SWTEST ASIA
PROBE TODAY, FOR TOMORROW

Automated Test Equipment (ATE) for EV Battery Management Systems (BMS): Challenges and Solutions

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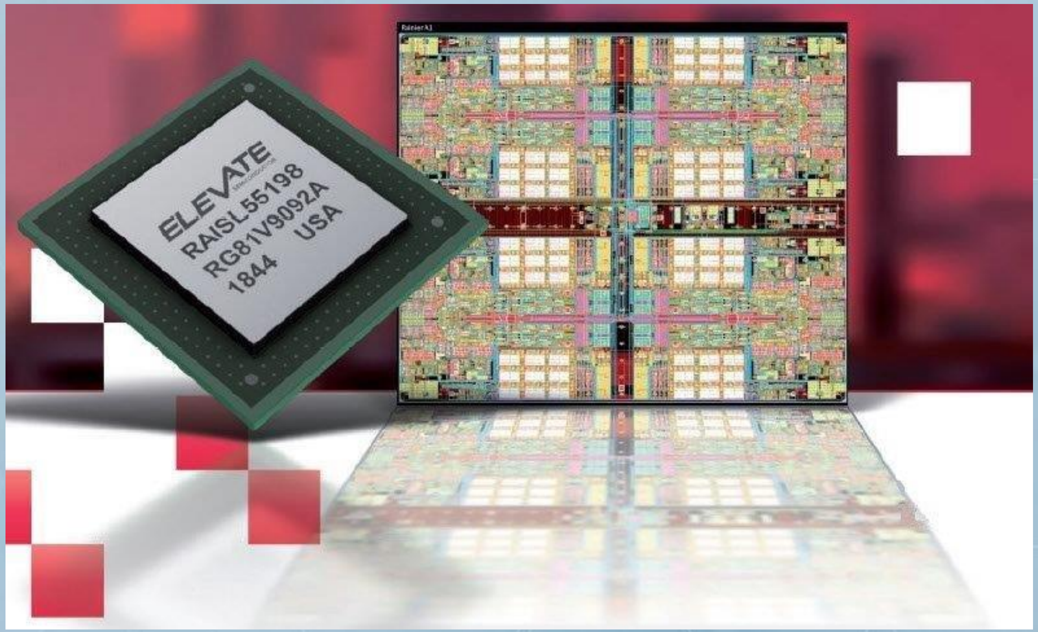
ElevATE Semiconductor



Company Vision

World-Class, pure-play supplier of Integrated Circuits (ICs) for Automated Test Equipment (ATE)

Company Mission

Deliver high-density, low-power ICs to test next-gen semiconductors, reducing cost of test

Overview

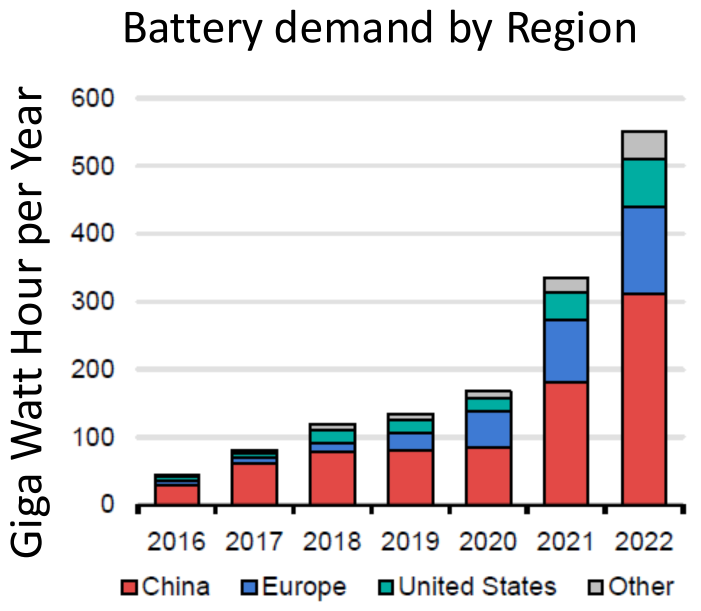
- **Battery pack and Battery Management Systems (BMS): Critical component of EV**
- **BMS and BMS-ATE: Key functions and challenges**
- **Proposed BMS-ATE Solution**
  - ➢ System architecture and modes of operation
  - ➢ Parametric Measurement Unit (PMU) based architecture
  - ➢ PMU measured results
- **Future trends**
- **Conclusion**

EV Battery Pack: The New "Fuel Tank"

- Exponential growth in EVs driven by consumer adoption and government mandates
- Battery pack critical to EV safety, reliability and range
  - Multiple electric cars, trucks, tuk tuk and motorcycles on the market!
- Largest growth area is China
  - Motivates discussion at SW Test Asia



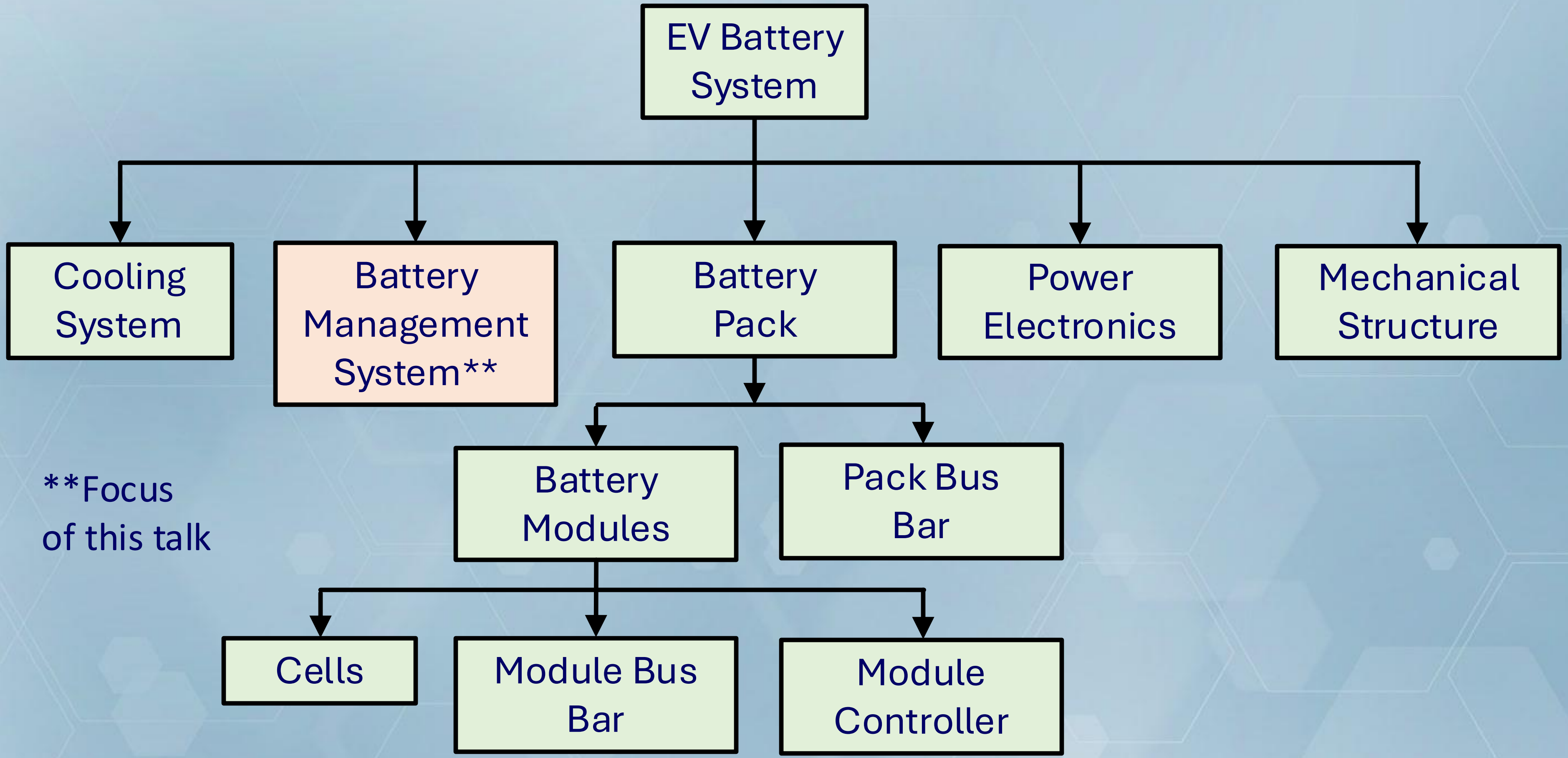




Largest growth area is China

EV Battery Pack System Architecture

- EV battery-pack ~ 400V to 800V: Series connection of ~ 16 battery modules
- Each Battery module : Matrix of (16 to 24 cells in series) X (70 to 100 cells in parallel)
- Each battery module has a dedicated BMS IC



**Focus of this talk

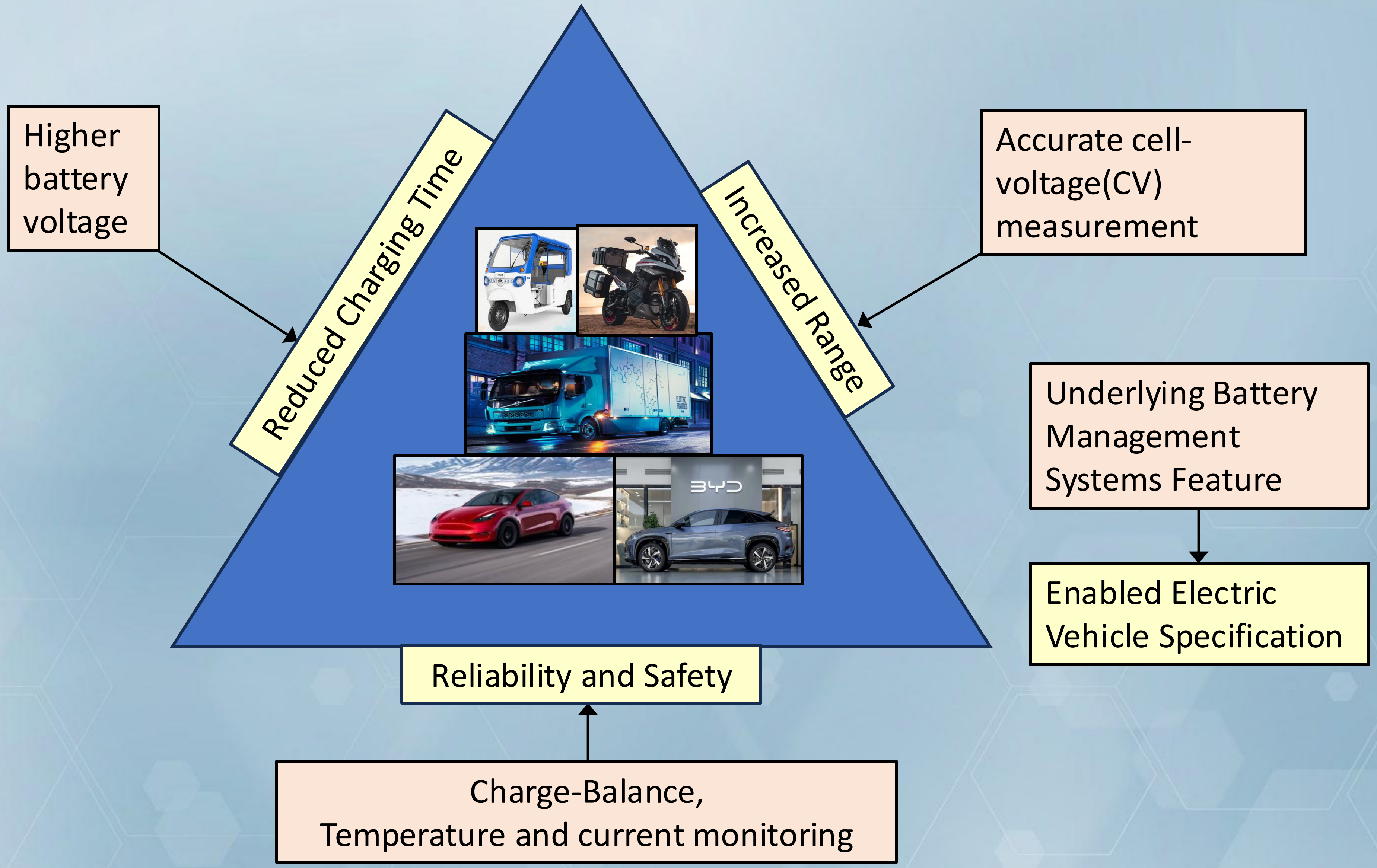
Example EV Battery Systems

Tesla Model S

BYD Blade

Rivian R1T

BMS Features: Key Enabler of EV Specifications



- BMS features enable current and future EV specifications
- BMS features validated by test by stringent ATE tests
- Details on BMS requirements, and resultant BMS-ATE challenges are on next slides

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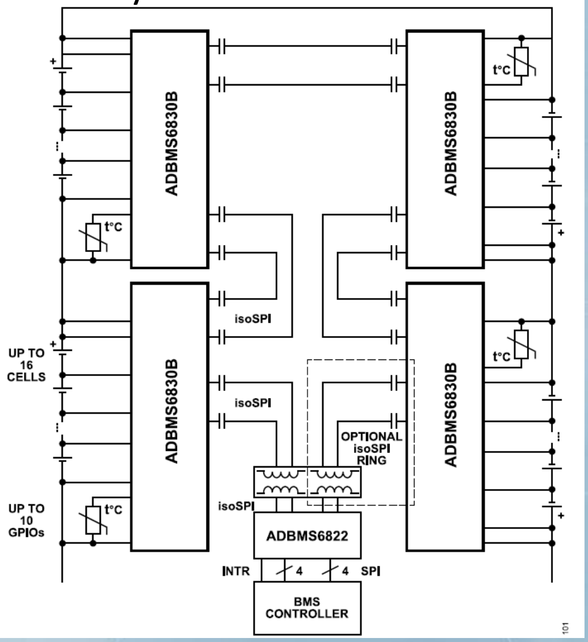
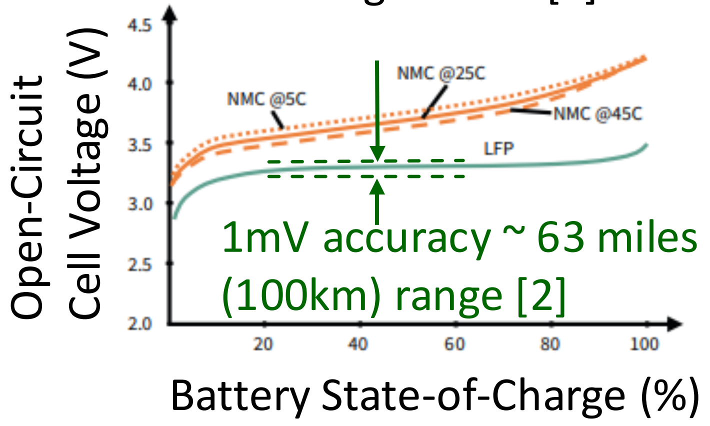
BMS & BMS-ATE requirements for accurate cell-voltage measurement

- EV battery State-of-Charge (SoC) needs measurement of each cell-voltage
- EV battery cells have very flat discharge curves
  - ➢ BMS : Need accurate Analog-to-Digital Converters (ADCs) for cell-voltage measurement
    - ➢ ~100s microVolt precision needed to accurately calculate EV range
  - ➢ BMS-ATE : Automated-Test Equipment (ATE) needs accurate Digital-to-Analog Converters (DACs) to generate stimuli outputs for test of BMS ADC capabilities
    - ❖ BMS-ATE needs low-noise, high-linearity DAC and analog-front end (AFE)

Example Battery Pack Electrical System Architecture



EV Battery Cell Discharge Curve [1]

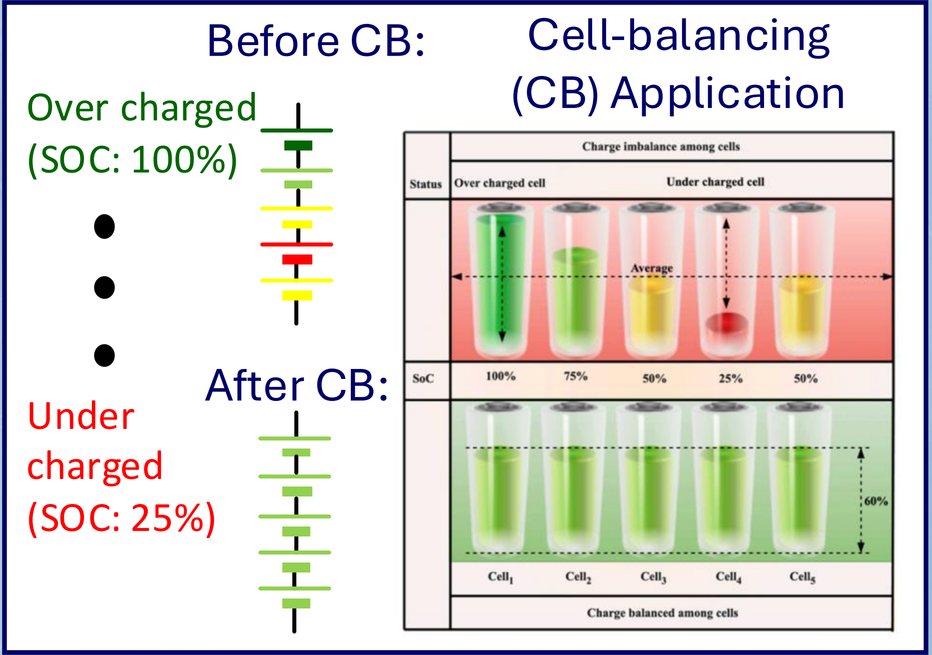


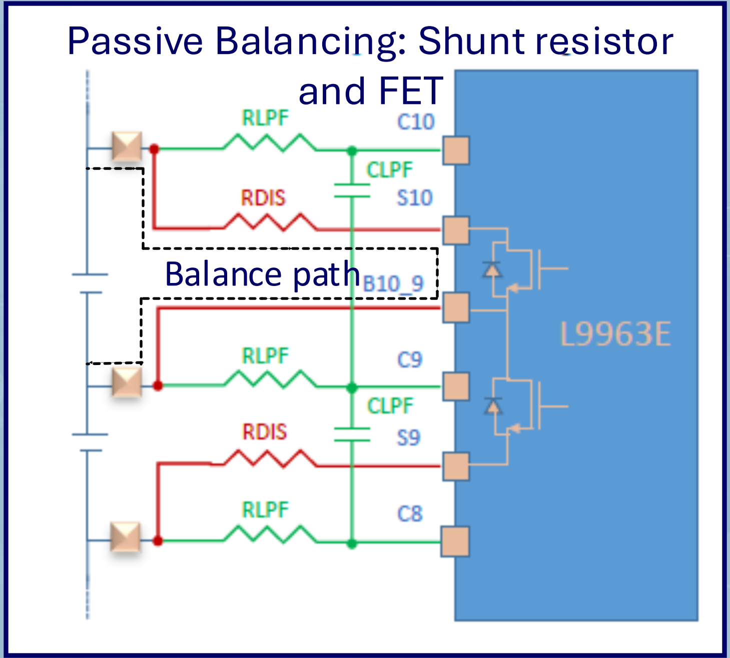
Parameter	BMS IC		
	ADI ADBMS6830B	TI BQ79616	ST L9963E
Cell Voltage Measurement LSB Resolution (uV)	150	190	89

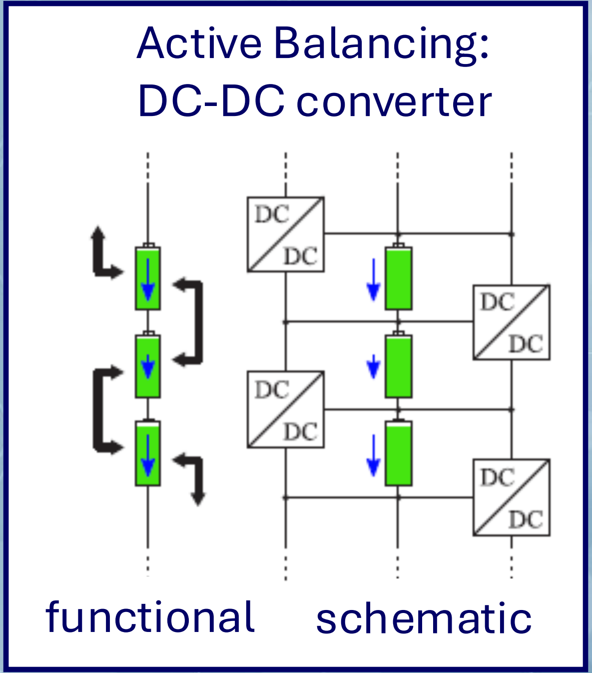
[1] Infineon-INF1197_ART_BMS_Whitepaper_d08-Whitepaper-v01_00-EN.pdf
[2] A new battery management system could boost EV range by 20 percent | Ars Technica

BMS & BMS-ATE requirements for EV battery Cell Balancing

- Series connected cells have different SoC due to differences in manufacturing, ageing and operational conditions
  - ➢ Over-charging and deep-discharging battery cells may lead to safety hazards
- Hence, BMS balance the series State-of-Charge (SoC)
  - ➢ Current method : Passive balancing: Shunt resistor to dissipate extra charge.
    - ❖ Low complexity, but generates heat and has low power efficiency
  - ➢ Next generation: Active cell-balancing: DC-to-DC converters which redistribute charge
- BMS-ATE requirements: (1) Measure internal / external discharge FETs, (2) Emulate small-signal battery cell characteristics







Challenges of BMS-ATE

Example BMS Application Circuit:
Analog Devices ADBMS6830 16-Channel Multicell Battery Monitor

- Series stack of 4 battery modules
- 1 BMS IC per battery module

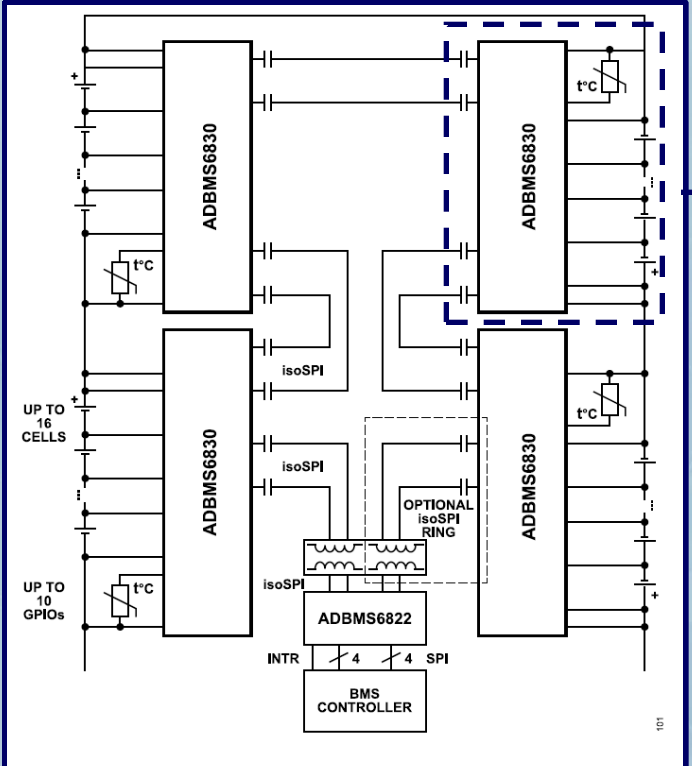
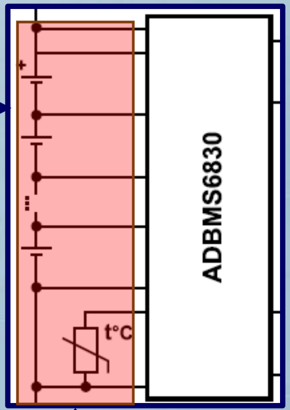


Figure 1. Typical Application Circuit

Zoom-in on one BMS-DUT



ATE hardware emulates Battery Cells

BMS-ATE needs to be high-precision, low-noise and highly-linear to accurately test BMS features:

BMS features ATE needs to test:	Required ATE-HW-features to implement test:
300uV or more accurate Analog-Front-End (AFE) and ADCs for battery Cell-voltage measurement	30-300uV accurate voltage sources
1uA or more accurate input-current	300nA – 1uA accurate current measurement capabilities
Battery temperature-sensing	Accurate I/V source and measurement capability

Additional challenges of BMS-ATE:

1. Need high channel-density, while testing 16 or higher cells
2. Series battery stack connection needs BMS to source high common-mode voltages

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- **Proposed BMS-ATE Solution**
  - System architecture and modes of operation
  - Parametric Measurement Unit (PMU) based architecture
  - PMU measured results
- **Future trends**
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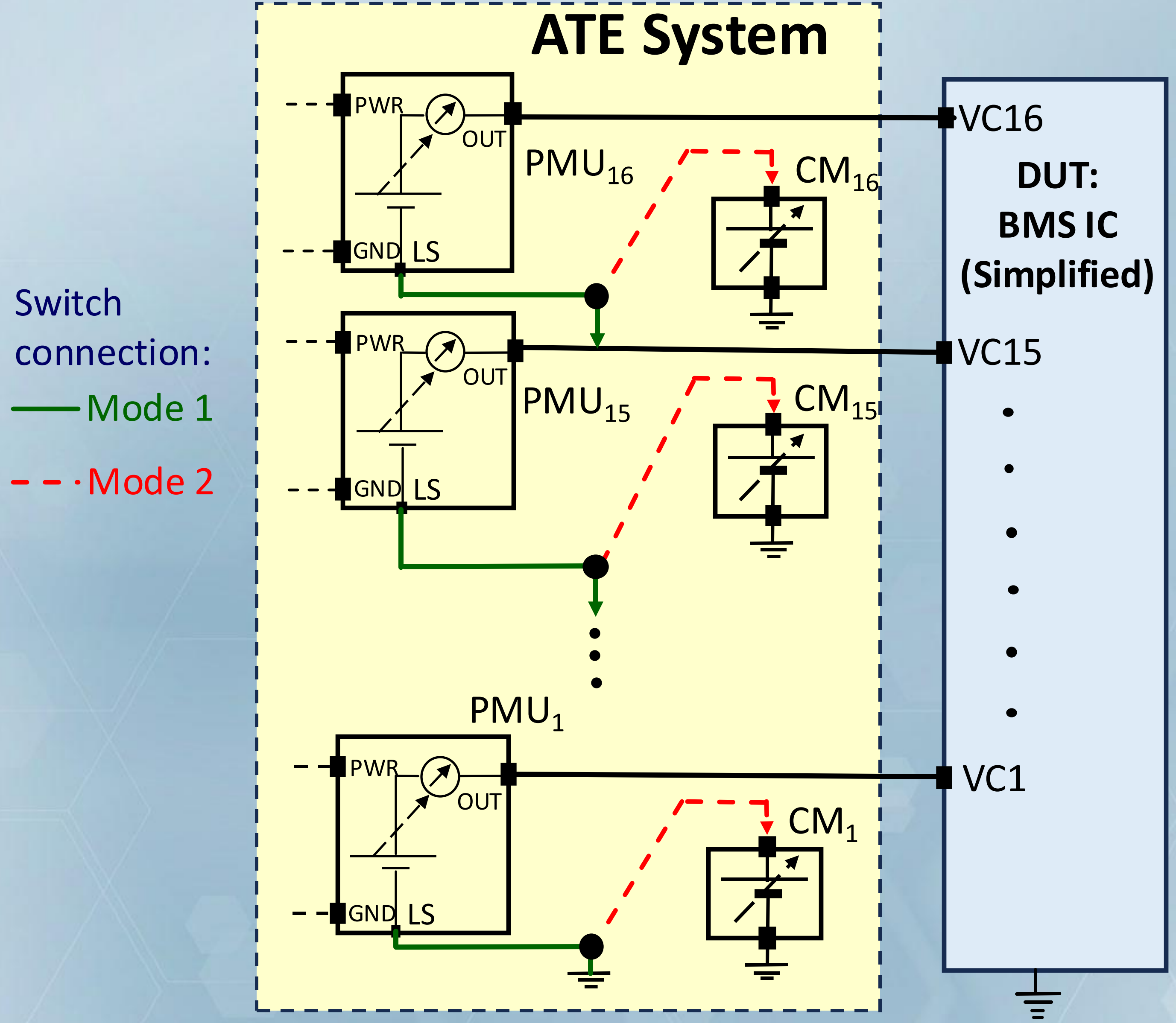
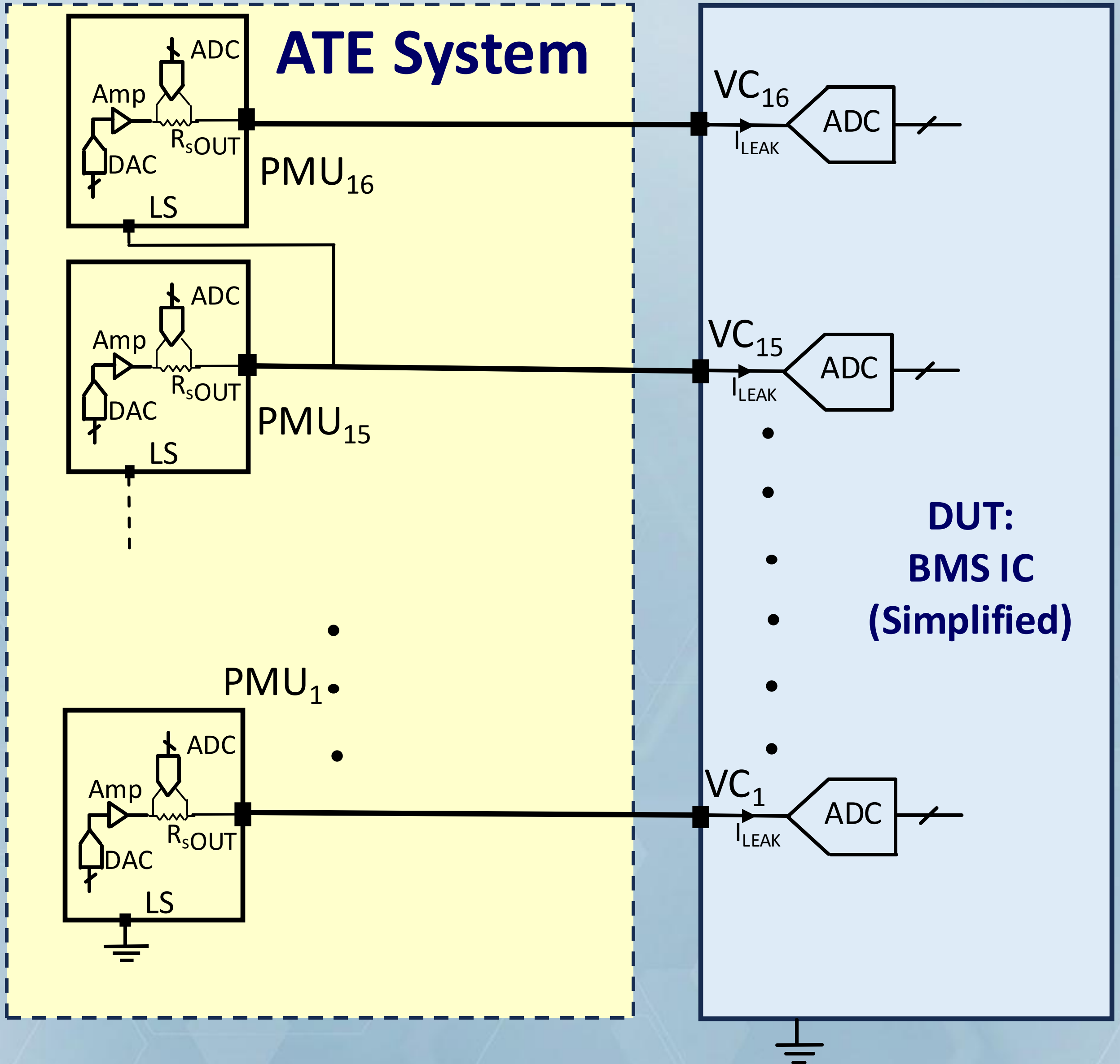
Proposed system solution for BMS-ATE: Reconfigurable stack of PMU



- System architecture based on **P**arametric **M**easurement **U**nit (PMU)
- Floating PMUs, $PMU_{16} - PMU_1$, emulate EV battery module series-connected cells
- Thanks to PMU floating-ground, hardware is configurable to two modes via switches:
  - Mode 1: PMUs connected in series emulating EV battery module
  - Mode 2: PMUs individually connected to high-voltage common-mode power supplies, $CM_{16} - CM_1$, for testing DUT maximum ratings

(Note: Figure shows a simplified system architecture for 16-series-cell BMS ATE)

BMS-ATE test (1): Measure Cell-Voltage ADC and Leakage



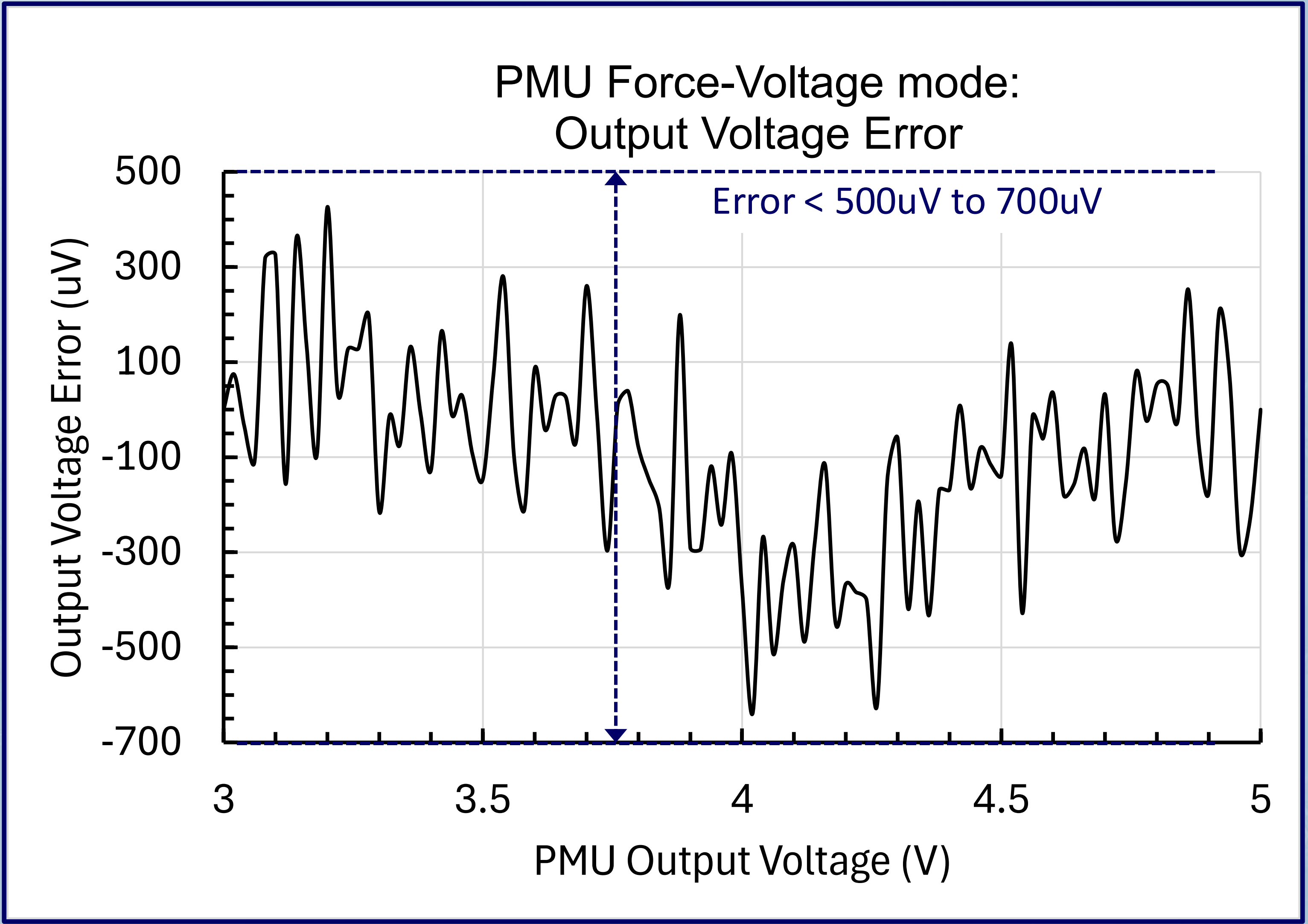
- DUT Specifications under test:
  - $CV_{16} - CV_1$: BMS channel Cell voltage Measurement LSB Resolution (uV)
  - I_{LEAK_16} - I_{LEAK_1} : BMS channel Input Leakage (nA)

- Typical DUT Specification Value:

Parameter	BMS IC		
	ADI ADBMS6830B	TI BQ79616	ST L9963E
Cell Voltage Measurement LSB Resolution (uV)	150	190	89
Input Leakage (nA)	250	100	300

- ATE Test Method: ATE emulates battery cells
  1. Test program sets DAC input digital code, e.g., 20-bit 0x87AF4
  2. PMU outputs set voltage to DUT VC terminal, e.g., 3.89765V
  3. Test program records:
     a. ADC cell-voltage measured by DUT
     b. ADC leakage current measured by PMU

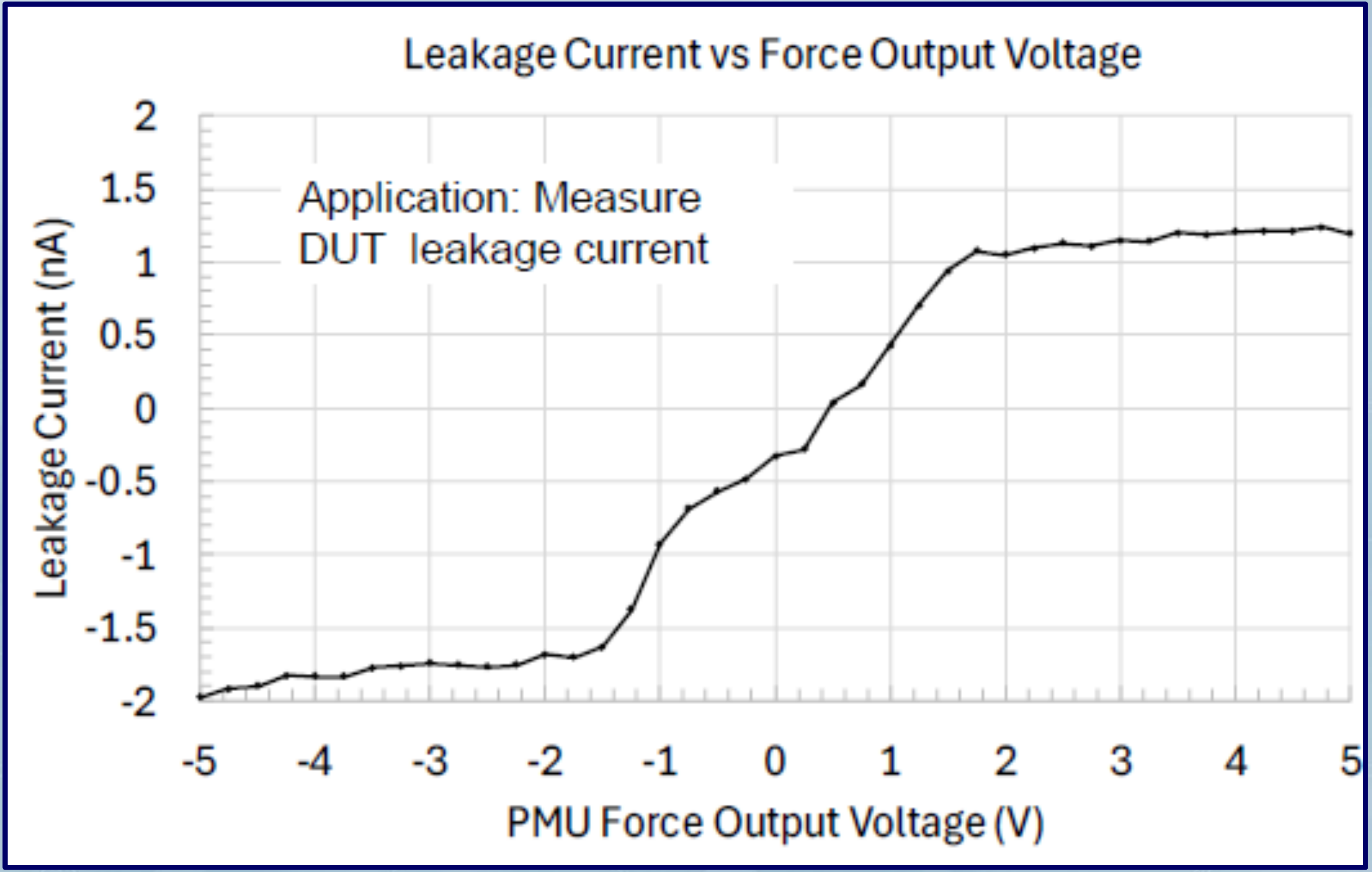
BMS-ATE test (1): Measured Elevate PMU Precision Force-Voltage



- PMU-Based ATE configuration:
  - PMU configured to drive BMS DUT with operational battery cell voltage, e.g., 3V to 5V
  - Accuracy of Forced-Voltage is within 500uV to 700uV
    (Can be further improved by system calibration)

- Applications:
  - Measure BMS-DUT cell-voltage resolution for state-of-charge determination

BMS-ATE test (1): Measured Elevate PMU ultra-low leakage current



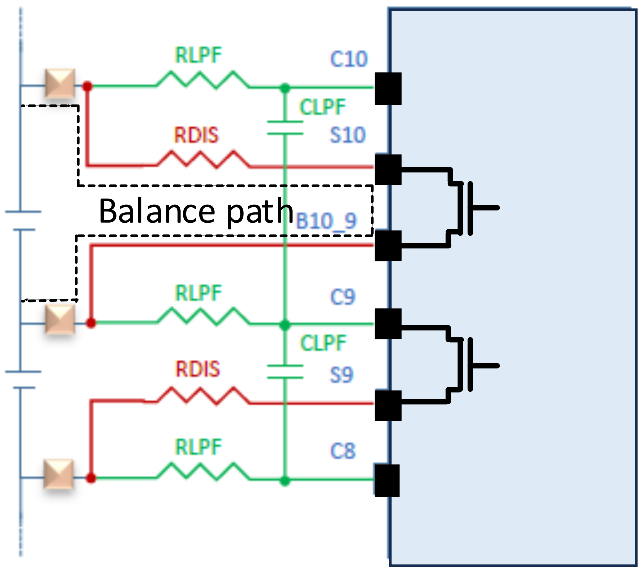
- DUT Specification-under-Test:
  - Input Leakage Current

Parameter	BMS IC		
	[4] ADBMS6830B	[5] BQ79616	[6] L9963E
Input Leakage (nA)	250	100	300

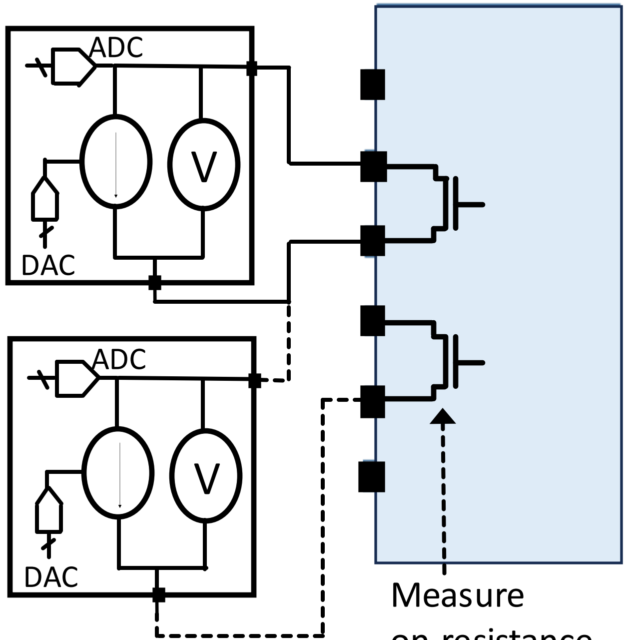
- PMU-Based ATE configuration:
  - PMU can be configured to drive BMS DUT with operational battery cell voltage, e.g., 3V to 5V
  - PMU leakage current is within +/-2nA, indicating accurate measurement of DUT leakage current

BMS-ATE test (2): Measure charge balancing FET On-Resistance (Ron)

Operational connection of DUT to Battery in EV:



Test connection of ATE to DUT-BMS



- DUT Specifications under test:
  - R_{ON}: BMS charge balancing On Resistance (Ω)

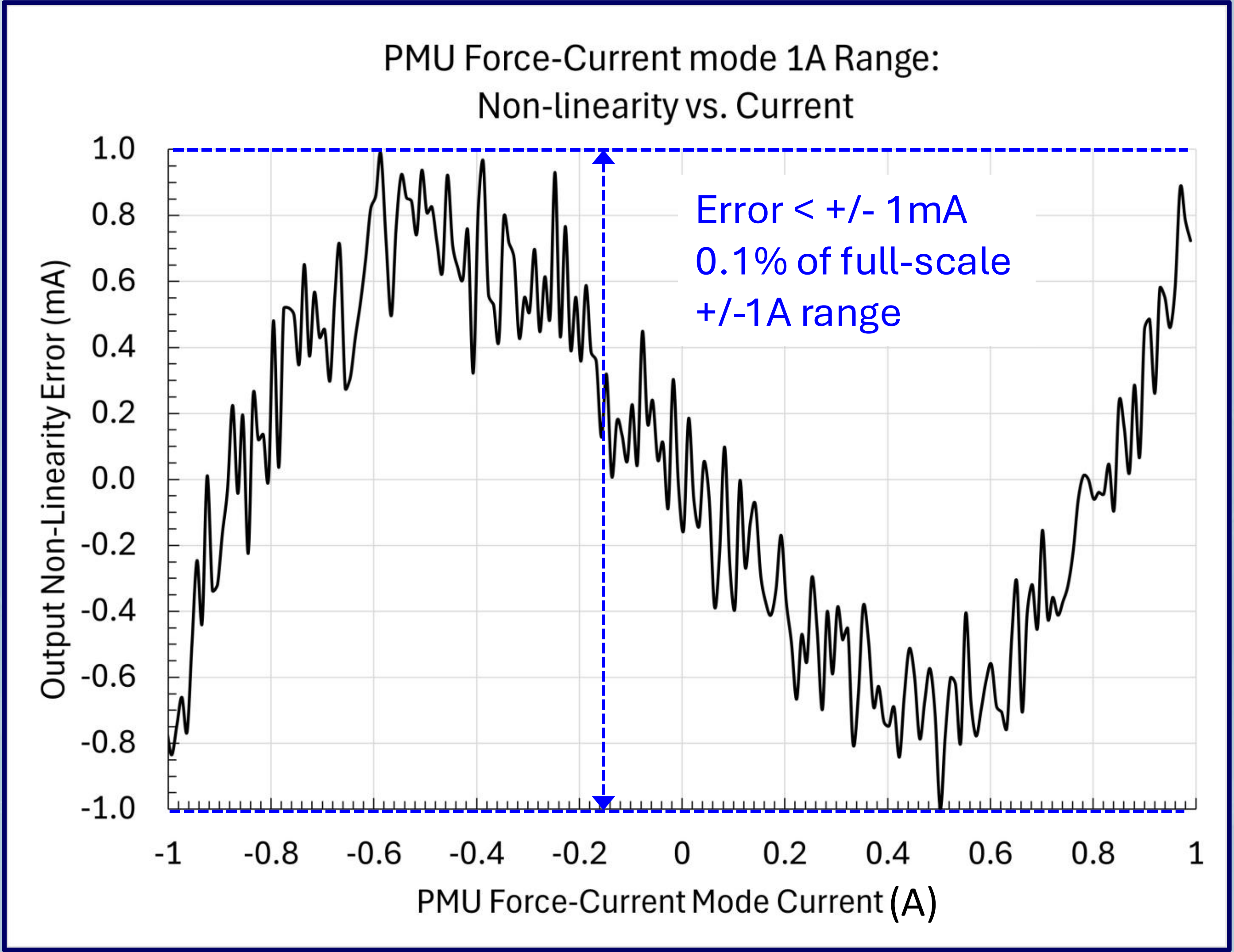
- Typical DUT Specification Value:

Parameter	BMS IC		
	[4] ADBMS6830B	[5] BQ79616	[6] L9963E
Maximum Charge Balancing FET On Resistance (Ω)	4	4.6	1.5

- ATE Test Method: ATE emulates battery cells
  1. Test program sets DAC input digital code
  2. PMU outputs set current, I_{FORCE} to DUT charge-balance terminal, e.g., 100mA
  3. Test program records measurements :
     - PMU ADC voltage across charge-balance FET
  4. Test program calculates:

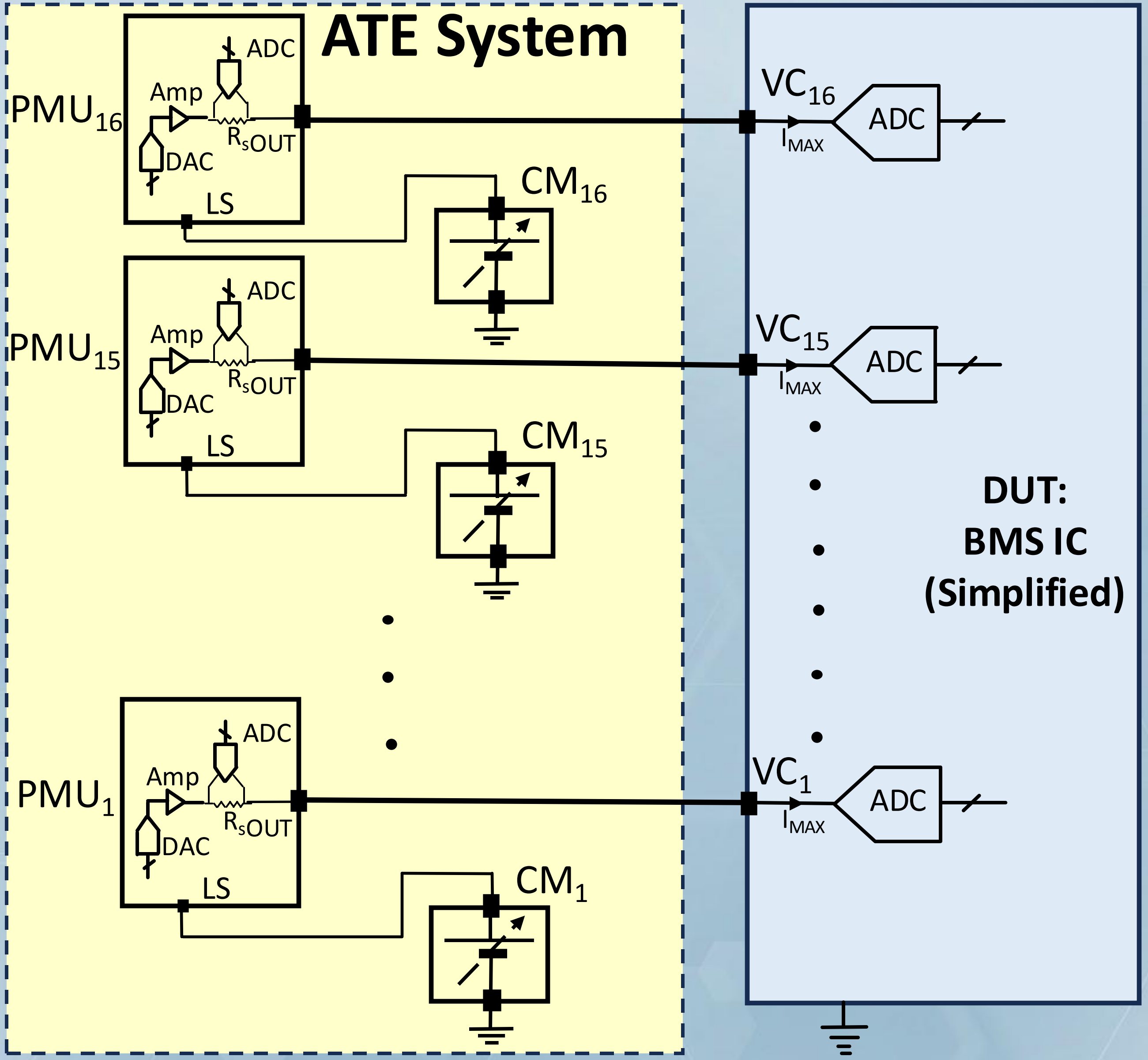
     $R_{ON} = V_{ADC} / I_{FORCE}$

BMS-ATE test (2):
Measured Elevate PMU Highly Linear 1Ampere Force-Current



- PMU-Based ATE configuration:
  - Large-signal current as high as +/-1A can be forced into DUT from ATE
  - Accuracy is within 0.1%, or +/-1mA
  - Note: Part supports ganging of several PMUs in parallel to source higher current into the DUT
- Applications:
  - Accurate measurements of BMS charge-balance FET on-resistance with run-time-level 1 Ampere current

BMS-ATE test (3): Test DUT Maximum Rating



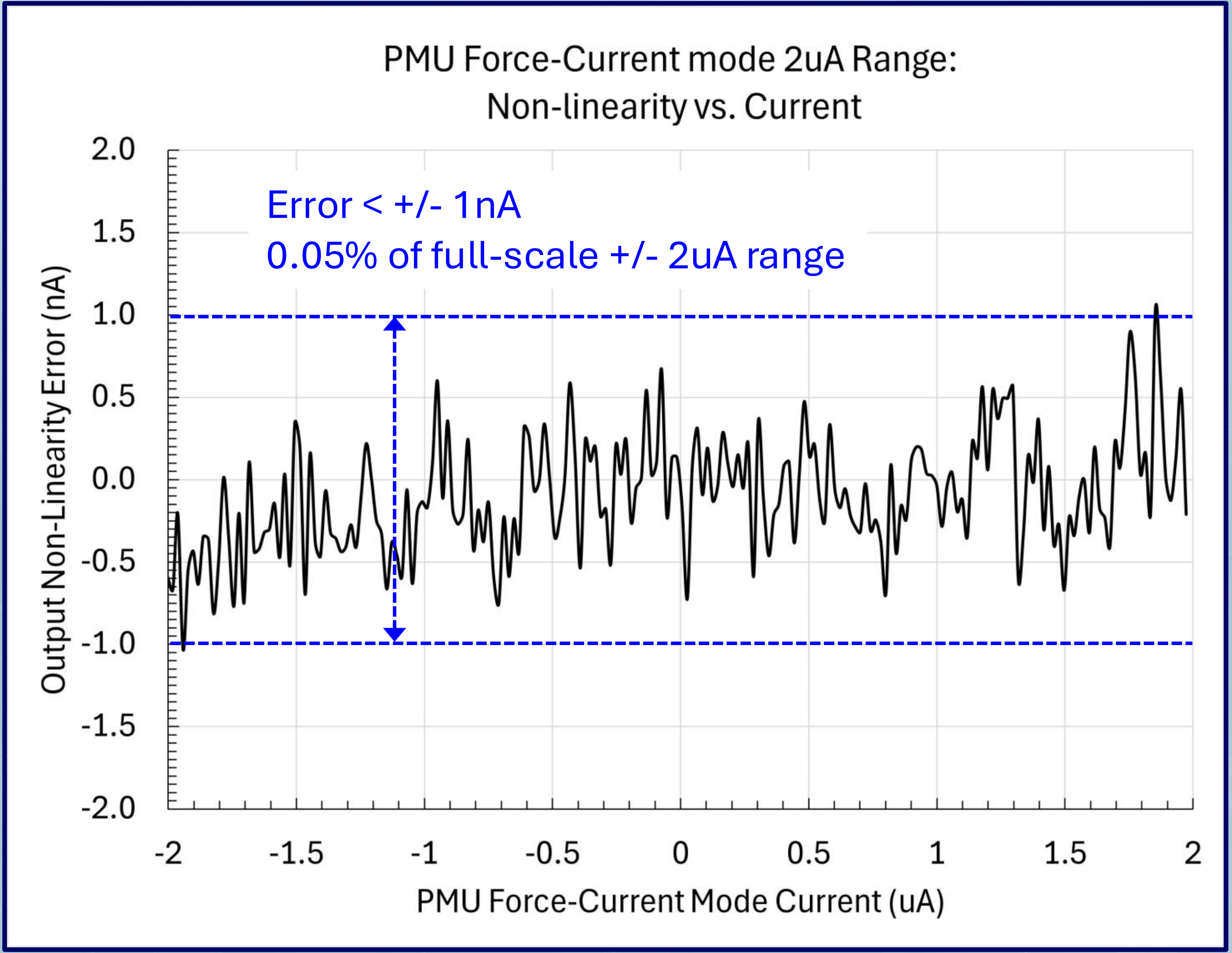
- DUT Specifications under test:
  - $V_{MAX16} – V_{MAX1}$: BMS maximum rated voltage
  - $I_{MAX16} – I_{MAX1}$: BMS current at maximum rated voltage

- Typical DUT Specification Value:

Parameter	BMS IC		
	ADI ADBMS6830B	TI BQ79616	ST L9963E
Maximum Rated Voltage (V)	-0.3V to 85V	-0.3V to 100V	-0.3V to 72V

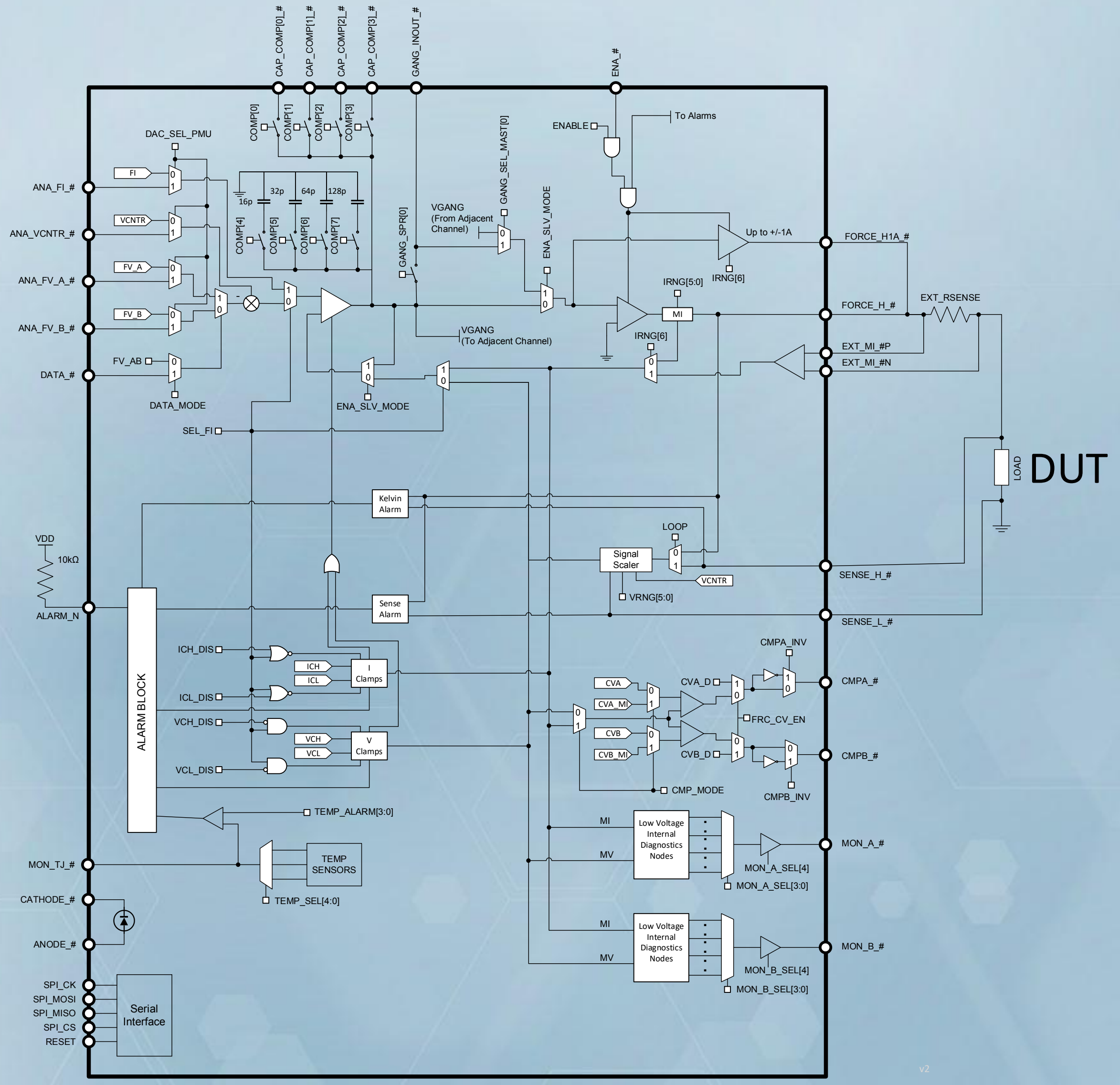
- ATE Test Method: ATE emulates battery cells
  1. Test program configures PMU to be connected in series with common-mode supply
  2. Test program sets output voltage per maximum DUT specification
  3. Test program measures DUT current and checks compliance vs. specification

Measured Elevate PMU: Ultra-Low Micro-Ampere force-current



- PMU-Based ATE configuration:
  - Small-signal current as low as +/- 2uA can be forced into DUT from ATE
  - Accuracy is within 0.05%, or +/- 1nA
- Applications:
  - Small-signal current-mode testing of the BMS-DUT

Elevate PMU ASIC High-Level Architecture



- Integrated DACs drive BMS-DUT Cell-Voltage and Charge-Balance and Bus-Bar terminals

- Multi-mode operation:
  - ➢ Force-voltage
  - ➢ Force-current
  - ➢ Measure-voltage
  - ➢ Measure-current

- High-dynamic range from micro-Ampere to Ampere, with 0.1% precision

- Test BMS-DUT Cell-Voltage resolution, input-current, balance-FET and other capabilities

- Integrated clamps with alarms for fault detection:
  - ➢ Temperature
  - ➢ Over-voltage
  - ➢ Over-current
  - ➢ Kelvin fault detection

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BMS Future Trends

- Increased EV Range which needs higher-voltage battery-packs, higher precision, active cell management and active cell balance
- EV Battery aging, state-of-charge and state-of-health tracking via electrochemical impedance spectroscopy
- EV cell-to-pack or module-free design
- ElevATE PMU roadmap intercepts these trends with 120V PMU, high-resolution DACs and small-signal analog-front-end under feasibility evaluation

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Conclusion

- EVs have proliferated the commercial mass-market
  - Continue to experience exponential growth

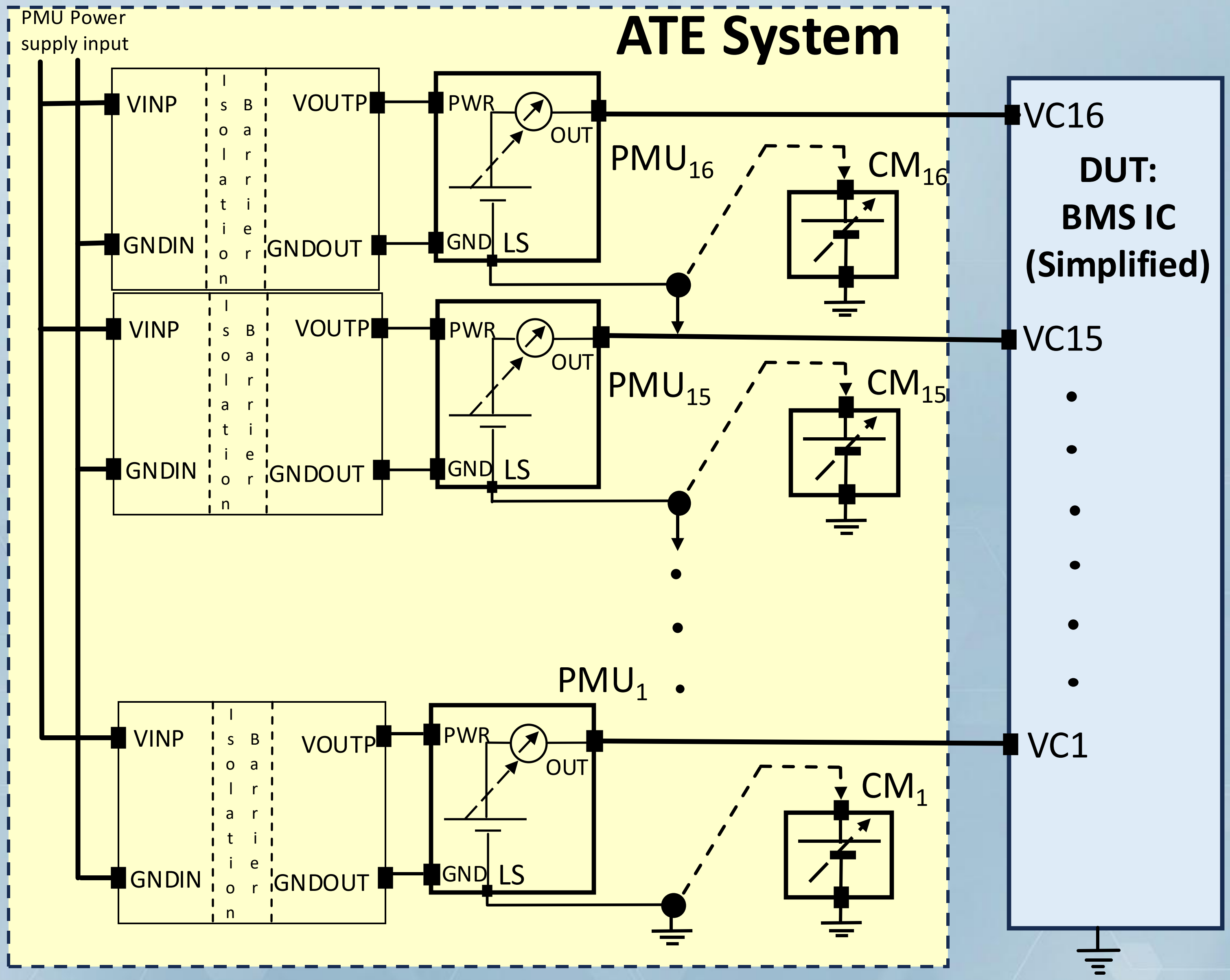
- BMS are key driver of EV safety, reliability and range

- Both current performance and future-trend of BMS critically depends on ATE
  - BMS is only as good as it is ~~designed~~ tested by ATE
  - Yet, BMS-ATE has many challenges

- ElevATE System and PMU-IC solution to BMS-ATE challenges has been presented
  - Configurable and scalable across battery-architecture, EV design, and future-trends

Back-Up

Proposed system solution for BMS-ATE: Reconfigurable stack of PMU



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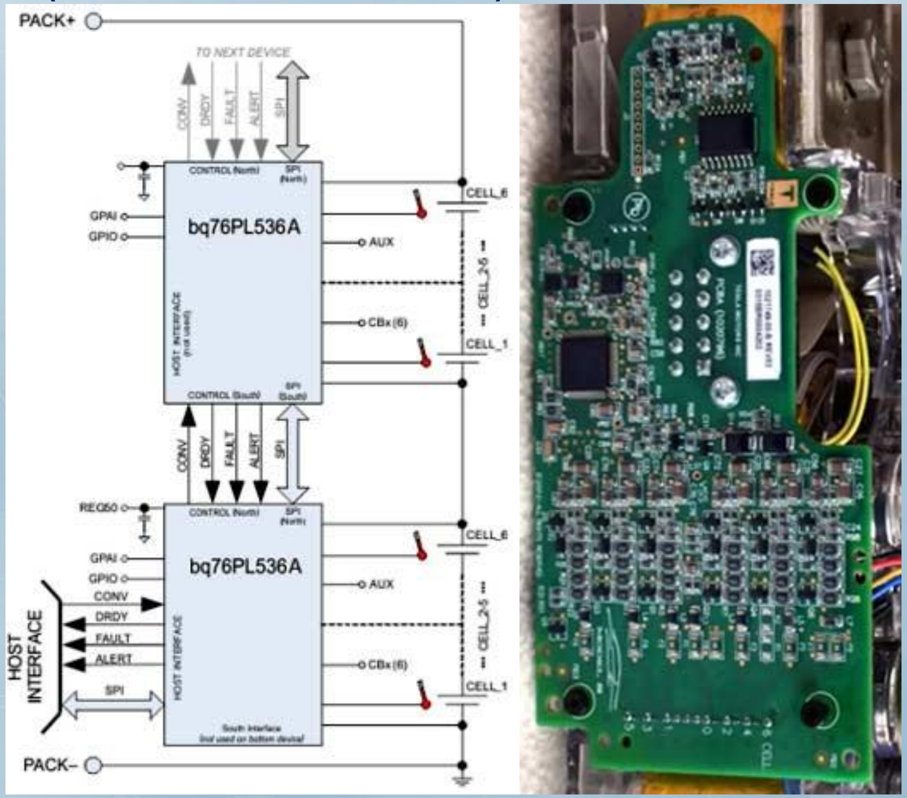
- PMUs' series connection emulates battery module
  - ➢ Thanks to PMU floating ground
- Connection to common-mode power supplies, $CM_{16} – CM_1$, for testing DUT maximum ratings

(Note: Figure shows a simplified system architecture for 16-series-cell BMS ATE)

EV Battery Management System IC

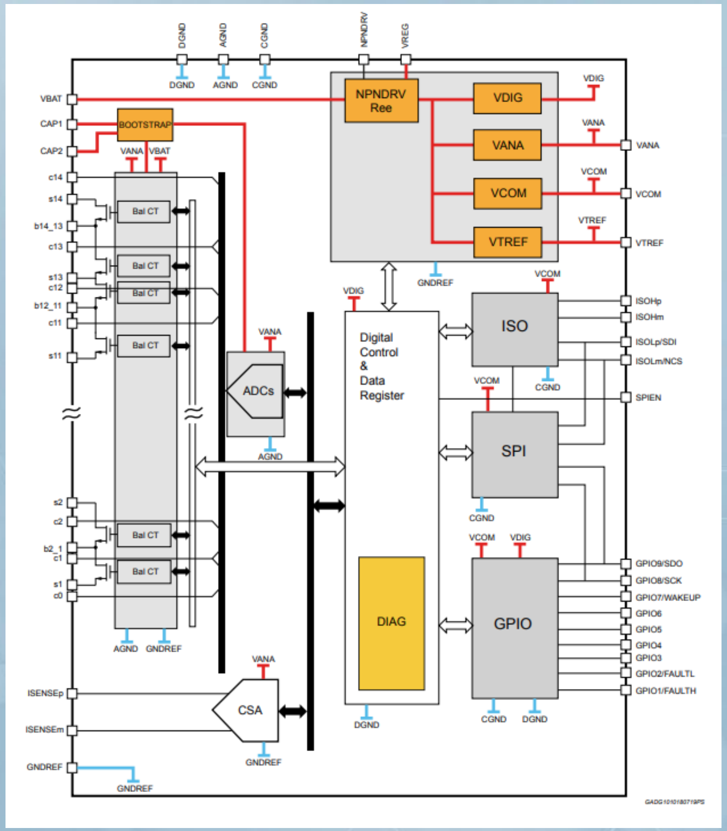
- TI BQ76PL536A

(3-to-6 cell in series)



- ST L9953E

(4-to-14 cells in series)



- ADI ADBMS6830 (up to 16 cells in series)