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PM8941 Battery Monitoring System (BMS) Overview

80-NA157-30 A

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U.S.A.

Revision History

Version	Date	Description
A	Aug 2012	Initial release

Contents

Overview

BMS Acronyms and Definitions

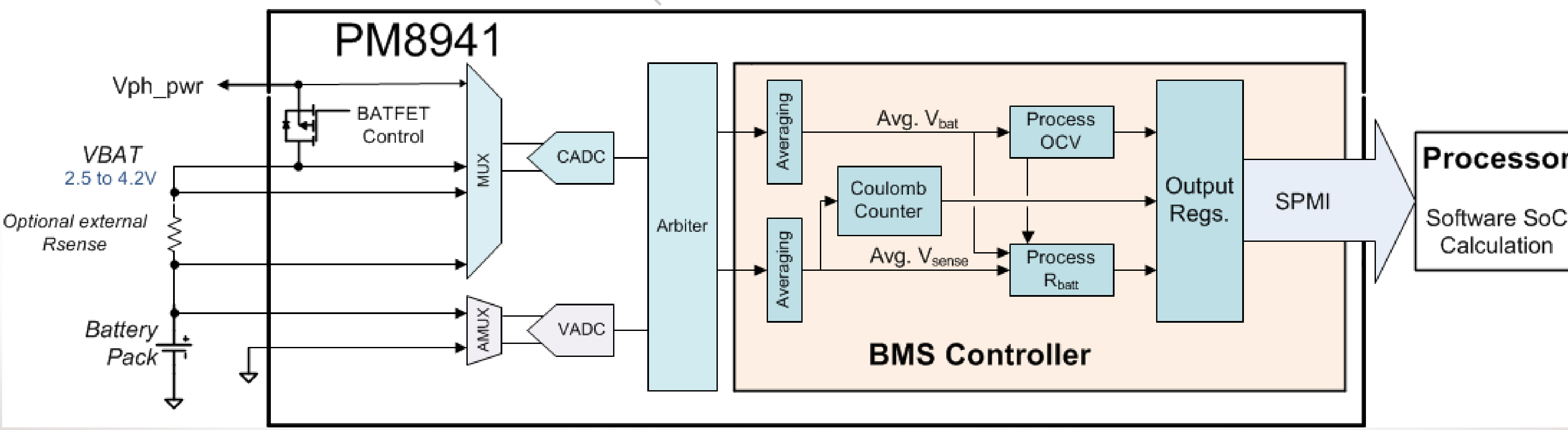
Acronym	Description
BMS	Battery monitoring system – A system that reports SoC
ICC	Intelligent Coulomb counter – The BMS system developed at Qualcomm
FCC	Full-charge capacity – The total amount of charge that can be extracted from a fully charged battery; FCC is defined as the amount that can be extracted from the battery at a discharge current less than 1/20 C; FCC changes with age and cycle life of the battery
RC	Remaining capacity – The amount of charge remaining in the battery at its current state; after a full charge, RC = FCC; like FCC, it is assumed that the discharge current is less than 1/20 C
UUC	Unusable capacity – The battery capacity that cannot be used due to the voltage drop across the battery impedance, reducing the battery voltage below the failure voltage; it is a function of discharging current
UC	Usable capacity – The charge held by a battery after a full charging cycle minus the charge that cannot be used at a given load due to battery impedance, UC=FCC-UUC
RUC	Remaining usable capacity – RC – UUC
SoC	State of charge – RC/FCC; when reported to the end user, it is useful to include UUC: SoC = RUC/UC = (RC - UUC) / (FCC - UUC)
C (rate)	A measurement of the discharge rate at which the battery would be depleted in 1 hour, i.e., a battery rated at 1 Ah provides 1 A for 1 hour, if discharged at 1 C; the same battery discharged at 0.5 C would provide 500 mA for 2 hours
OCV	Open circuit voltage – Battery voltage at steady-state near-zero (generally, less than C/20) current; note that battery voltage takes 5 to 30 min to settle to OCV after a load

PM8941 BMS

- The PM8941 Battery Monitoring System (BMS) builds on the success of the PM8921 BMS design
- PM8941 BMS change summary (relative to PM8921)
  - Internal R_{sense}→Voltage sensed across BATFET
  - BATFET R_{ds} is kept constant
  - Eliminates larger and more expensive component (R_{sense})
  - Option for external R_{sense} is still available
- Master band gap settling time is reduced→Improved power-on Open Circuit Voltage (OCV) measurement
- Selectable hardware- or software-based Coulomb counter reset
- Selectable range for ignoring OCV updates→Flat portion of battery profile
- I_{bat} > threshold interrupt (if system current peaks are large, an interrupt is generated so that HLOS can mitigate the situation)

PM8941 BMS Block Description

- CADC samples V_{sense} generated across BATFET (10 mΩ)→current measurement
- VADC samples V_{bat}→OCV measurement
  - Shared use with other housekeeping functions
- BMS Controller autonomously manages ADCs and key measurements
  - Controls measurement frequency, averaging, Coulomb counting, and CC resets
  - All data for SoC calculations stored, read as desired by software→No periodic software intervention
  - BMS Controller utilizes Qualcomm-proprietary algorithm
- PMIC software reads stored data, executes software algorithms, and calculates SoC

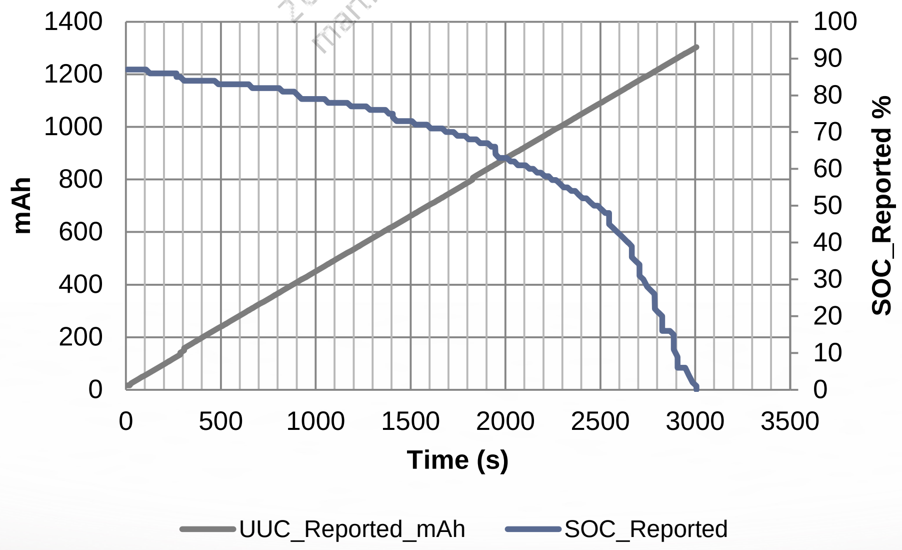


PM8941 BMS – Algorithm Summary

- PM8941 BMS architecture provides flexibility
  - Existing Qualcomm software/algorithms can be used
  - Custom fuel-gauging solutions with unique algorithms can be used
- Software and algorithms are continually being updated
  - New algorithms are being added to meet customer demands
  - Existing software is being optimized as test results dictate

PM8941 BMS – Dynamic UUC Algorithm

- Carriers require 4-hour operating time at -20°C with low current
  - Battery resistance is very high when cold
  - UUC is determined by battery resistance and peak system current
  - UUC can be so large that battery reads 0% SoC for fully charged battery
  - A solution is needed to maintain 4-hour operation
- A software algorithm was created to change from fixed to dynamic UUC
  - When SoC is high→UUC is based on average current draw
  - When SoC is low→UUC is based on peak system current setting



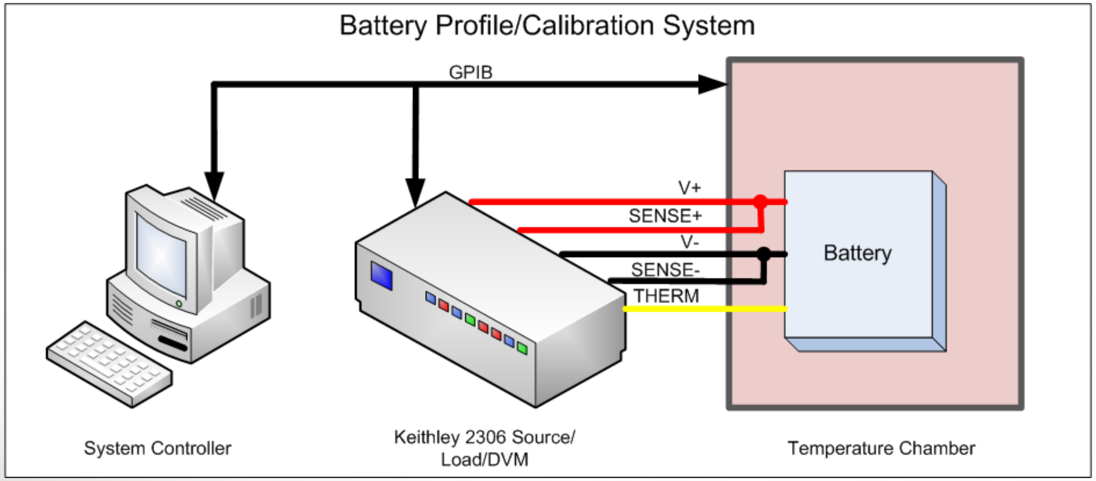
CC and VADC Specs

Spec	Condition	Min	Typ	Max
CCADC accuracy	Using internal BATFET			
	1 A	-3%	2%	3%
	100 mA	-5%	3%	5%
	Using external R_{sense}			
	1 A	-2%	1%	2%
	100 mA	-4%	2%	4%
VADC accuracy	Using new trim method (V_{bat} channel only), over temperature	-0.2%	0.1%	0.2%
Current consumption	CC and ADC active (does not include BATFET control bias current)			
	Average state 1 (low)		13 µA	
	Average state 2 (high)		700 µA	

Battery Characterization

Battery Calibration Tool

- Qualcomm provides the battery data-collection tool
  - Automate data collection
  - Generate data tables
  - Load data tables
- Uses Keithley 2306/2420 or Agilent N6705 as battery source/load
- The tool can scale data collection to meet customer needs
  - Higher discharge current (faster run time, poorer data)
  - Skip charge-cycle aging, if desired
  - Skip temperature compensation, if desired



Battery Calibration Tool (cont.)

Example table

		Temperature (ºC)										Charge cycles – Aging scale factor				
		-30	**-20**	**-10**	**0**	**10**	**25**	**40**	**60**			**100**	**200**	**300**	**400**	**500**
FCC		730	780	850	880	940	1000	1020	1040	FCC scale factor		0.9	0.84	0.81	0.78	0.74
OCV @ percent charge	100	3.65	3.79	3.92	4.00	4.08	4.14	4.15	4.15	OCV scale factor @ percent charge	100	0.99	0.95	0.92	0.88	0.87
	95	3.58	3.68	3.84	3.93	4.00	4.07	4.08	4.08		95	0.99	0.95	0.92	0.88	0.87
	90	3.53	3.59	3.78	3.87	3.95	4.02	4.02	4.02		90	0.99	0.95	0.92	0.88	0.87
	85	3.48	3.53	3.70	3.82	3.89	3.96	3.97	3.98		85	0.99	0.95	0.92	0.88	0.87
	80	3.42	3.49	3.65	3.78	3.85	3.91	3.92	3.92		80	0.99	0.95	0.92	0.88	0.87
	75	3.37	3.44	3.57	3.72	3.80	3.86	3.86	3.87		75	0.99	0.95	0.92	0.88	0.87
	70	3.35	3.41	3.54	3.68	3.75	3.81	3.81	3.82		70	0.99	0.95	0.92	0.88	0.87
	65	3.33	3.39	3.50	3.64	3.71	3.76	3.76	3.76		65	0.99	0.95	0.92	0.88	0.87
	60	3.31	3.36	3.47	3.60	3.66	3.71	3.70	3.71		60	0.99	0.95	0.92	0.88	0.87
	55	3.29	3.34	3.43	3.56	3.62	3.66	3.65	3.66		55	0.99	0.95	0.92	0.88	0.87
	50	3.27	3.31	3.40	3.52	3.57	3.61	3.60	3.61		50	0.99	0.95	0.92	0.88	0.87
	45	3.25	3.28	3.37	3.48	3.52	3.56	3.55	3.55		45	0.99	0.95	0.92	0.88	0.87
	40	3.23	3.26	3.33	3.44	3.48	3.51	3.50	3.50		40	0.99	0.95	0.92	0.88	0.87
	35	3.21	3.23	3.30	3.40	3.43	3.46	3.44	3.45		35	0.99	0.95	0.92	0.88	0.87
	30	3.19	3.21	3.26	3.36	3.39	3.41	3.39	3.39		30	0.99	0.95	0.92	0.88	0.87
	25	3.17	3.18	3.23	3.32	3.34	3.36	3.34	3.34		25	0.99	0.95	0.92	0.88	0.87
	20	3.15	3.15	3.20	3.28	3.29	3.31	3.29	3.29		20	0.99	0.95	0.92	0.88	0.87
	15	3.13	3.13	3.16	3.24	3.25	3.26	3.24	3.23		15	0.99	0.95	0.92	0.88	0.87
	10	3.11	3.10	3.13	3.20	3.20	3.21	3.18	3.18		10	0.99	0.95	0.92	0.88	0.87
	9	3.10	3.09	3.11	3.19	3.19	3.19	3.17	3.16		9	0.99	0.95	0.92	0.88	0.87
	8	3.09	3.08	3.10	3.17	3.17	3.18	3.15	3.15		8	0.99	0.95	0.92	0.88	0.87
	7	3.07	3.07	3.09	3.16	3.15	3.16	3.13	3.13		7	0.99	0.95	0.92	0.88	0.87
	6	3.06	3.06	3.07	3.14	3.14	3.14	3.12	3.11		6	0.99	0.95	0.92	0.88	0.87
	5	3.05	3.05	3.06	3.13	3.12	3.13	3.10	3.09		5	0.99	0.95	0.92	0.88	0.87
	4	3.04	3.04	3.04	3.11	3.11	3.11	3.08	3.07		4	0.99	0.95	0.92	0.88	0.87
	3	3.03	3.03	3.03	3.10	3.09	3.09	3.07	3.06		3	0.99	0.95	0.92	0.88	0.87
	2	3.01	3.01	3.02	3.08	3.07	3.08	3.05	3.04		2	0.99	0.95	0.92	0.88	0.87
	1	3.00	3.00	3.00	3.07	3.06	3.06	3.03	3.02		1	0.99	0.95	0.92	0.88	0.87
	0	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00		0	0.99	0.95	0.92	0.88	0.87

Battery Current Limiting

Battery Droops

- The combination of battery chemical and electrical resistances can exceed 250 mΩ.
- High-current use case combinations can exceed 4 A at V_{bat}.
  - 2 A – GSM Tx burst
  - 2 A – Camera flash
  - >2 A – Kraits
  - 1 A – GPU
- 4 A and 250 mΩ results in a 1 V V_{bat} droop.
- Some sort of battery current limiting will need to be implemented in a combination of hardware and software.

Battery Hardware/Software Automatic V_{dip} Mitigation Tools

Module	Function	ASIC	Attack time
WLED boost	Reduces current when VDD droops	PM8941	20 µs
Camera flash	Clips current when VDD or V_{bat}/V_{chg} droops	PM8941	20 µs
Camera flash	Clips current when PA_ON is true (GSM Tx burst)	PM8941	<0 µs
Far field speaker amp	Clips speaker audio peaks when V_{bat} droops	WCD9320 (codec)	20 µs
WAN Tx	Software should close this loop with the BATALARM interrupt		
WiFi Tx PA	Software		

Battery System Measurement Tools

Measurement	Polled/ Interrupt	Comment	Source	Linux Android Software API	PM8921 (A-class)	PM8941 (B-class)
SoC	Polled	Value updated when BMS is polled	BMS driver	int pm8921_bms_get_percent_charge(void);	In 1% resolution	
Battery temperature	Polled		ADC driver	pm8921_adc_read(CHANNEL_BATT_THERM, struct pm8921_adc_chan_result *result)		
V_{bat} slow sync to GSM	Polled:	V_{bat} min measured over 400 µs GSM Tx burst; HK_ADC	ADC driver	The feature for conversion sequencer is for the MP and not supported on apps processor.	▪ 20 mV accuracy ▪ 400 µs measurement	▪ 20 mV accuracy ▪ 400 µs measurement
V_{bat} slow async	Polled	V_{bat} measured when software requests	ADC driver	pm8921_adc_read(CHANNEL_VBAT, struct pm8921_adc_chan_result *result);	▪ 20 mV accuracy ▪ 400 µs measurement	▪ 20 mV accuracy ▪ 400 µs measurement
V_{bat} alarm	Interrupt	Analog thresholds	Hardware comparator		▪ Alarm ▪ 50 mV accuracy, 100 mV steps ▪ ~instant	▪ 2x alarm ▪ 50 mV accuracy, 100 mV steps ▪ ~instant
I_{bat}	Polled	BMS updates measurement every 1 ms	BMS driver	int pm8921_bms_get_battery_current(int *result);	▪ 5 mA accuracy ▪ 1 ms	▪ 10 mA accuracy ▪ 1 ms
I_{bat}	Interrupt	BMS updates measurement every 1 ms	BMS			▪ 10 mA accuracy ▪ 1 ms
Battery resistance	Polled	BMS updates this value in hardware state machine when conditions permit	BMS driver	adb shell /sys/module/pm8921_bms/parameters/last_rbatt	▪ 20 mΩ accuracy ▪ 1 ms	▪ 20 mΩ accuracy ▪ 1 ms

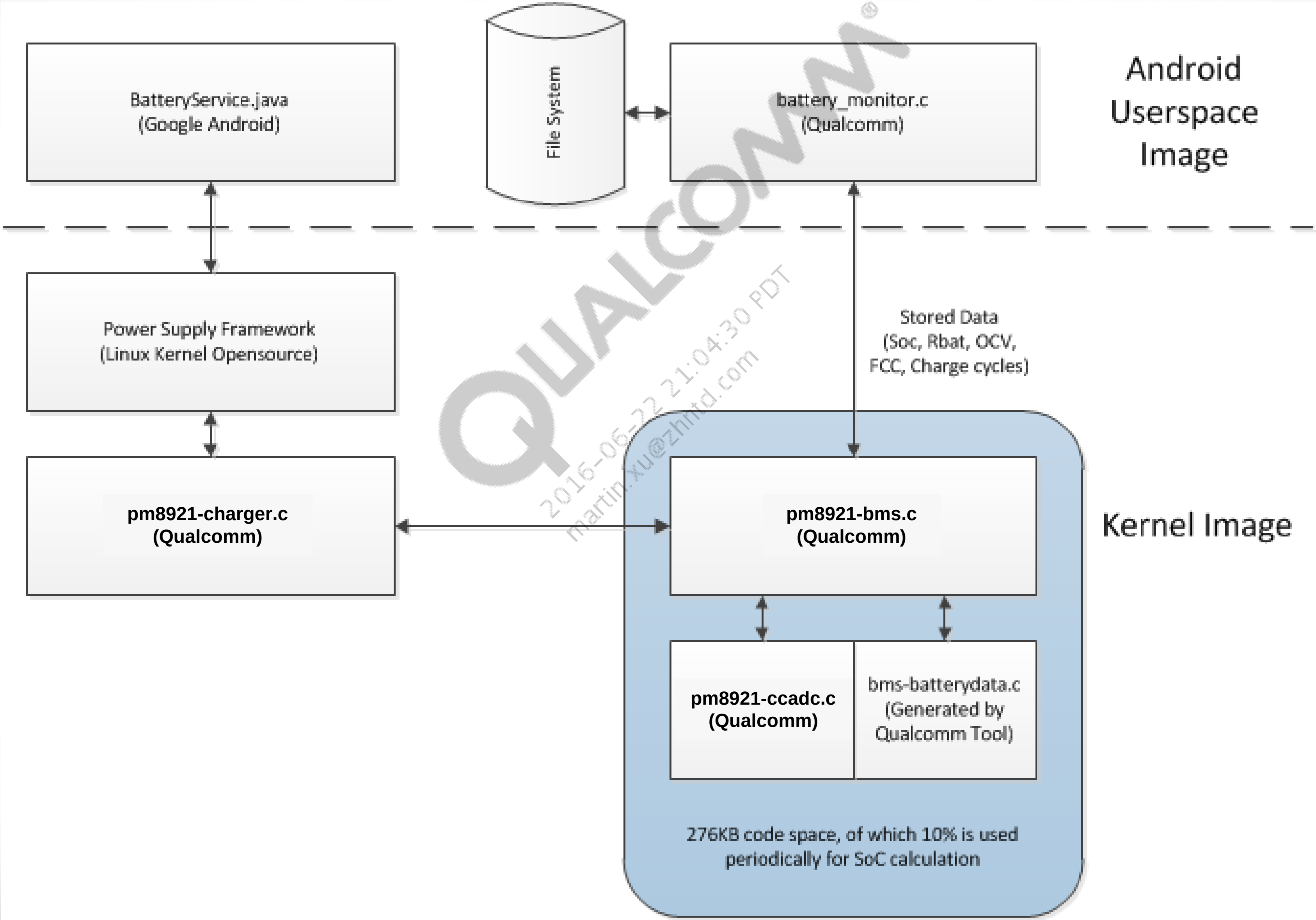
PM8941 BMS – SoC Error Correction Algorithm

- Compensates for system errors
  - Battery not matching stored battery profile
  - Power-on OCV in flat portion of battery curve
  - Coulomb counter error
- Software creates estimated SoC and compares to actual SoC
  - Simultaneous battery voltage and current readings are taken
  - OCV estimate is generated from readings
  - OCV estimate is turned into SoC estimate
  - Estimated SoC is compared to actual SoC to create SoC delta
  - Correction reduces delta→Weighted to reduce faster at low SoC

SoC start (%)	Software est OCV stop (V)	Meas OCV stop (V)	OCV stop error (mV)	Starting SoC error (%)	Ending SoC error (%)
99	3.593	3.572	-28	0.01	0.49
77	3.587	3.528	-72	0.45	0.10
48	3.571	3.540	-60	7.02	-0.29
32	3.567	3.591	-9	8.89	-0.24

BMS Software Architecture

PM8921/PM8941 BMS Linux Android Software Architecture



Application Processor Software

- Role of software
  - Calculate SoC using raw data from BMS controller
    - Execute SoC calculation when polled by host
      or
    - Periodically calculate SoC and notify host at specified SoC thresholds
  - Perform temperature corrections based on V_{therm} data
  - Store and use battery-specific data
    - OCV vs SoC curve
    - Temperature coefficients
    - Programmed BMS settings
  - Handle special cases (learning cycle, initialization)
  - Can take direct control of BMS using Debug mode and reading ADC outputs through controller
    - Otherwise, direct control of BMS is unnecessary during normal device operation

References

Ref.	Document	
Qualcomm		
Q1	*Application Note: Software Glossary for Customers*	CL93-V3077-1

Questions?

https://support.cdmatech.com