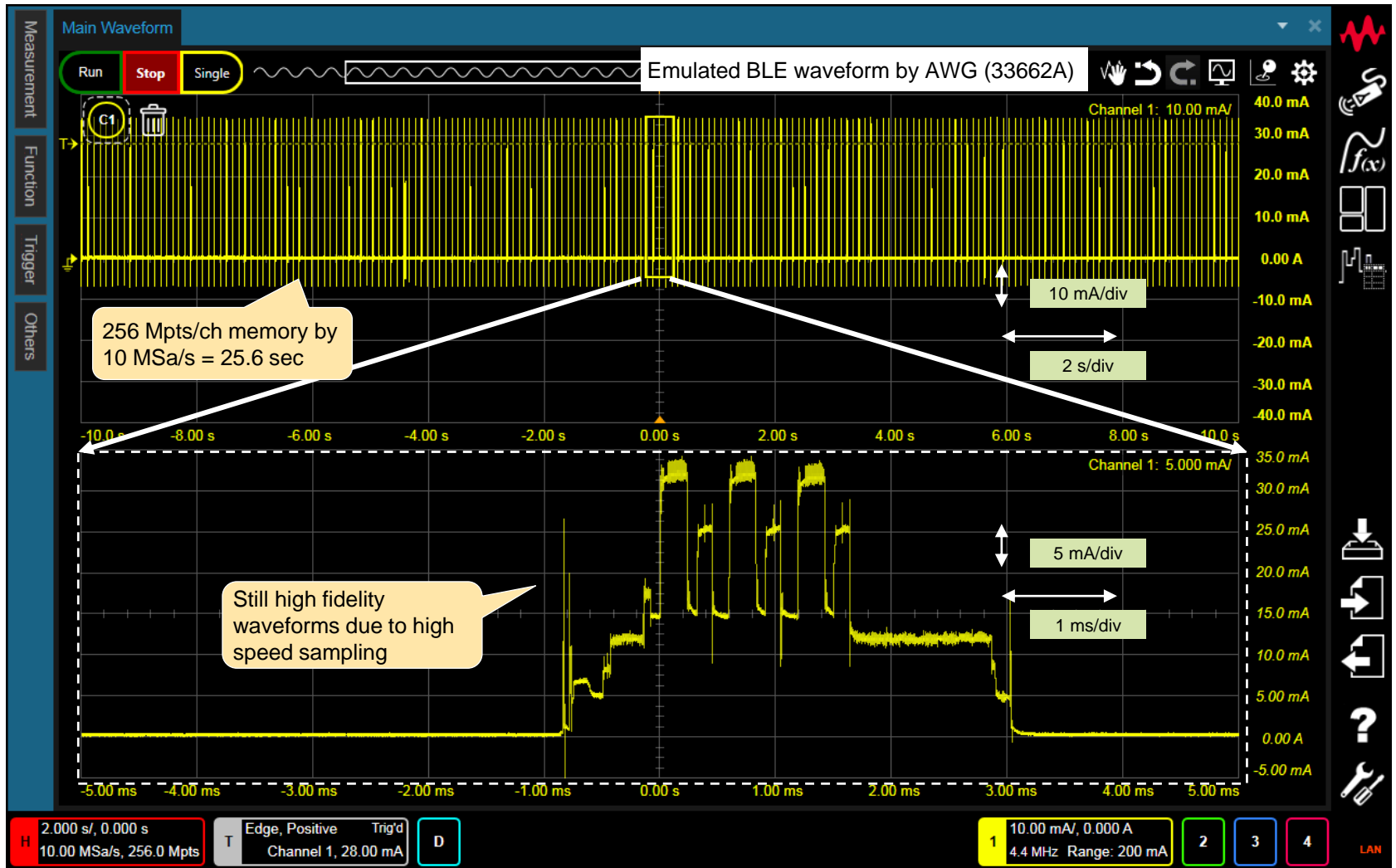


If you connect here, the additional current flows into current sensor due to the voltage difference between ground lead and circuit common of current sensor

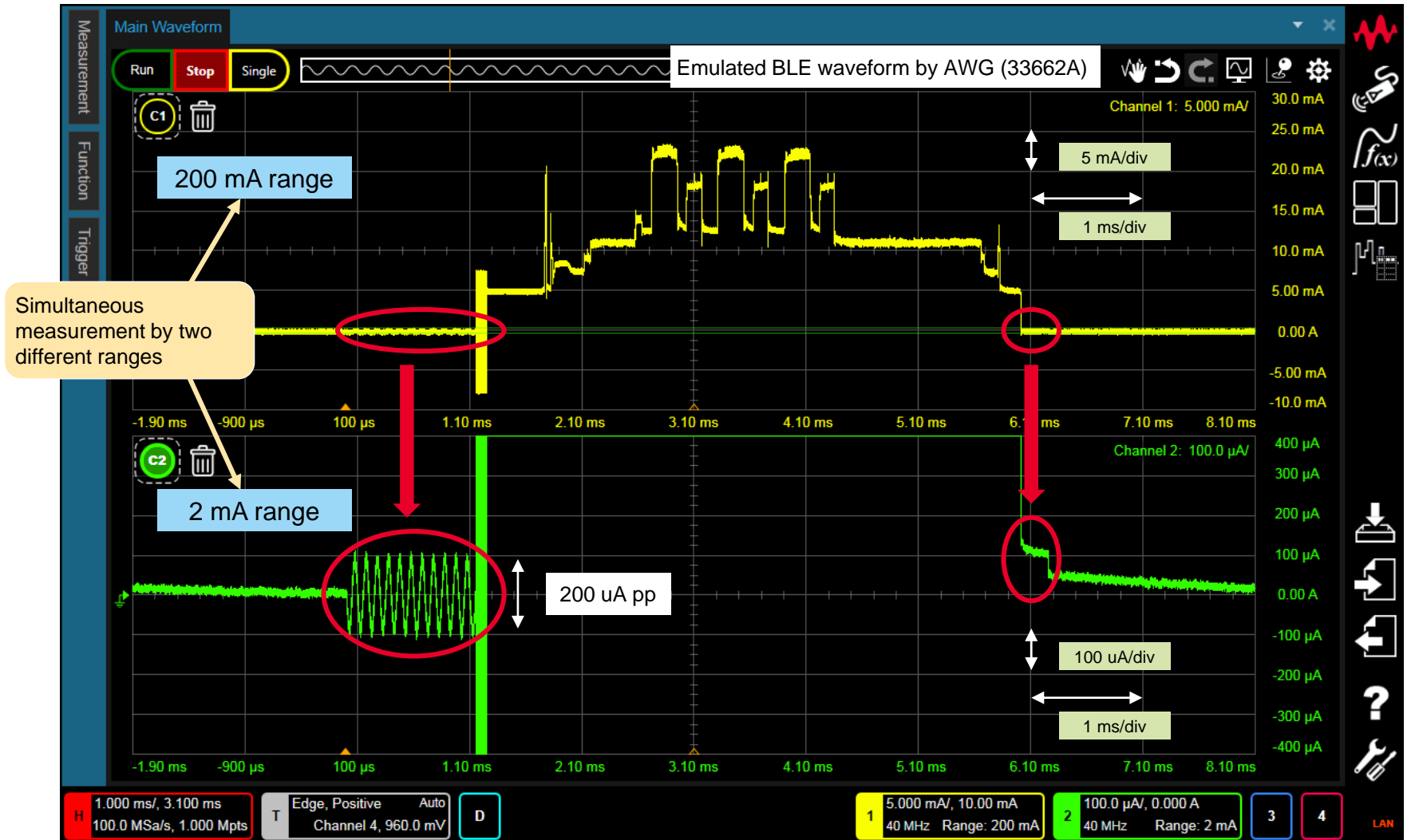
Waveform example #1: "Anywhere" Zoom (CX1101A)



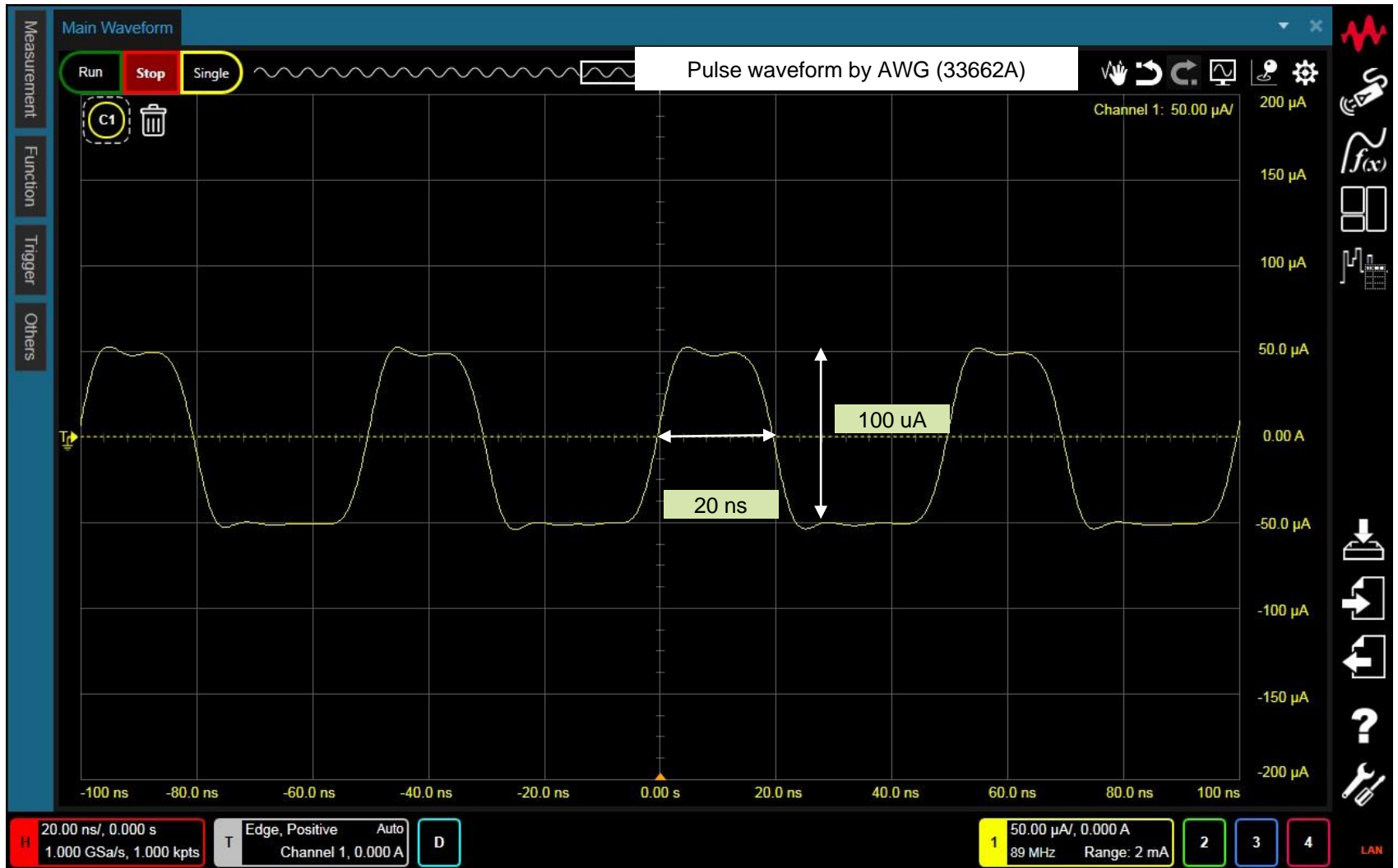
Waveform example #2: Long duration measurement (CX1101A)



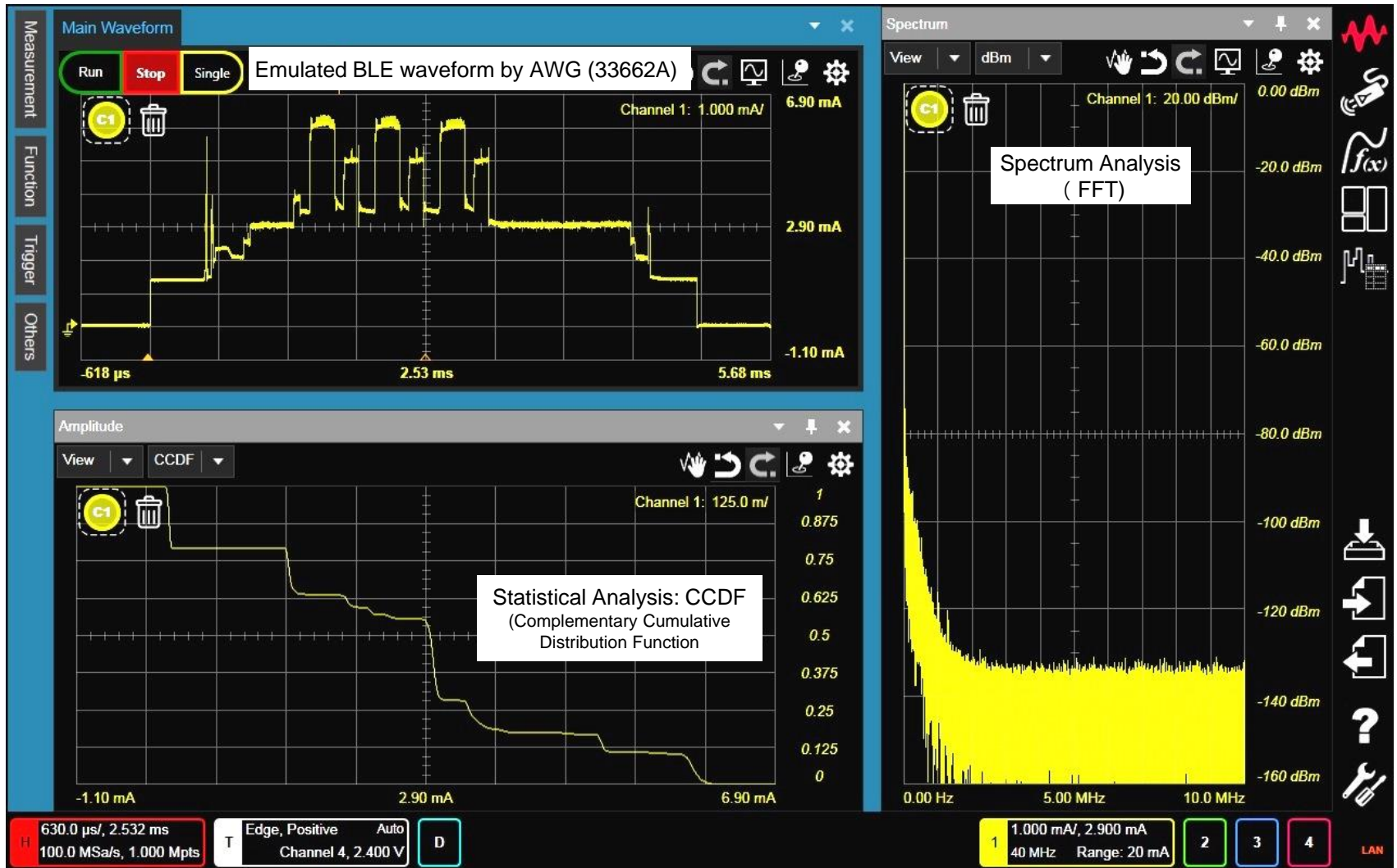
Waveform example #3: Dual Channel Current Sensor (CX1102A)



Waveform example #4: 20 ns pulse transient (CX1103A)

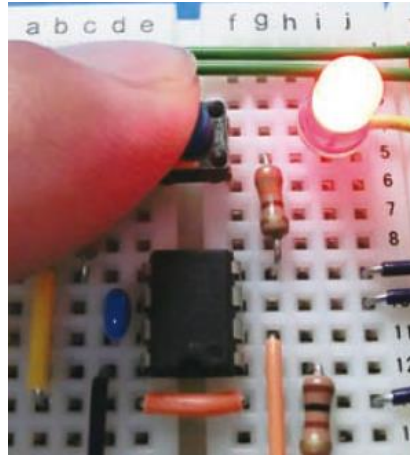


Additional analysis capabilities



Case Study : Supply current monitoring for MCU + LED

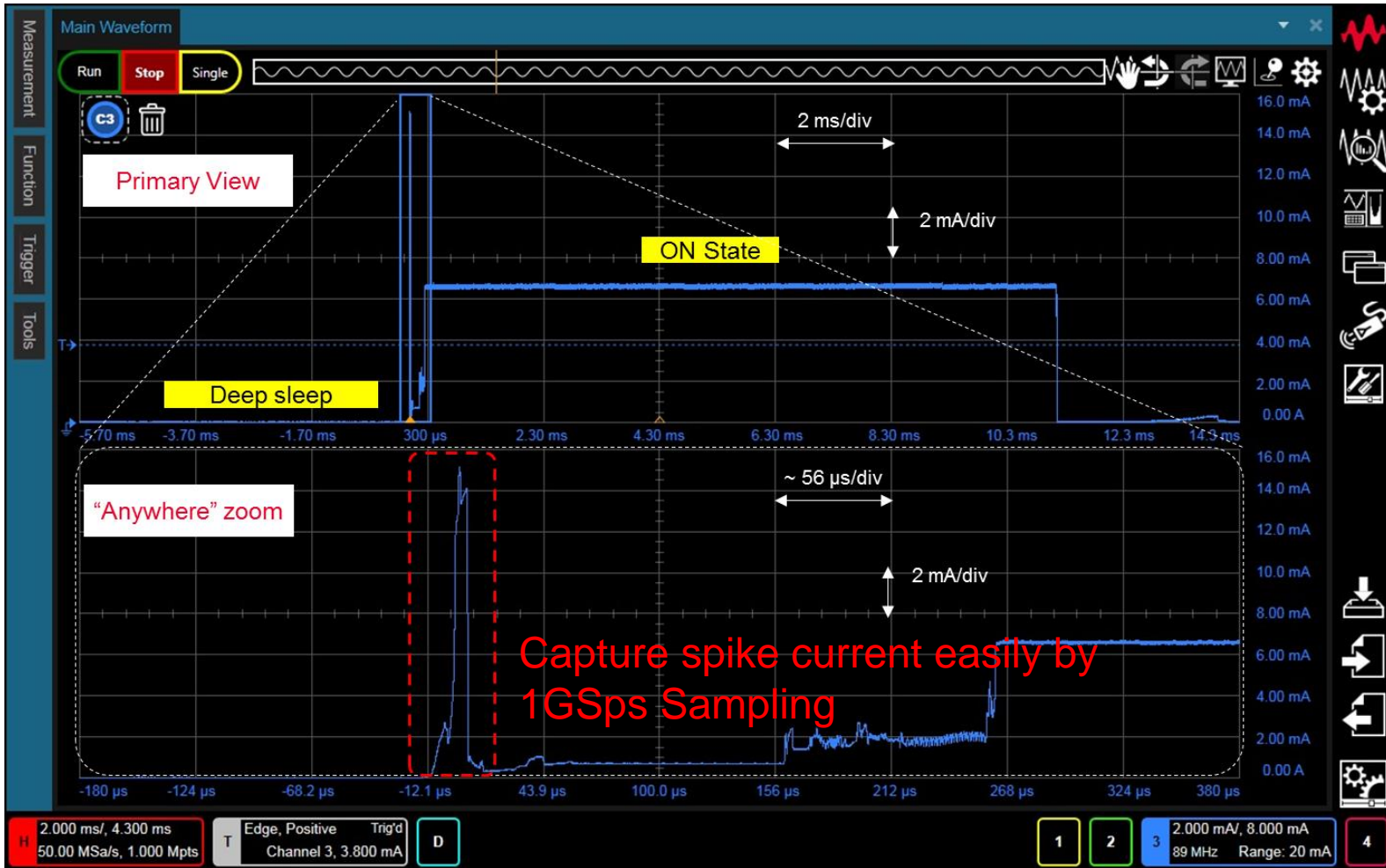
LPC810 (NXP) just turns on/off an LED periodically



- Turn on an LED after waiting for a long time in standby mode

Current Waveform Measurement by CX3300

Supply current monitoring for MCU + LED



Keysight Technologies Current Measurement Solutions

Choose the right solutions to meet your needs.

34470



CX3300



N6705



Scope & N2820
current probe



B2900



Enable IoT modules development with Keysight advance low current measurement capabilities

For more IoT Test information, please visit:

<http://www.keysight.com/Find/IoT>

For more low current measurement, please visit:

<http://www.keysight.com/Find/CX3300A>

Thank You !

