Texas Instruments

TI POWER

TI *Live!* BATTERY MANAGEMENT SYSTEMS SEMINAR

DAMIAN LEWIS

TI GAUGES: A STEP-BY-STEP GUIDE TO PRODUCTION

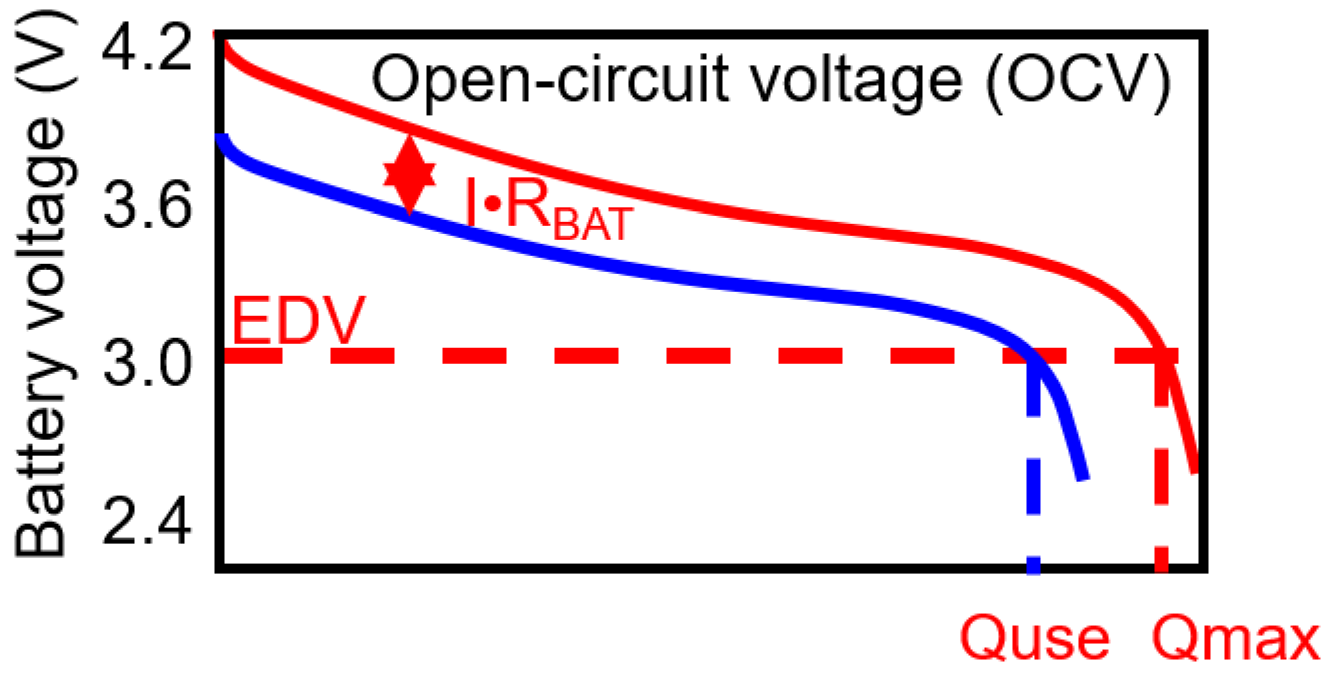
Agenda

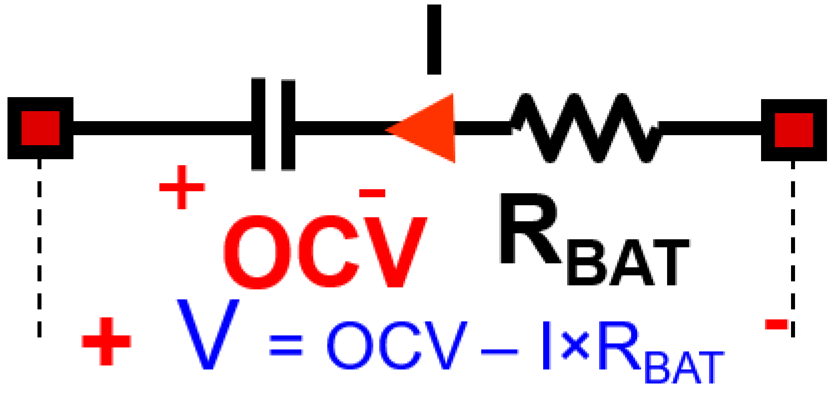
- What is Impedance Track™ technology?
- High-level overview of Impedance Track gauges.
- Voltage and resistance table (ChemID).
- Design process steps:
  1. Identify product requirements and select Impedance Track gauge.
  2. Identify the ChemID.
  3. Program the ChemID and configure the gauge.
  4. Optimize the gauge for low-temperature performance.
  5. Perform a learning cycle.
  6. Extract a golden file.
  7. Calibrate 20 units.
  8. Mass production.
- Conclusion.
- Questions.

What is Impedance Track technology?

- TI's patented algorithm that combines a voltage and resistance look-up table and Coulomb counting for battery gauging.

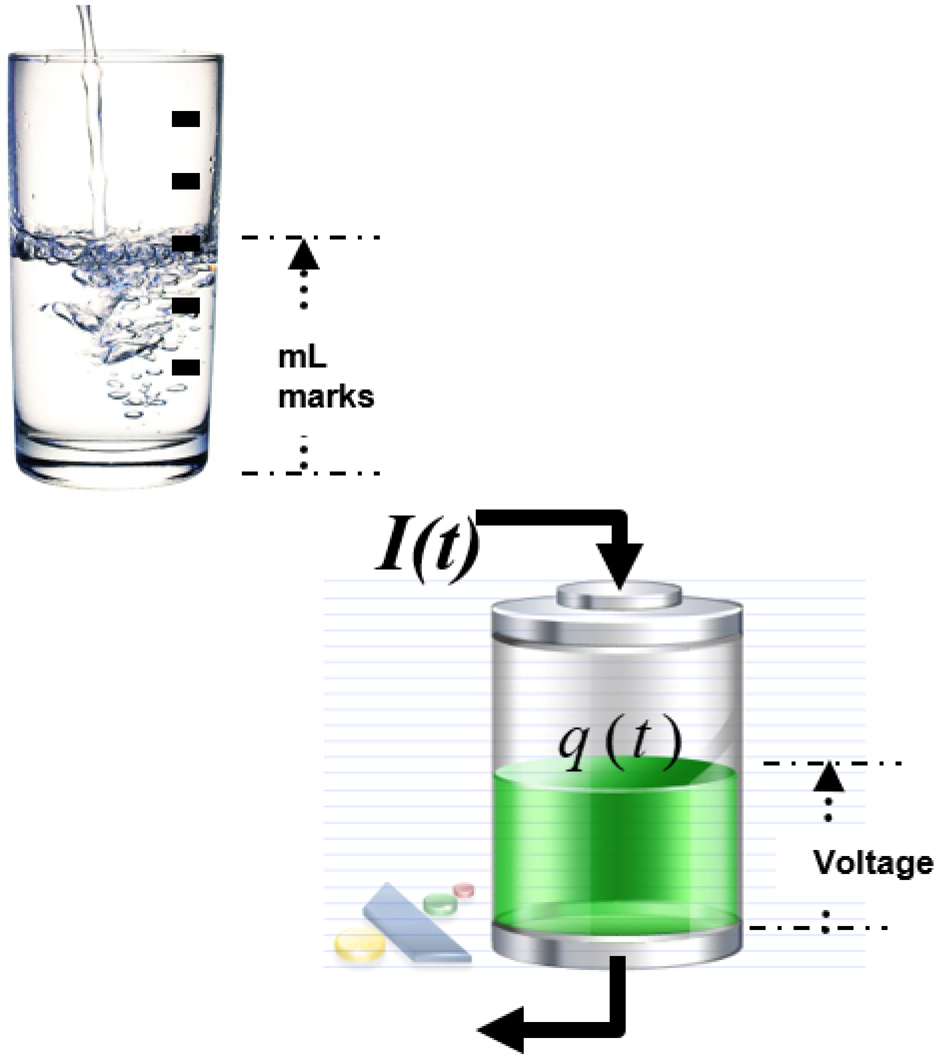
Voltage and resistance look up





Coulomb counting

$$q(t) = \int I$$



High-level overview of Impedance Track technology

1. Chemistry table in data flash:
   OCV = f (DOD)
   DOD = g (OCV)

2. **Impedance learning** during discharge:

$$R = \frac{OCV - V}{I}$$

3. Update maximum chemical capacity for each cell:

   Qmax = PassedCharge/(DOD1 – DOD2)

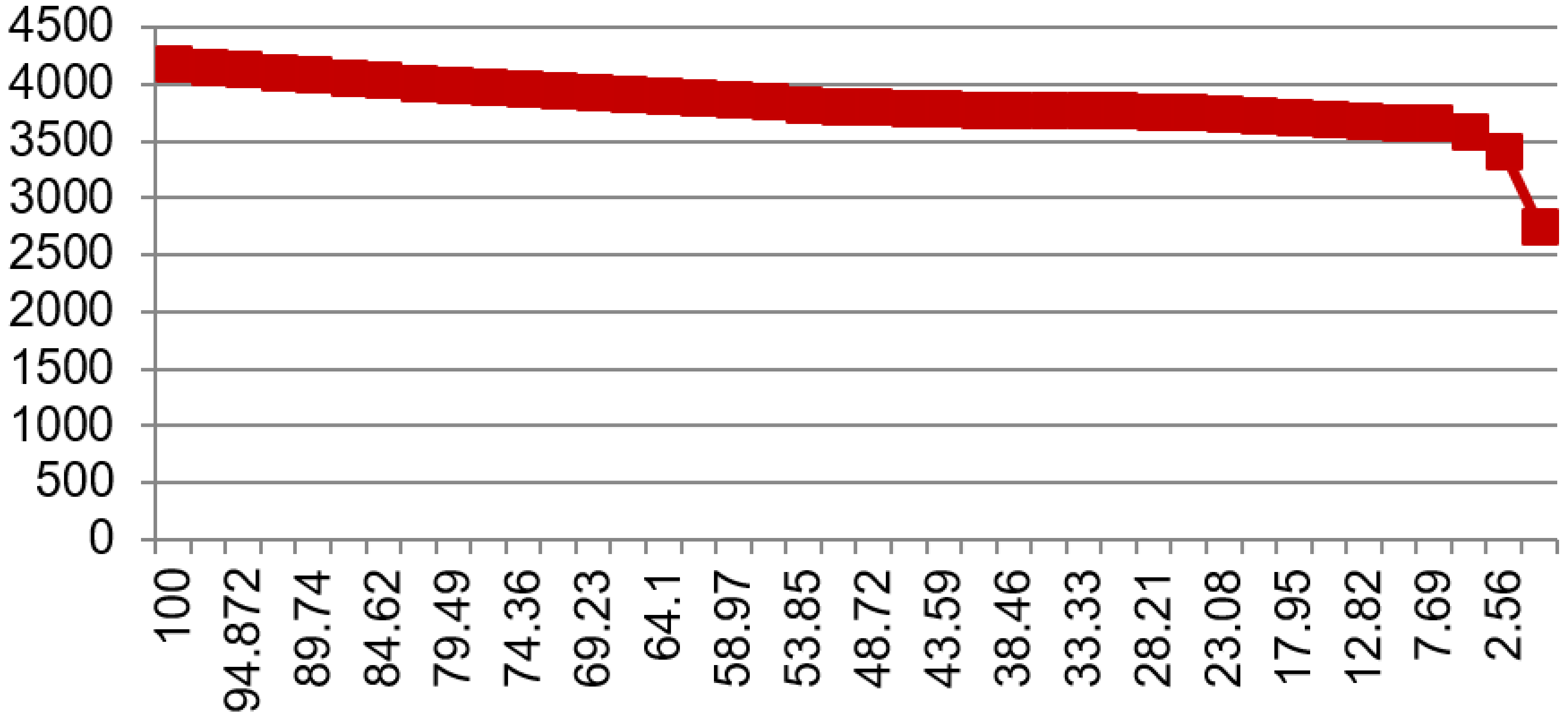
4. Run periodic **simulations** to update predictions of remaining and full capacity.

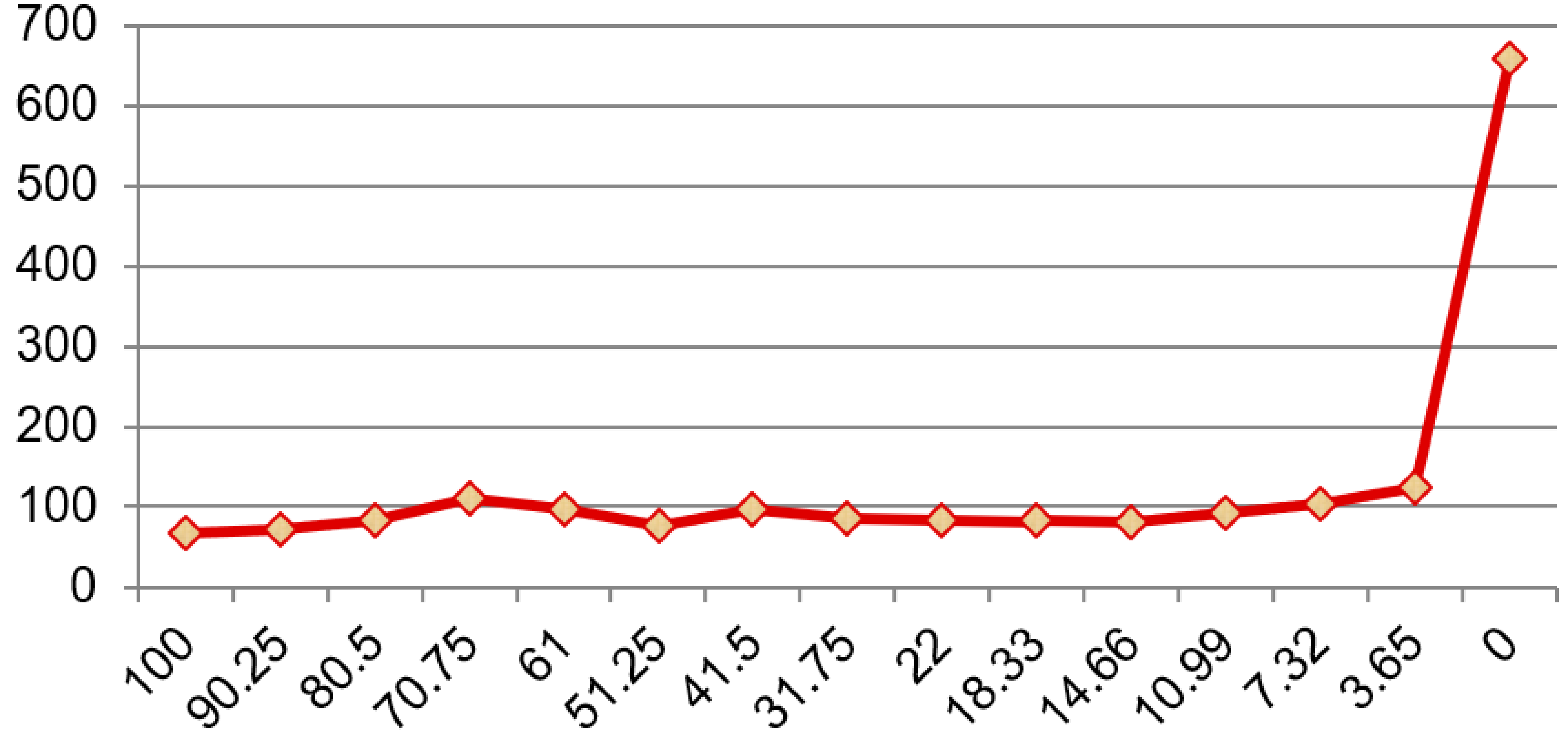
DOD = depth of discharge
DOD (%) = 100% state of charge

State of charge = Remcap/FCC

Voltage and resistance table (ChemID)

- The ChemID consists of the OCV profile of the battery and the resistance tables.
- There are 40 equally spaced OCV grid points and 15 resistance grid points.

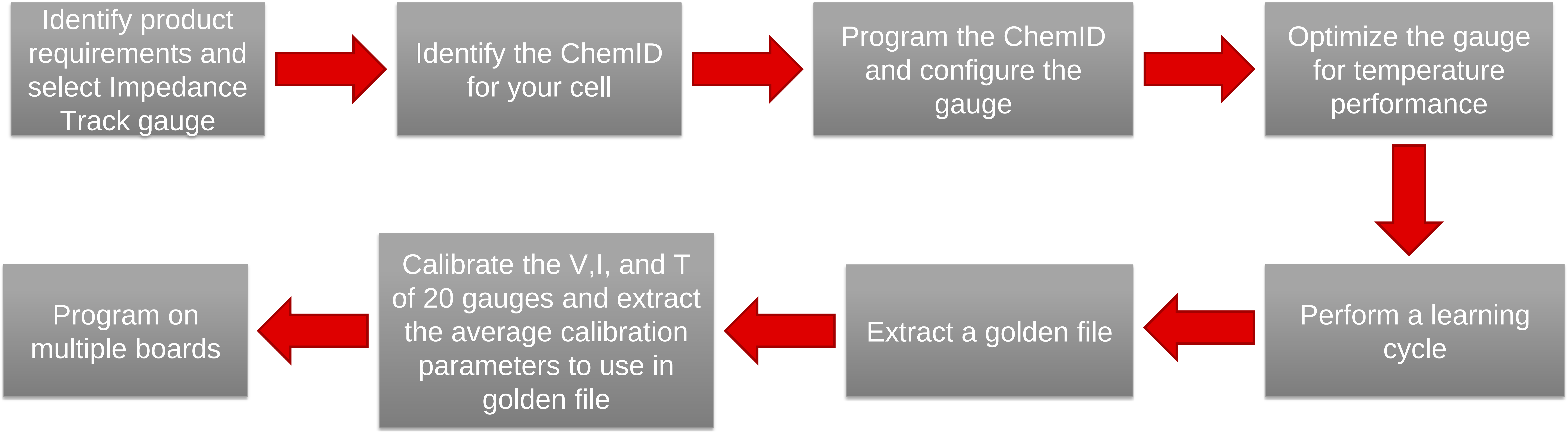




- TI generates a ChemID for most cells.
- The gauging parameter calculator (GPC) GPCCHEM online tool can help determine a close ChemID match for your battery.
- Needs to be programmed in each Impedance Track gauge.
- Used to determine the depth of discharge (DOD) of a relaxed cell.
- Pertinent for high accuracy of the gauge.

Design process

Design process



Step No. 1: Identify product requirements and select the Impedance Track gauge

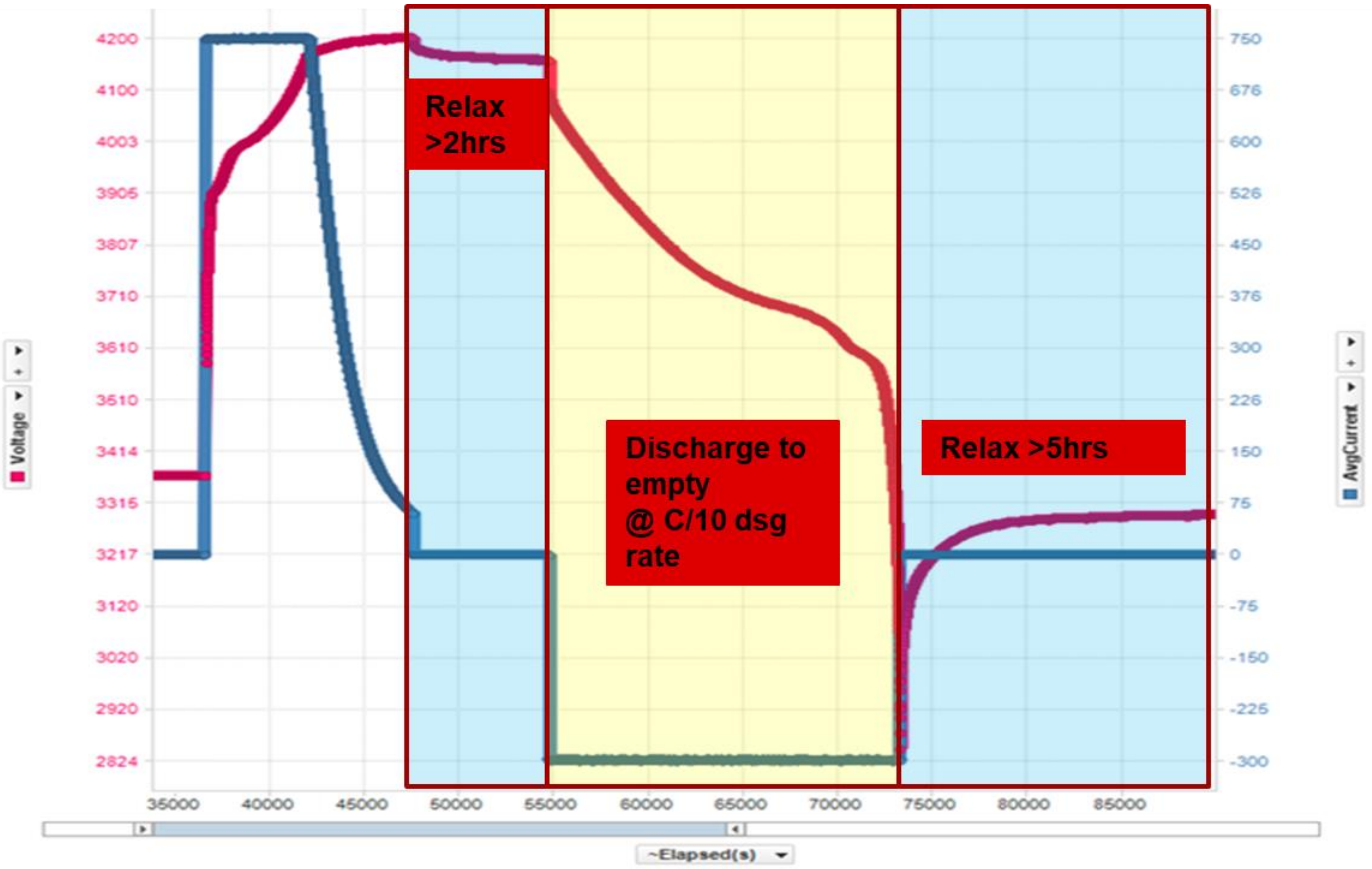
- Number of cells in series.
- Number of cells in parallel.
- Cell balancing.
- Protection.
- Chemistry.
- System or pack side.
- Read-only memory or flash.
- High- or low-side protection field-effect transistors.

Step No. 2: Identify the ChemID

- To ensure high accuracy of Impedance Track gauges, you must program the correct look-up tables (ChemID).
- TI has a large repository of already characterized cells.
- We recommend following the instructions in our GPCCHEM online tool to identify a close-match ChemID for the cell.
- If there is no match, send the cells to TI for characterization.

Step No. 2: Identify the ChemID

- Identify the ChemID of the battery:
  - Perform a relax-discharge-relax test whil logging voltage (V), current (I) and temperature (T) with bqStudio or any other logging tool.
  - Upload results to the GPCCHEM online tool.
  - Program the best ChemID returned on the device using bqStudio.



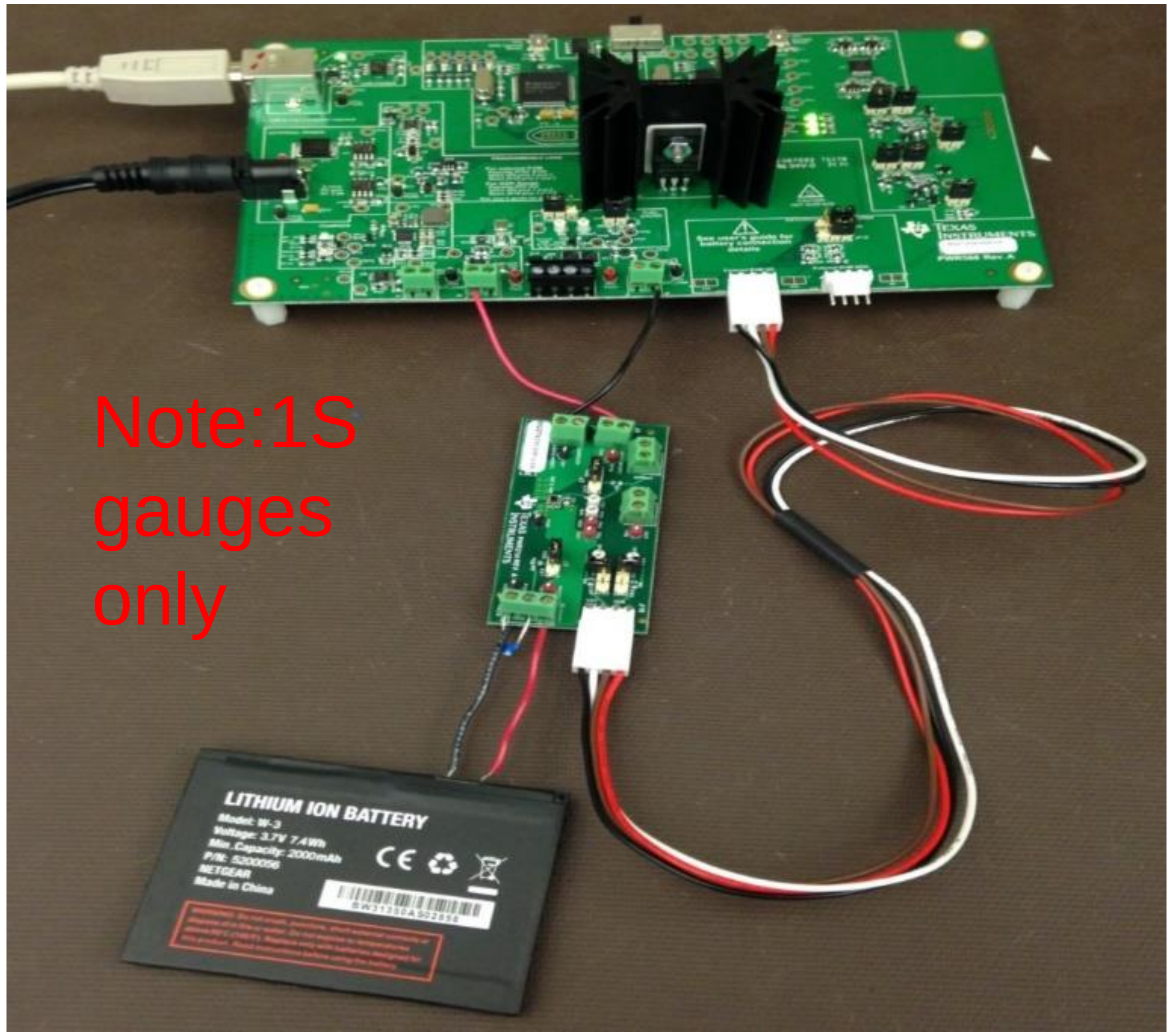
Step No. 2: Identify the ChemID – hardware requirements

- Acquire data files using either one of these systems:
  - A commercial battery cycler such as Arbin or Maccor, as long as you can satisfy a 1-mV voltage measurement accuracy, a 0.1% current measurement accuracy and a ±1°C temperature measurement directly on the cell surface.
  - A power supply or electronic load to perform charging and discharging while logging using any of our calibrated evaluation modules (EVM) plus EV2300 or EV2400, and bqStudio.
  - A power supply or electronic load, logging software as LabView or Python.
  - TI's gauge development kit (GDK).

Step No. 2: Identify the ChemID – hardware requirements (GDK)

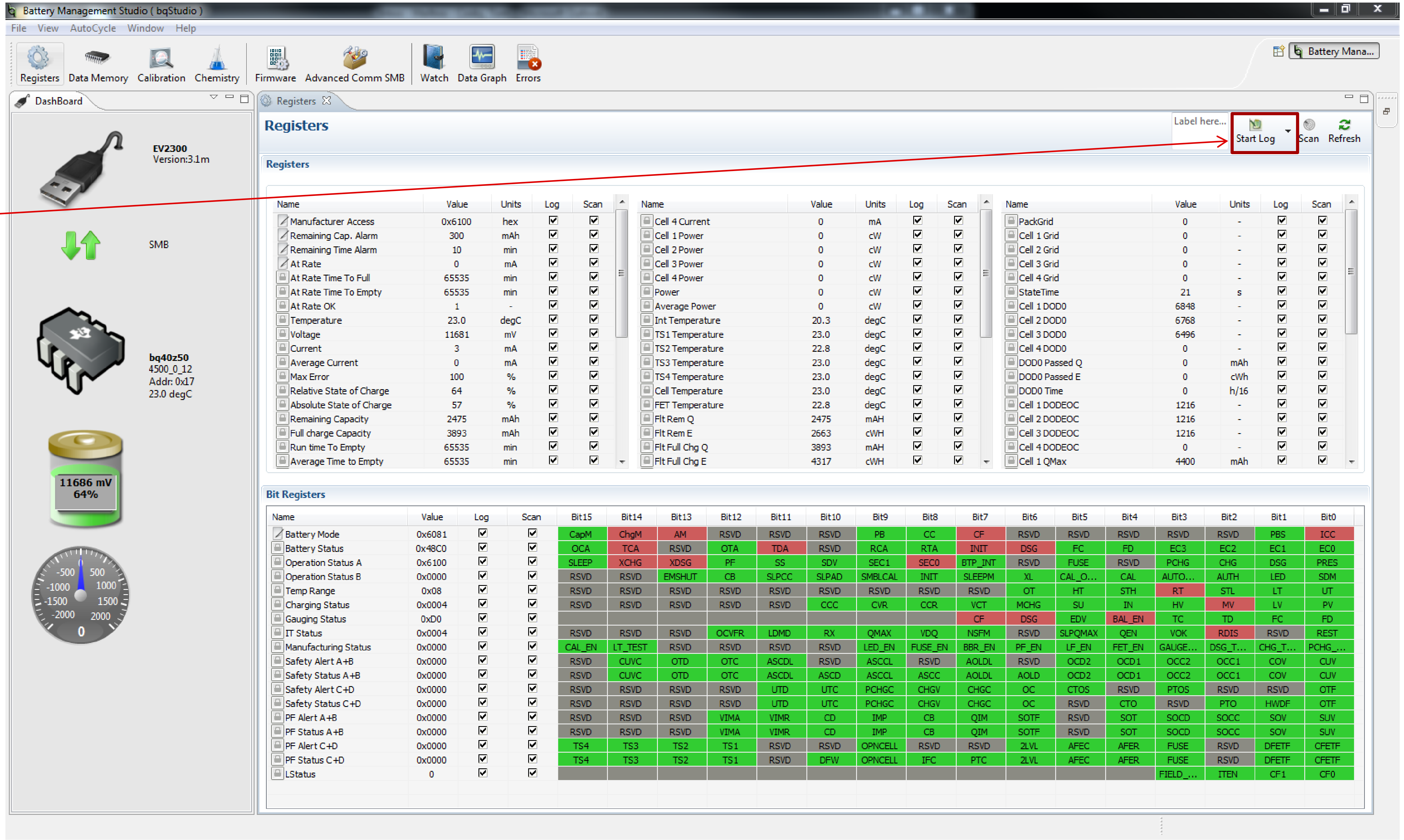
Features

- Automated cycling for 1-series cells with customizable profiles:
  - Pulsed loads.
  - Constant current/power loads.
- Programmable load.
- Programmable charger.
- Onboard fuel gauge (bq27421-G1A).
- External EVM connection to evaluate other I^2C-compatible single-cell fuel gauges.
- Data logging for evaluation of cycling.



Step 2: Identify the ChemID – software requirements (bqStudio)

- bqStudio enables the logging of V, I and T using a TI gauge EVM.



Step No. 2: Identify the ChemID – GPCCHEM

http://www.ti.com/tool/gaugeparcal

Gauging Parameter Calculator

(ACTIVE) GAUGEPARCAL

Description & Features | Technical

Description

GPC variants based on gas gauge types and type of optimization

A. GPC for Compensated End of Discharge Voltage (CEDV) algorithm gas gauges
B. GPC for Impedance Track (IT) algorithm gas gauges
   1. GPC - Find closest chemistry match (chemID selection) Must be done before (2) or (3).
   2. GPC -Optimize room temperature performance (calculate Qmax, Ra, and Thermal coefficients).
   3. GPC - Optimize room and low temperature performance. Includes (2).

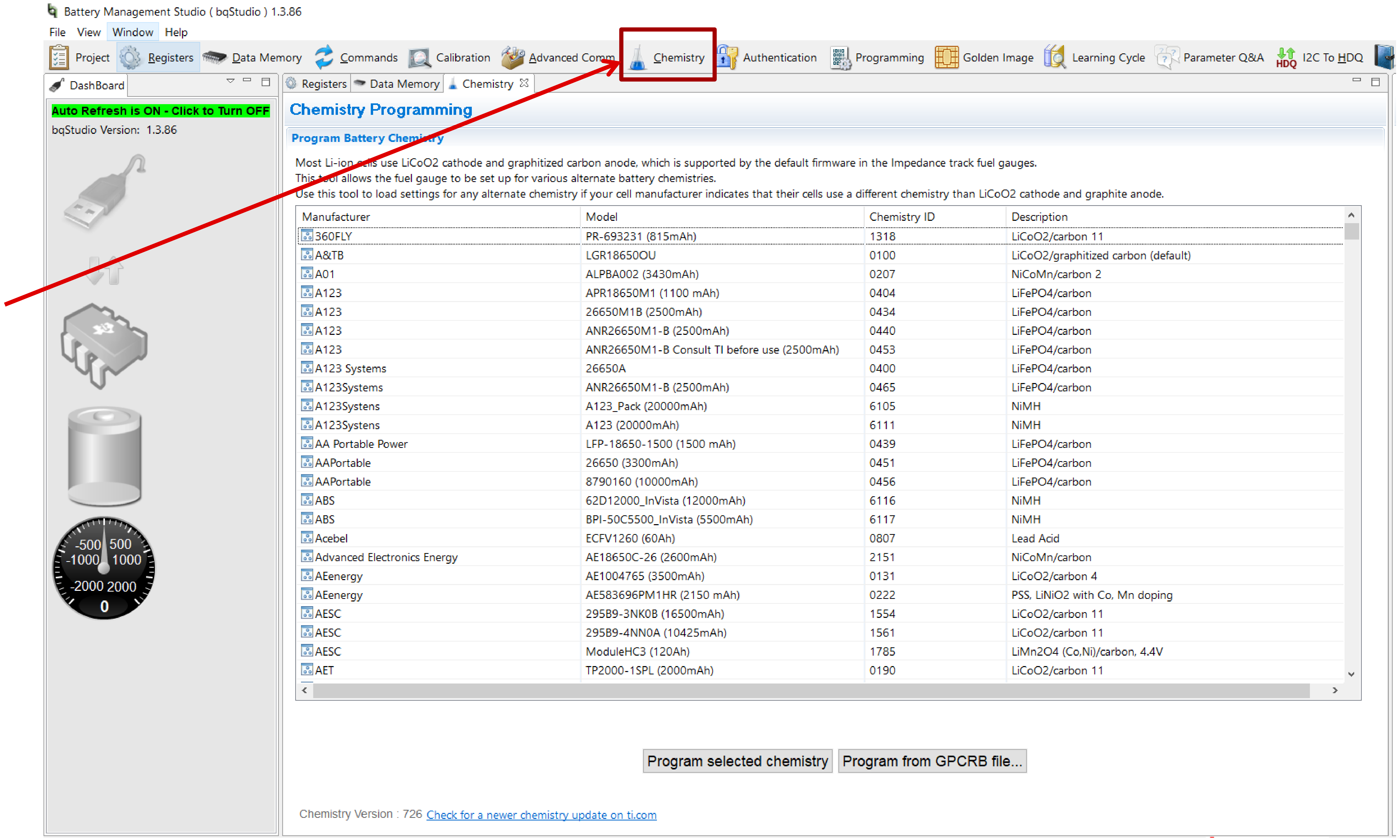
Send
1 room temperature C/10 relaxation / discharge relaxation file
to get ChemID selection by e-mail

Step No. 2: Identify the ChemID – GPCCHEM

- Instruction manual: http://www.ti.com/lit/an/slva725/slva725.pdf.
- Files needed:
  - Configuration setup file → config.txt.
  - Cell data file → roomtemp_rel_dis_rel.csv.

Step No. 3: Program the ChemID and configure the gauge

Programming the ChemID can occur within bqStudio because it contains proprietary data.



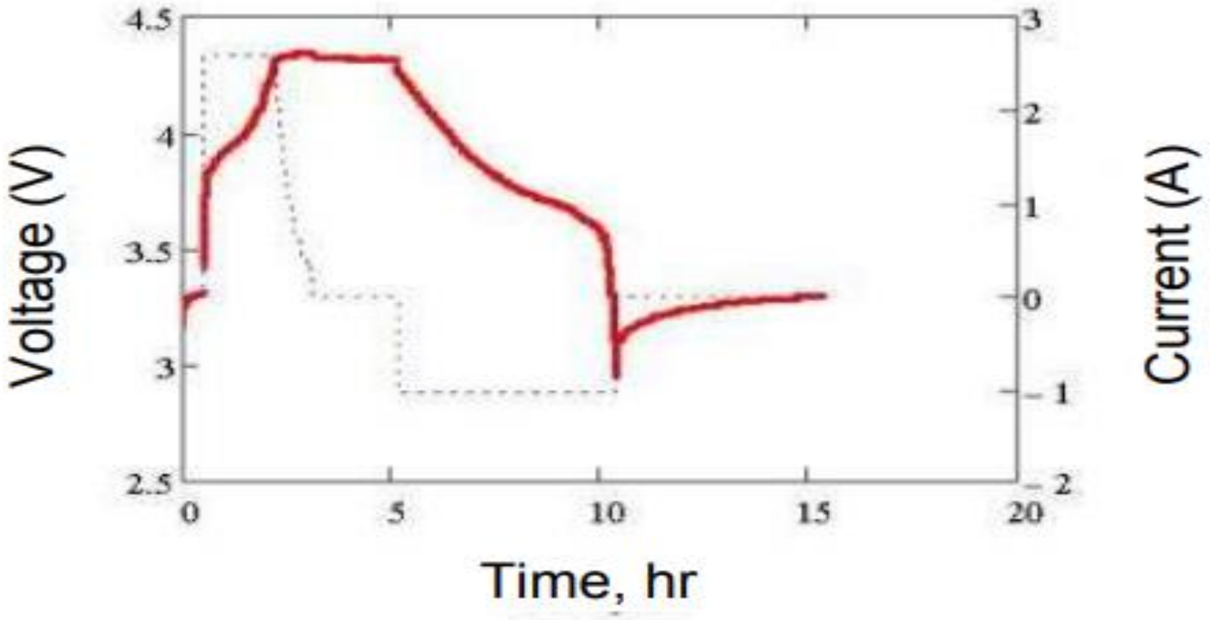
Manufacturer	Model	Chemistry ID	Description
360FLY	PR-693231 (815mAh)	1318	LiCoO2/carbon 11
A&TB	LGR18650OU	0100	LiCoO2/graphitized carbon (default)
A01	ALPBA002 (3430mAh)	0207	NiCoMn/carbon 2
A123	APR18650M1 (1100 mAh)	0404	LiFePO4/carbon
A123	26650M1B (2500mAh)	0434	LiFePO4/carbon
A123	ANR26650M1-B (2500mAh)	0440	LiFePO4/carbon
A123	ANR26650M1-B Consult TI before use (2500mAh)	0453	LiFePO4/carbon
A123 Systems	26650A	0400	LiFePO4/carbon
A123Systems	ANR26650M1-B (2500mAh)	0465	LiFePO4/carbon
A123Systens	A123_Pack (20000mAh)	6105	NiMH
A123Systens	A123 (20000mAh)	6111	NiMH
AA Portable Power	LFP-18650-1500 (1500 mAh)	0439	LiFePO4/carbon
AAPortable	26650 (3300mAh)	0451	LiFePO4/carbon
AAPortable	8790160 (10000mAh)	0456	LiFePO4/carbon
ABS	62D12000_InVista (12000mAh)	6116	NiMH
ABS	BPI-50C5500_InVista (5500mAh)	6117	NiMH
Acebel	ECFV1260 (60Ah)	0807	Lead Acid
Advanced Electronics Energy	AE18650C-26 (2600mAh)	2151	NiCoMn/carbon
AEenergy	AE1004765 (3500mAh)	0131	LiCoO2/carbon 4
AEenergy	AE583696PM1HR (2150 mAh)	0222	PSS, LiNiO2 with Co, Mn doping
AESC	295B9-3NK0B (16500mAh)	1554	LiCoO2/carbon 11
AESC	295B9-4NN0A (10425mAh)	1561	LiCoO2/carbon 11
AESC	ModuleHC3 (120Ah)	1785	LiMn2O4 (Co,Ni)/carbon, 4.4V
AET	TP2000-1SPL (2000mAh)	0190	LiCoO2/carbon 11

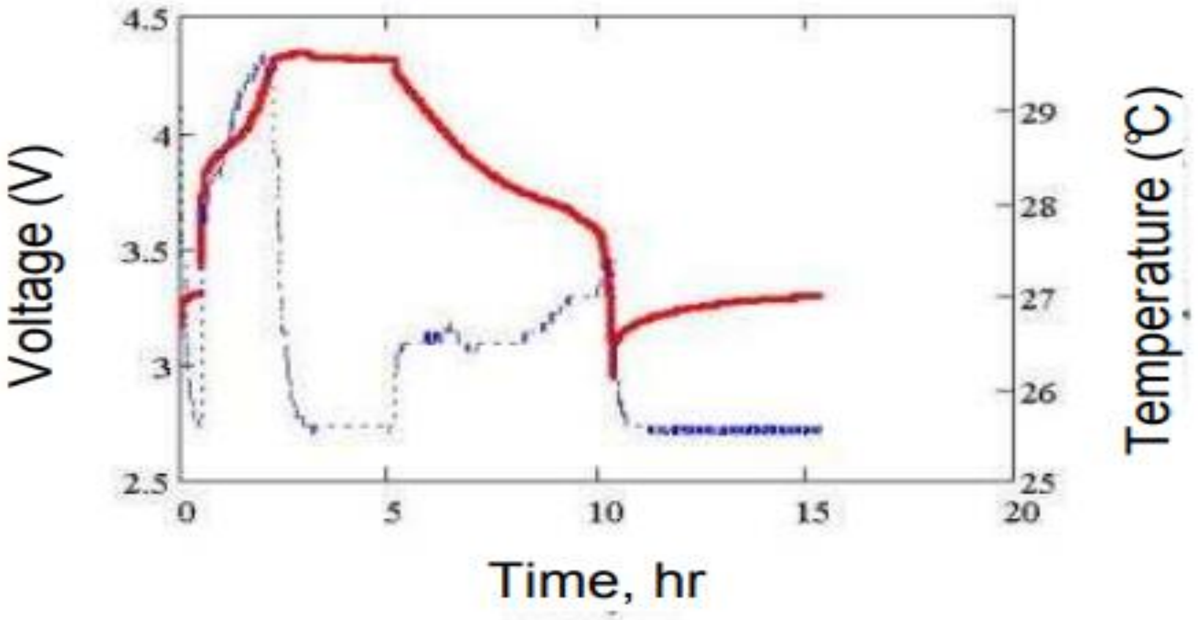
Step No. 3: Program the ChemID and configure the gauge

- Configure the data flash. At minimum, configure the:
  - Taper current: use values between C/10 and C/20.
  - Discharge current threshold: should be less than the taper current.
  - Charge current threshold: should be less than the taper current.
  - Quit current: determines the gauge’s relaxation state. This value should be less than Dsg and Chg current thresholds and typically less than or equal to C/20.
  - Design capacity: the rated nominal capacity of the cell.
  - Design voltage: the rated nominal voltage of the cell.
  - Charge voltage for the different temperature levels.
  - Terminate voltage: the minimum voltage stated in the cell data sheet to which the cell can be discharged.

Step No. 4: Optimize the gauge for low-temperature performance

- Optimize for low-temperature performance using the EVM and GDK (or your own setup for multicell):
  - Run a charge-relax-discharge profile at room temperature while logging using bqStudio.
  - Run a charge-relax-discharge profile at the lowest temperature at which the application is expected to function.
  - Extract a gg file with the default ChemID values (simply program the ChemID and extract a gg file).
  - Submit the room-temperature log file, a cold-temperature log file, a gg file and a config.txt file to the GPCRB online tool.
  - You will receive a gpcreport via email. Program the returned chemdat12 and gg file using bqStudio.





Step No. 4: Optimize the gauge for low-temperature performance (GPCRB)

Gauging Parameter Calculator

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   2. GPC -Optimize room temperature performance (calculate Qmax, Ra, and Thermal coefficients).
   3. GPC - Optimize room and low temperature performance. Includes (2).

Send room temperature and low temperature application rate relax / discharge /relax files with original GG file to get learned GG and optimized Rb chemdat by e-mail

Step No. 4: Optimize the gauge for low-temperature performance (GPCRB)

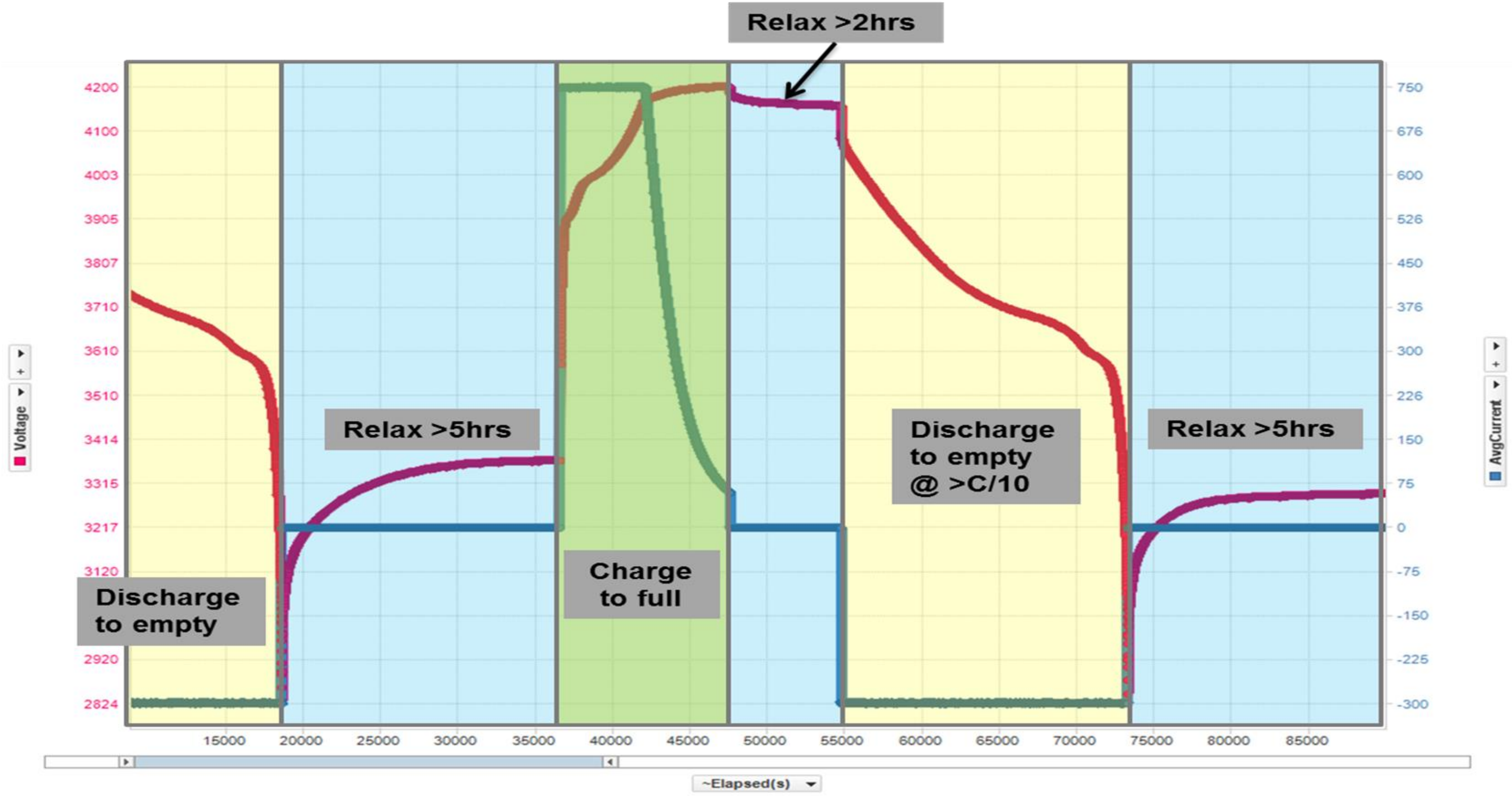
- Instruction manual: http://www.ti.com/lit/ug/sluubd0/sluubd0.pdf.
- Files needed:
  - config.txt.
  - gg.csv.
- Data files:
  - roomtemp.csv.
  - lowtemp.csv.

Step No. 5: Perform a learning cycle

- Cell-to-cell capacity variation can be as much 5%.
- Resistance variation exists among cells of the same type from the same manufacturer.
- A matched ChemID could have a vastly different capacity than the cell being used. GPCCHEM checks for the similarity of the OCV profile.
- The points mentioned above create the need to perform a learning cycle so that the gauge learns the Qmax and resistance tables of the cell.
- The learning cycle involves enabling the algorithm, and then running a discharge-rest-charge-rest-discharge-rest profile.

Step No. 5: Perform a learning cycle

Graphical representation of the learning cycle



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Step No. 5: Perform a learning cycle

- Issue an Impedance Track enable command (0x21). Then issue a reset command (0x41).
- Discharge to empty (terminate voltage) using a constant-current value between C/5 and C/10.
- Rest for 5 hours.
- Charge the battery to full (charge voltage specified in DS of cell) and make sure to taper to a value below the taper current programmed in data flash.
- Rest for 2 hours (Qmax should update at this point). Update status will go from 04 to 05 for pack-side gauges, while for system-side gauges it will go from 00 to 01.
- Discharge to empty using the same discharge rate as before.
- Rest for 5 hours.
- At the end of discharge, update status will change to 06 for pack-side gauges and 02 for system-side gauges.

Step No. 6: Extract a golden file

- On pack-side gauges, change update status to 02. This indicates that Qmax and Ra are learned and lifetime data collection is disabled.
- Change the cycle count to 00.
- Extract a golden file with bqStudio, which could be srec, bqfs or dffs.
  - Most devices support flashstream (bqfs, dffs) formats. Write code to parse the flashstream files to the gauge. A bqfs file contains instructions and dataflash. A dffs file contains just data flash. Use dffs if the programming device has the same firmware.
  - An srec is a standard Motorola file format and contains the instruction flash and data flash. Write code to program the srec on the gauge.

Step No. 7: Calibrate 20 units

- If high-measurement accuracy is not required, calibrate the V, I and T measurement of 20 units.
- Take the averaged calibrated parameters and program on a gauge programmed with the golden file.
- Extract a new golden image. This will be the new image that will be programmed on multiple units.
- If high-measurement accuracy is required, then each board requires calibration after programming the golden file.

Name	Private	Value	Unit
◢ Voltage			
Cell Gain			-
Pack Gain			-
BAT Gain			-
◢ Current			
CC Gain			mOhm
Capacity Gain			mOhm
◢ Current Offset			
CC Offset			-
Coulomb Counter Offset Samples			-
Board Offset			-
Max CC Auto Offset	Private		-
CC Auto Config			hex
CC Auto Offset			-
◢ Temperature			
Internal Temp Offset			°C
External1 Temp Offset			°C
External2 Temp Offset			°C
External3 Temp Offset			°C
External4 Temp Offset			°C
◢ Internal Temp Model			
Int Gain			-
Int base offset			-

Step No. 8: Mass production – single cell

- Most single-cell customers write code to parse the flashstream (bqfs, dffs) file to the gauge from their host.
- Application note with sample code for programming the flashstream file: http://www.ti.com/lit/an/slua801/slua801.pdf.

0542_2_01-bq27542G1.bq.fs - Notepad

File Edit Format View Help

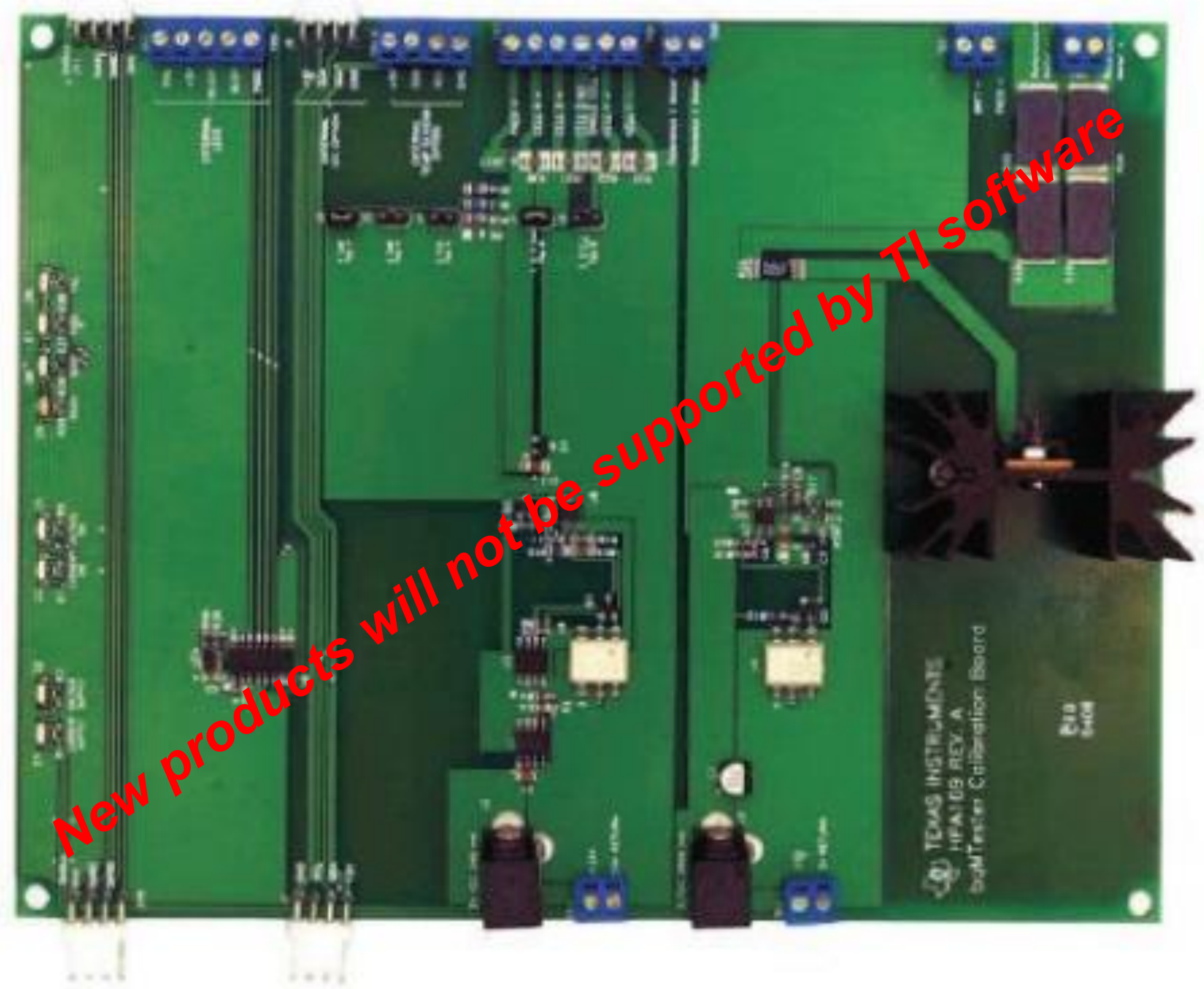
```
;--------------------------------------------------------
;Unseal device
;--------------------------------------------------------
W: AA 00 14 04
W: AA 00 72 36
W: AA 00 FF FF
W: AA 00 FF FF
X: 1000
;--------------------------------------------------------
;Go To ROM Mode
;--------------------------------------------------------
W: AA 00 00 0F
X: 1000
;--------------------------------------------------------
;Data Block
;--------------------------------------------------------
W: 16 00 04 00 00 00 83 DE
W: 16 64 65 01
X: 200
C: 16 66 00
W: 16 00 02 00 00 00 EA FF 33 A0 FA 33 12 FB 33 8C FE 33 D1 FE 33 FF FF 3F FF FF 3F FF FF 3F FF FF 3F FF FF 3F FF FF 3F FF FF 3F FF FF
W: 16 64 D5 35
X: 2
C: 16 66 00
W: 16 00 02 01 00 00 63 A2 0E BD A5 0E 52 A4 0E CA FF 3A FE A1 0E 62 A0 0E FE A3 0E 62 A2 0E CA FF 3A C4 FF 3A D6 FF 33 FF AF 0E 01 4F
W: 16 64 A9 2D
X: 2
C: 16 66 00
W: 16 00 02 02 00 00 DD BC 01 FB 1C 0E AF FF 32 FE A1 0E ED A0 0E 0B AF 18 60 2F 0E 0B CF 02 DF BF 0E 0B CF 02 C1 AB 0E E2 7F 3A BC AF
W: 16 64 D5 2A
X: 2
C: 16 66 00
```

Step No. 8: Mass production – multicell production tools hardware – Advanced BqMTester

- Most customers design their own hardware for mass production **(recommended)**.
- TI developed Advanced bqMTester hardware for programming multiple boards.
- TI provides Advanced bqMTester and bqProduction software **(no new product support)**.

Advanced BqMTester features:

- Programs and calibrates multicell smart battery modules based on these devices: bq306x and bq28xxx, bq40xx, and Impedance Track devices bq20z4x, bq20z6x, bq20z7x, bq20z80, bq20z9x, bq28zxx and bq40zxx.
- Calibrates Coulomb counter offset, voltage, temperature and current.
- Programs serial number, date and pack lot code.
- Works with bqMTester software and bqProduction.
- No support for new features or new TI devices.



Step No. 8: Mass production – multicell production tools hardware – EV2300

- bqProduction and Advanced bqMTester require the EV2300.
- The EV2300 is obsolete.
- MKST-3P-ALT-EV2300 is an EV2300 alternative.
  - Available from third party.
  - Requires additional downloading of software updates from third party.
- Production solutions also available from third parties.

https://www.ti.com/tool/MKST-3P-ALT-EV2300

MKS Technology Inc.

MKST-3P-ALT-EV2300

MKS Technology alternative for EV2300 communications transceiver

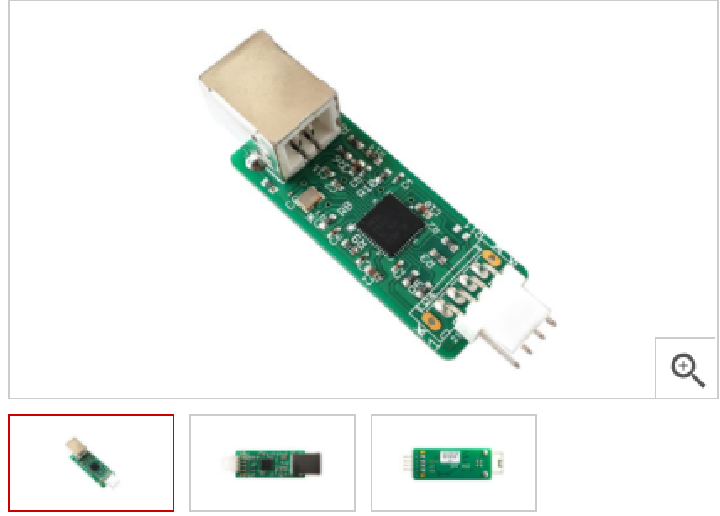
Order now

Overview | Order & start development | Technical documentation | Related design resources | Support & training

Overview

Description & features | Supported products

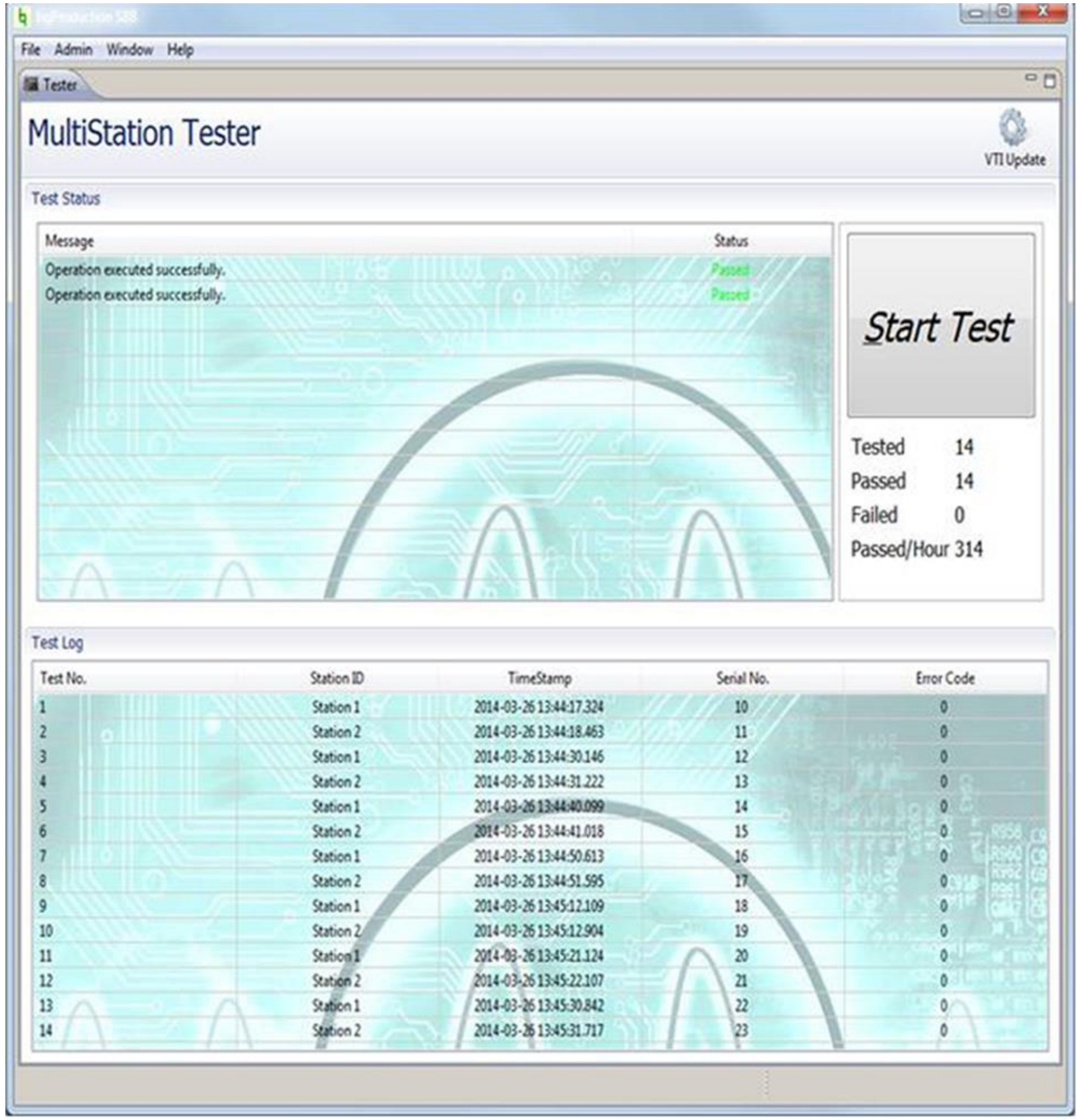
This solution, available from MKS Technology, is an alternative for the EV2300 communications transceiver. The solution from MKS Technology has been validated and works with both the BQMTESTER and ADVANCED-BQMTESTER. It has been validated and works with bq Evaluation software (bqEVSW). Using the MKS Technology transceiver, you can communicate from a PC USB port to I2C, SMBus and HDQ products.



Photos courtesy of MKS Technology Inc

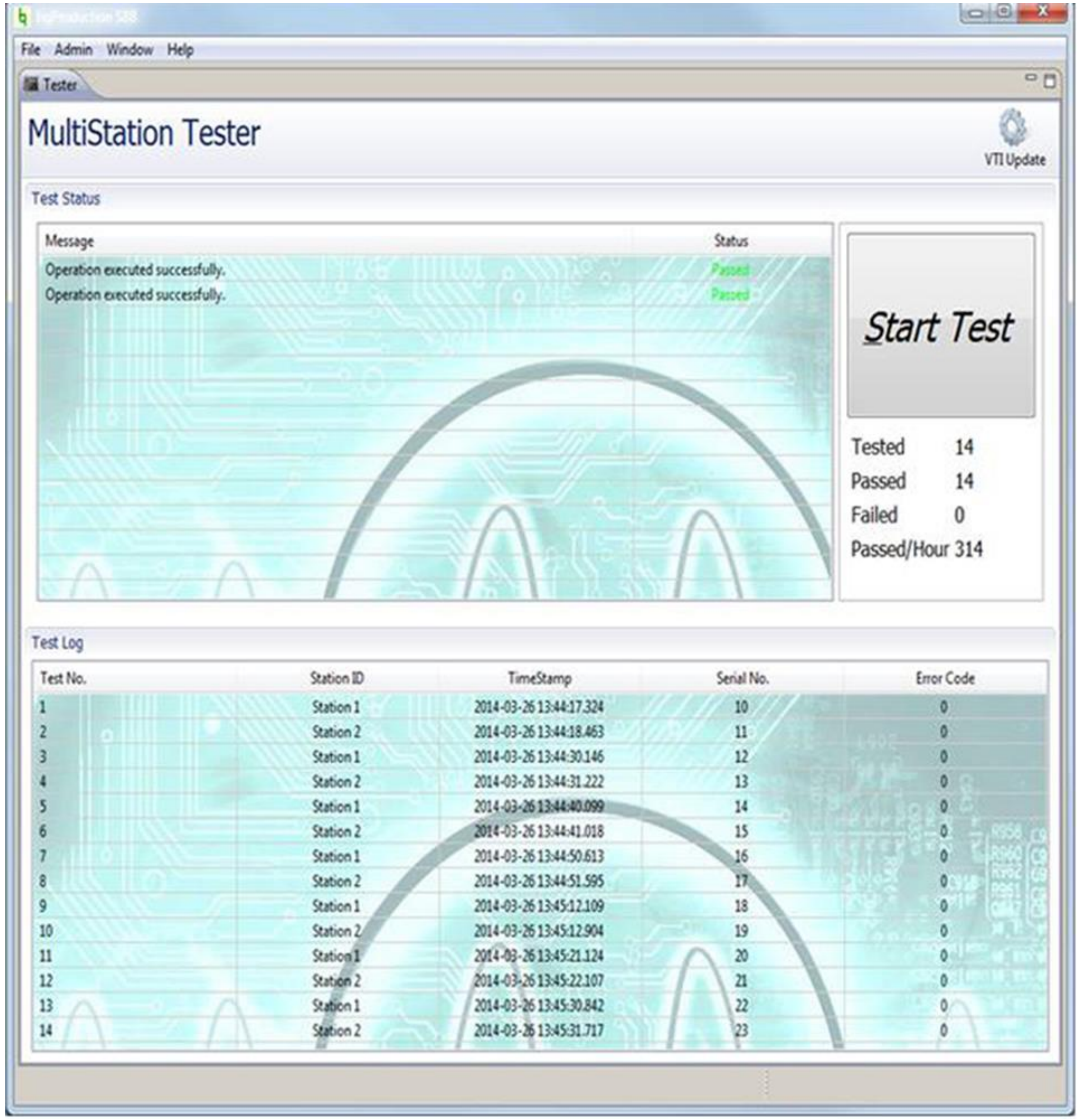
Step No. 8: Mass production – multicell production tools software – bqProduction

- Supports bq28z610 and the bq40zxx family of devices, such as the bq40z60 and bq40z50-r1.
- Works with Advanced bqMTester hardware.
- Control multiple stations from a single graphical user interface.
- Run up to 12 stations in parallel from a single computer.
- Calibration and test automation unique serial number assignment/programming.
- Date of manufacture programming calibration limits filter to detect anomalies.
- Uses industry-standard Motorola srec format golden image programmer.



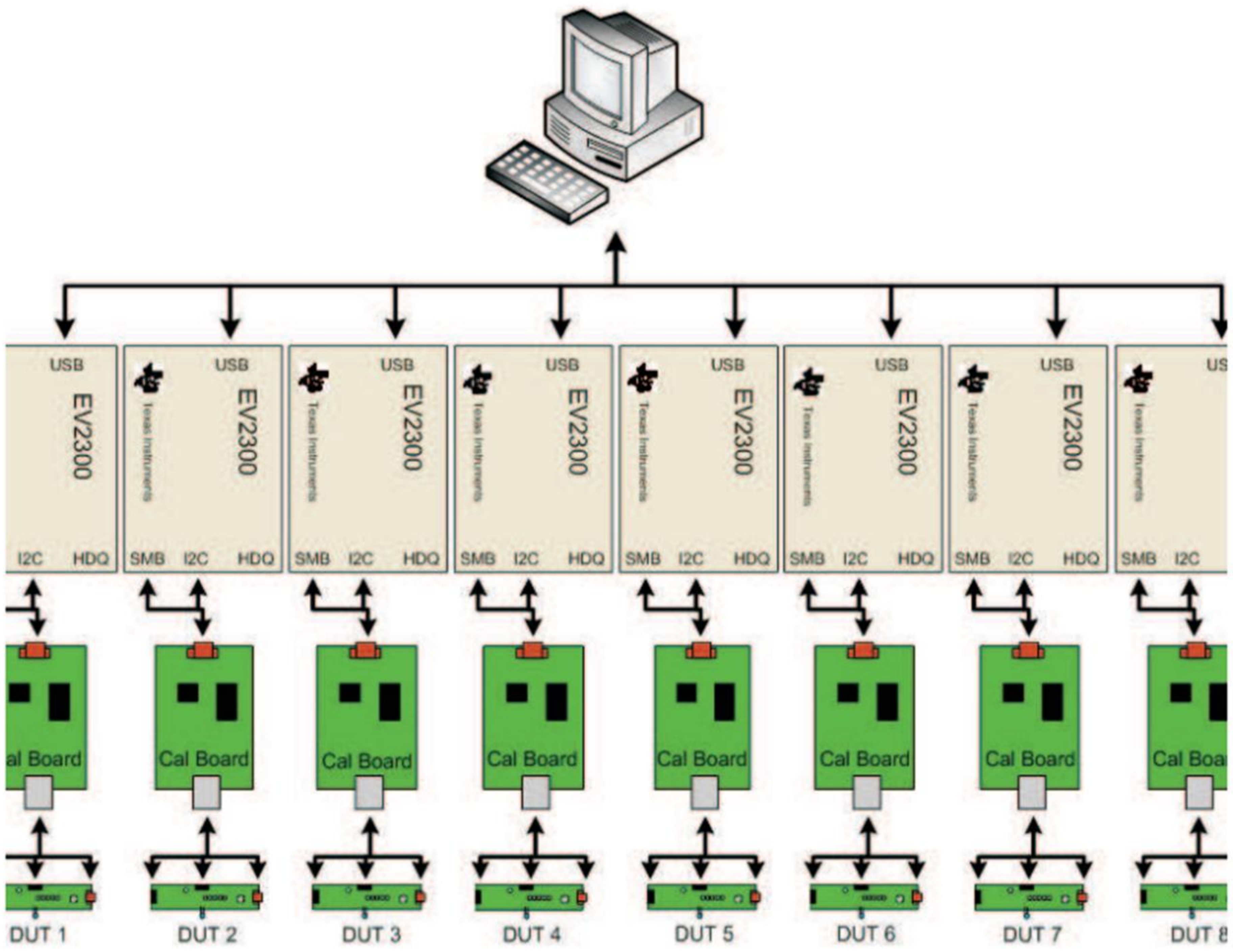
Step No. 8: Mass production – multicell production tools software – Advanced bqMTester

- Supports the bq20zxx, bq30xx and bq30zxx family of devices such as the bq20Z40-R1, bq20Z45-R1, bq3060 and bq30Z554-R1.
- Works with Advanced bqMTester hardware.
- Control multiple stations from a single graphical user interface.
- Run up to 12 stations in parallel from a single computer.
- Calibrates Coulomb counter offset, voltage, temperature and current.
- Programs serial number, date, pack lot code, other defaults obtained from a golden image file.
- Preserves calibration records with its data logging feature.



Step No. 8: Mass production – multicell setup

- bqProduction, bqMTester, and EV2300 can be set up as shown to program multiple units – a maximum of 12 at once.



Conclusion

Conclusion

- **The steps for designing and going to production with an Impedance Track gauge are:**
  - Identify product requirements and select Impedance Track gauge.
  - Identify the ChemID for your cells using the GPCCHEM online tool.
  - Program the ChemID and configure the data flash parameters based on your application.
  - Optimize the gauge for low-temperature performance using GPCRB.
  - Perform a learning cycle.
  - Extract the golden file.
  - Calibrate 20 units; modify the calibration section of the golden file using the averaged calibrated values. Extract a new golden file, **or** –
  - Program each unit with the golden file and calibrate each unit.
  - Use either the srec, bqfs or dffs, through the host or a separate setup, to program each unit.
  - Customers can continue using bqProduction and Advanced bqMTester for mass production with existing production setups, but TI no longer supports customer production tools (evaluation tools only).

Thank you

Questions?