Smart Battery Gas Gauge

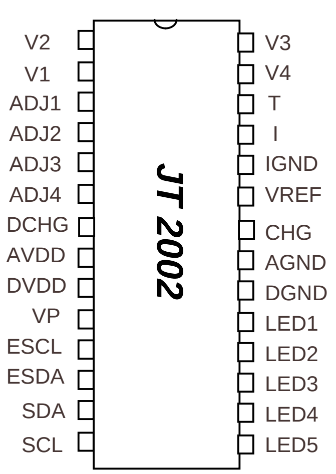
Features

- Provides accurate measurement of available charge in Li-Ion rechargeable batteries
- Supports SBS Smart Battery Data Specification v1.1
- Supports the 2-wire SMBus v1.1 interface with PEC
- Reports individual cell voltages
- Monitors and provides control to charge and discharge MOSFETs in Li-Ion protection circuit
- Provides cell balance control output for charge control.
- Provides 14-bit resolution for voltage, temperature, and current measurements
- Consumes less than 0.5mW operating
- Drives a 4- or 5-segment LED display for remaining capacity indication
- 28-pin 150-mil SSOP

General Operation

The JT2002 SBS-Compliant Gas Gauge IC for battery pack or in-system installation maintains an accurate record of available charge in rechargeable batteries. The JT2002 monitors capacity and other critical battery parameters dedicated for Li-Ion chemistries. The JT2002 uses an A-to-D converter with automatic offset error correction for voltage, temperature, and current reporting. The cumulated charged into (or discharged from) the battery is continuously calculated. The onboard ADC also monitors individual cell voltages in the battery pack and allows the JT2002 to generate control signals that may be used in conjunction with a pack supervisor to enhance pack safety. The JT2002 supports the smart battery data (SBData) commands and charge-control functions. It communicates data using the 2-wire system management bus (SMBus). The data available include the battery's remaining capacity, temperature, voltage, current, and remaining run-time predictions. The JT2002 provides LED drivers to depict remaining battery capacity from full to empty in 20% or 25% increments with a 4 or 5-segment display. The JT2002 works with an external EEPROM. The EEPROM stores the configuration information for the JT2002, such as the self-discharge rate, measurement calibration, and design voltage and capacity. The JT2002 uses the programmable self-discharge rate and other compensation factors stored in the EEPROM to accurately adjust remaining capacity for use and standby conditions based on time, rate, and temperature. The JT2002 also automatically calibrates or learns the true battery capacity in the course of a discharge cycle from near full to near empty levels. The VREF output regulates the operating voltage for the JT2002 from the battery cell stack using an external MOSFET.

Pin Connections



28-Pin Narrow SOIC

Pin Names

V2	Voltage from tip of cell 2	V3	Voltage from tip of cell 3
V1	Voltage from tip of cell 1	V4	Voltage from tip of cell 4
ADJ1	Cell1 bypass control	T	Temperature sense resistor input
ADJ2	Cell2 bypass control	I	Current sense resistor input
ADJ3	Cell3 bypass control	IGND	Current sense resistor ground port
ADJ4	Cell 4 bypass control	VREF	Voltage reference output
DCHG	Discharge FET control output	CHG	Charge FET control output
AVDD	Analog VDD	AGND	Analog Ground
DVDD	Digital VDD (4.5V~5.5V)	DGND	Digital ground
VP	EEPROM supply output	LED1	LED segment (MSB)
ESCL	EEPROM clock (output)	LED2	LED segment
ESDA	EEPROM data (input/output)	LED3	LED segment
SDA	SMB data (input/output)	LED4	LED segment
SCL	SMB clock (input/output)	LED5	LED segment (LSB)

Figure 1 JT2002 pin assignment

Pin Description

Pin Name	Pin No	I/O	Description
ADJ1	3	Input/Output[1]	Cell balance bypass control for cell 1 (Timer in for calibration)
ADJ2	4	Output[1]	Cell balance bypass control for cell 2
ADJ3	5	Output[1]	Cell balance bypass control for cell 3
ADJ4	6	Output[1]	Cell balance bypass control for cell 4
AGND	21	Input	Analog ground
AVDD	8	Input	Analog positive supply
CHG	22	Output	Charge MOSFET control output. High output to terminate charge
DCHG	7	Output	Discharge MOSFET control output. High output to terminate discharge
DGND	20	Input	Digital ground
DVDD	9	Input	Digital positive supply
ESCL	11	Output	EEPROM I^2C clock line
ESDA	12	Input/Output	EEPROM I^2C data line
I	25	Input[2]	Current sense resistor battery negative terminal
IGND	24	Input	Current sense resistor ground (pack negative) terminal
LED1	19	Output[4]	LED display segment (MSB)
LED2	18	Output[4]	LED display segment
LED3	17	Output[4]	LED display segment
LED4	16	Output[4]	LED display segment
LED5	15	Output[4]	LED display segment (LSB)
SCL	14	Input/Output	SMbus clock line
SDA	13	Input/Output	SMbus data line
T	26	Input[3]	Temperature sense resistor voltage divider circuits terminal
V1	2	Input[3]	Divided voltage input from cell 1 (the cell connect to battery negative terminal)
V2	1	Input[3]	Divided voltage input from cell 2
V3	28	Input[3]	Divided voltage input from cell 3
V4	27	Input[3]	Divided voltage input from cell 4 (highest voltage)
VP	10	Output	EEPROM positive supply
VREF	23	Output	Voltage regulator's voltage reference output

Note 1: Input/outputs are TTL compatible level.

Note 2: Input voltage range is –160mV to +80mV.

Note 3: Divided voltage input range should be from 0.5V to 3.5V.

Note 4: Open drain output.

Voltage Thresholds

In conjunction with monitoring the voltage at I pin for charge/discharge currents, the JT2002 monitors the battery potential through the V pin. The voltage potential is determined through a resistor-divider network on tips of cells. The dividing factors of networks are calculated during calibration and saved in EEPROM. The battery voltage is obtained by the measuring input voltages on tips of cells and dividing factors stored in EEPROM. The battery voltage is monitored for battery LOW and battery EXHAUSTED (PLV and PEV). Alarm warning will be sent to host when battery voltage is lower than PLV or PEV. Both PLV and PEV are dynamically adjusted according to present load and temperature. Exhausting charge threshold levels are used to determine when the battery has reached a programmable "empty" state. If the discharge current is greater than the overload current value stored in the EEPROM, PLV monitoring is disabled and resumes after the current falls below the programmed value.

Reset

The JT2002 is at reset state either first connected to the battery pack or receives RESET command from SMBus. Two categories of reset command, hard reset and soft reset, are acceptable from SMBus. On hard reset, the JT2002 initializes and reads the EEPROM to configure the battery pack. On soft reset, the JT2002 keeps current state of battery. The soft-RESET command is a byte command with command code 0xF5. The hard-RESET command is sent through manufacture access data 0404.

Sleep mode

The JT2002 switches into sleep while either pack pulled out from the notebook PC or detecting no charge flow through for more than 90 seconds. In the sleep mode, most of logic circuitry in the chip is turned off to minimize the power consumption. JT2002 will be waked up either SMBus was pulled high by host or received SBD command or detected current flow through the sense resistor.

Measurement Operation

The JT2002 accumulates a measure of charge and discharge currents, and estimates self-discharge. Charge currents are compensated for temperature and state-of-charge of the battery. The battery capacity is denoted as Remaining Capacity (RCAP) in terms of either current or power, represents the available battery capacity at any given time. Charging increments the RCAP, while discharging and self-discharging decrement the RCAP. An internal register is used to accumulate the amount of discharge to adjust the Full Charge Capacity (FCCAP). FCCAP is updated only if a complete battery discharge from full to empty occurs without any partial battery charges. Therefore, the JT2002 adapts its capacity determination based on the actual conditions of discharge. The battery's initial full capacity is set to the value stored in EEPROM. Until FCCAP is updated, RCAP counts up to, but not beyond, this threshold during subsequent charges. The battery's empty state is also programmed in the EEPROM. The battery low percentage stores the percentage of FCCAP while the battery voltage drops to the PLV threshold.

1. Full Charge Capacity (FCCAP):

FCCAP is the latest measured discharge capacity of the battery. On initialization, FCCAP is set to the value stored in the EEPROM. During subsequent discharges, FCCAP is updated with the latest recognized complete discharging (or learning cycle), representing a discharge from full to PLV, plus the battery low amount. A learning cycle is necessary for updating the FCCAP register. The FCCAP also serves as the 100% reference threshold used by the relative state-of-charge calculation and display.

2. Design Capacity (DCAP):

The DCAP is the user-specified battery capacity and is programmed in the external EEPROM. The DCAP also provides the 100% reference for the absolute state-of-charge calculation.

3. Remaining Capacity (RCAP):

RCAP counts up during charge to a maximum value of FCCAP and counts down to 0 during discharge and self-discharge. RCAP is set to the battery low amount after the PLV threshold has been reached. If RCAP is equal to the battery low amount, RCAP keeps until voltage drops below PLV threshold. To prevent overstatement of charge during periods of overcharge, RCAP stops incrementing when RCAP = FCCAP.

4. Cumulated Discharge Count (CDC):

The Cumulated Discharge Count is used to record the usage of the battery which response to the life of battery. The CDC counts up during discharge independent of RCAP and can continue increasing after RCAP has decremented to 0. The CDC resets to 0 when CDC = FCCAP and the Cycle Count will be increased by 1.

Charge Counting

Charge activity is detected based on a positive voltage on the I input. The voltage input at the I input is measured and converted into current through the sense resistor. If charge activity is detected, the JT2002 increase the RCAP. Charge actions increment the RCAP according to the cumulated charge counts. If the measured current is lower than the threshold of digital filter and the digital filter is enabled, the charge current is set as zero.

Discharge Counting

Discharge activity is detected based on a negative voltage on the I input. The voltage input at the I input is measured and converted into current through the sense resistor. If discharge activity is detected, the JT2002 decrease the RCAP. If the measured current is lower than the threshold of digital filter and both SMD and SMC are high, the discharge current is set to light discharge load. The threshold of the digital filter and light discharge load are stored in EEPROM.

Self-Discharge Estimation

The JT2002 decrements RCAP for self-discharge, periodically, until the charge full or charge empty condition is detected. The estimated self-discharge rate is programmed in EEPROM. JT2002 adjusts the self-discharge rate with the pack temperature.

Charge Control

JT2002 supports SBS charge control by broadcasting the ChargingCurrent() and the ChargingVoltage() to the Smart Charger every 60 seconds. Broadcasting can be either suspended by setting bit 14 of BatteryMode to 1 or turned off the Master functionality by clear bit 2 of ControlMode. The JT2002 updates the charging current broadcasting based on the battery's state of charge, voltage, and temperature. The JT2002 uses current taper detection for Li-Ion primary charge termination and over voltage detection to suspend charging. The JT2002 also provides a number of safety terminations based on battery capacity, voltage, temperature and conditions of individual cells.

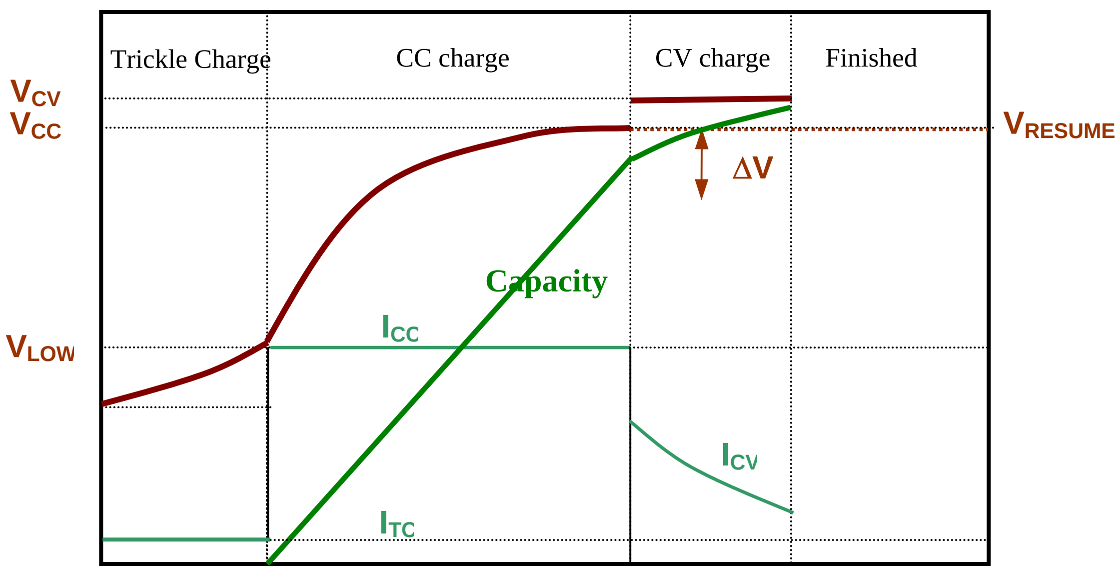


Figure 3 Charging control

Alarm Mode

If any of the bits 8-15 is set, JT2002 broadcasts AlarmWarning() messages to the SMBus host. If any of the bits 12-15 is set, AlarmWarning message is broadcasted to the Smart Battery as well. The message sent by the AlarmWarning() function is the same as the message returned by the BatteryStatus() function, except for the lowest nibble (4 bits). The Smart Battery will continue broadcasting the AlarmWarning() messages at 10 second intervals until the critical condition(s) has been corrected. The AlarmWarning() message broadcasting can be suspended by setting bit 13 (AlarmMode) of BatteryMode or turned off by clear bit 0 of ControlMode..

Cell Balancing

The JT2002 balances the cells during charge by partial bypassing the charges through the bypass resistors for those cells above the bypass charge threshold set in *EEPROM*. The cell balancing ceases when voltages of all cells were over the bypass charge threshold. Depending upon control circuit in gas gauge module, the cell balancing can be enabled/disabled through control bit in control mode register in *EEPROM*.

Digital Filter

The JT2002 does not measure charge or discharge counts below the digital filter threshold. The digital filter threshold is programmed in the *EEPROM* and should be set sufficiently high to prevent false signal detection with no charge or discharge flowing through the sense resistor.

Current

The JT2002 uses the voltage drops across sense resistor to measure and calculate the battery charge and discharge current. And reports in the data register Current().

Voltage

While monitoring charge and discharge currents, the JT2002 monitors the individual series cell voltages. JT2002 supports optional function to report individual cell voltage measurement and report. Connecting tips of cells to JT2002 pins, JT2002 can measure voltage of each battery cell. The JT2002 also provide line resistance correction factors, which are store in EEPROM, to accurately determine the individual cell voltage

Temperature

The JT2002 monitors temperature sensing using an external thermistor. The temperature is used to adapt charge and self-discharge compensations as well as to monitor for maximum temperature. Temperature may be accessed over the SMBus with standard SBD command 0x08.

Calibration

JT2002 provides calibration on the gauge board (module) for voltage, current and temperature measurement. After calibration, both slope and offset of each channel will be stored in *EEPROM*. To calibrate the module, calibration kit providing standard signals is required. As AD converter is affected by temperature, the current offset is keep adjusting during normal operation.

Display port

The display port drives low-power LEDs as bar-graph display. Each LED segment represents 20% or 25% of the FCC determined by the LED bit in the ControlMode register stored in *EEPROM*. The LED outputs are active all the time.

SMBus Communication Protocol

The JT2002 receives and transmits data with or without PEC. Figure 4 shows the communication protocol for the Read Word, Write Word, and Read Block messages without PEC. Figure 5 includes PEC. In the Write Word protocol, the slave device waits for the PEC after the last byte of data from the master device. If the master device does not support PEC, the last byte of data is followed by a STOP condition. After receipt of the PEC, the slave device compares the value to its calculation. If the PEC is correct, the slave device responds with an ACKNOWLEDGE. If it is not correct, the slave device responds with a NOT ACKNOWLEDGE and sets an error code.

SMBus commands from host

As an SMBus slave device, JT2002 accepts three types of SMBus protocol: read-word, write-word and read-block, according to the command send from the host. Table 1 shows the commands the JT2002 serves. All the commands (or register functions) proposed in the Smart Battery Data Specification (SBD) version 1.1 are implemented in the JT2002. In addition, other optional functions and non-standard commands are provided as well. All the non-standard commands and some of the manufacturer functions can be sealed.

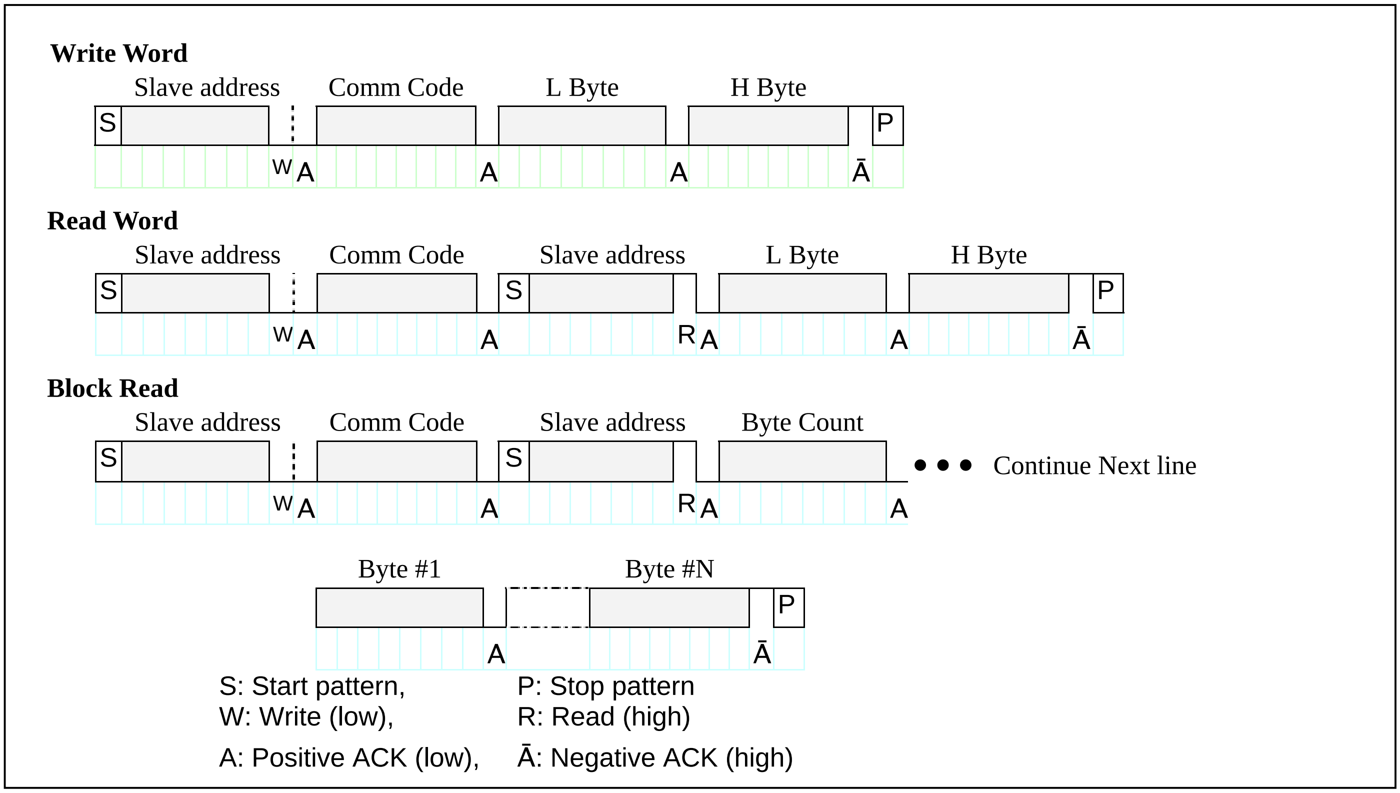


Figure 4. SMBus Communication Protocols without PEC

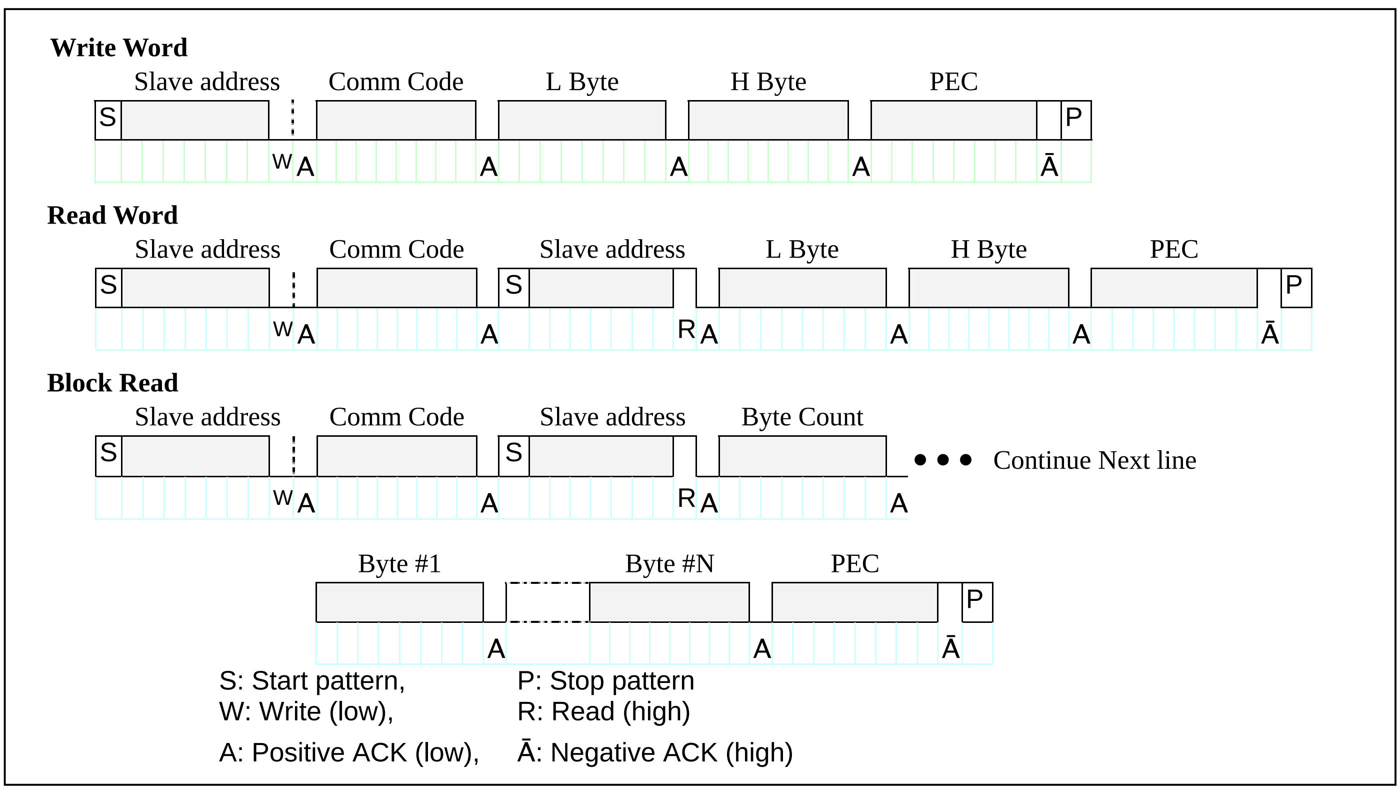


Figure 5. SMBus Communication Protocols with PEC

Table 1. Host-to-JT2002 Commands

Function	Code	Access	Units	Initial value	Note
ManufacturerAccess	0x00	read/write	—	—	
RemainingCapacityAlarm	0x01	read/write	mAh	E^2	
RemainingTimeAlarm	0x02	read/write	minutes	E^2	
BatteryMode	0x03	read/write	bit flags	—	
AtRate	0x04	read/write	mA	—	
AtRateTimeToFull	0x05	read	minutes	—	
AtRateTimeToEmpty	0x06	read	minutes	—	
AtRateOK	0x07	read	Boolean	—	
Temperature	0x08	read	0.1°K	2980	
Voltage	0x09	read	mV	0	
Current	0x0a	read	mA	0	
AverageCurrent	0x0b	read	mA	0	
MaxError	0x0c	read	percent	0	
RelativeStateOfCharge	0x0d	read	percent	—	
AbsoluteStateOfCharge	0x0e	read	percent	—	
RemainingCapacity	0x0f	read	mAh	E^2	
FullCahrgeCapacity	0x10	read	mAh	E^2	
RunTimeToEmpty	0x11	read	minutes	—	
AverageTimeToEmpty	0x12	read	minutes	—	
AverageTimeToFull	0x13	read	minutes	—	
ChargingCurrent	0x14	read	mA	E^2	
ChargingVoltage	0x15	read	mV	E^2	
BatteryStatus	0x16	read	bit flags	—	
CycleCount	0x17	read	cycle	E^2	
DesignCapacity	0x18	read	mAh	E^2	
DesignVoltage	0x19	read	mV	E^2	
SpecificationInfo	0x1a	read	—	E^2	
ManufactureDate	0x1b	read	—	E^2	
SerialNumber	0x1c	read	integer	E^2	
Reserved	0x1d-0x1f	—	—	—	
ManufactureName	0x20	read	string	E^2	
DeviceName	0x21	read	string	E^2	
EviceChemstry	0x22	read	string	E^2	
ManufacturerData	0x23	read	bit flags	E^2	
PackConfigure/Status	0x2f	read	bit flags	E^2	Note 1
Reserved	0x30~0x3b	—	—	—	
VCELL4	0x3c	read	mV		Note 1
VCELL3	0x3d	read	mV		Note 1
VCELL2	0x3e	read	mV		Note 1
VCELL1	0x3f	read	mV		Note 1
Reserved	0x40~0xef	—	—	—	
Download EEPROM	0xf0	write	—	—	Note 2
Reserved	0xf1-0xf4	—	—	—	
Reset JT2002	0xf5	command	—	—	Note 2
Reserved	0xf6-0xff	—	—	—	

Note1: Optional manufacturer function
Note2: Not SBD standard function

ManufacturerAccess() (0x00)

This function provides means to control the JT2002 during normal operation and pack manufacturing. The following commands are available.

01XX Engineer support command
02XX Engineer support command
03XX Calibration command:
0301: Standard Voltage high (16V, 12V, 8V, 4V) input
0302: Standard Voltage low (12V, 9V, 6V, 3V) input
0303: Standard discharge current (-2A) and temperature (25°C) input
0304: Standard charge current (2A) and temperature (60°C) input
0305: Calculate standard signals into calibration parameters and report
0404 Reset (cold start, can be sealed)
05XX LED control command:
0501: LED test
0502: Normal mode
06XX Engineer support command
All the engineer support commands are used for maintenance support only.

Input/Output: Set command and get return value in certain sort of commands.

RemainingCapacityAlarm() (0x01)

This function sets or returns the remaining capacity alarm value. When ReminingCapacity falls below the RemainingCapacityAlarm value initialized from the external EEPROM, the Remaining_Capacity_Alarm bit is set in BatteryStatus. The system may alter this alarm during operation.

Input/Output: unsigned integer. This sets/returns the value where the Remaining_Capacity_Alarm bit is set in Battery Status.
Units: mAh/10mWh
Range: 0 to 65,535

RemainingTimeAlarm() (0x02)

This function sets or returns the remaining time alarm value. When the AverageTimeToEmpty falls below the RemainingTimeAlarm value initialized from EEPROM, the Remaining_Time_Alarm bit in BatteryStatus is set. The system may alter this alarm during operation.

Input/Output: unsigned integer. This sets/returns the value where the Remaining_Time_Alarm bit is set in Battery Status**.**
Units: minutes
Range: 0 to 65,535 minutes

BatteryMode() (0x03)

This read/write word selects the various battery operational modes. The lower byte is read-only, any input data will be no effects on the lower byte. The JT2002 support neither internal charge control nor primary battery support. Bit definition is shown in Table 2. Since bits 0 and 1 are 0s, bits 8 and 9 have no effect. The JT2002 does support the battery capacity information specified in **both** mAhr **and** 10**m**W**h** modes.

Table 2. Bit Definition of Battery Mode

Field	Bits Used	Access	Allowable Values
INTERNAL_CHARGE_CONTROLLER	0	R	0 – Function Not Supported
PRIMARY_BATTERY_SUPPORT	1	R	0 – Function Not Supported
Reserved	2-6		Undefined
RELEARN_FLAG	7	R	0 – Battery OK 1 – Capacity Re-Learn Cycle Required
CHARGE_CONTROLLER_ENABLED	8	R/W	No effect
PRIMARY_BATTERY	9	R/W	No effect
Reserved	10-12		Undefined
ALARM_MODE	13	R/W	0 – Enable Alarm Warning broadcasts to Host and Smart Battery Charger 1 – Disable Alarm Warning broadcasts to Host and Smart Battery Charger

CHARGER_MODE	14	R/W	0 – Enable Charging Voltage and Current broadcasts to Smart Charger 1 – Disable broadcasts of Charging Voltage and Current to Smart Charger
CAPACITY_MODE	15	R/W	0 – Report in mA or mAh 1 – Report in 10mW or 10mWh

AtRate() (0x04)
This read/write word is the first half of a two-function set used to set the AtRate value used in calculations made by the AtRateTimeToFull() and AtRateTimeToEmpty(). When the AtRate value is positive, the AtRateTimeToFull function returns the predicted time to charge full at the AtRate value of charge. When the AtRate value is negative, the AtRateTimeToEmpty function returns the predicted operating time until charge empty at the AtRate value of discharge.

Input/Output: signed integer. AtRate is positive for charge and negative for discharge.
Units: mA/10mW
Range: -32,768 to 32,767

AtRateTimeToFull() (0x05)
This read-only word returns the predicted remaining time to fully charge the battery at the AtRate value (mA). The calculation is according to the latest set of AtRate value.

Output: unsigned integer. Returns the predicted time to full charge.
Units: minutes
Range: 0 to 65,534
Invalid Data Indication: 65,535 indicates that the AtRate is a negative value.

AtRateTimeToEmpty() (0x06)
This read-only word returns the predicted remaining operating time if the battery is discharged at the AtRate value. The calculation is according to latest set of AtRate value.

Output: unsigned integer. Returns the predicted time to empty.
Units: minutes
Range: 0 to 65,534
Invalid Data Indication: 65,535 indicates that the AtRate is a positive value.

AtRateOK() (0x07)
This read-only word returns a Boolean value that indicates whether or not an additional load with AtRate (mA) can be provided for longer than 10 seconds.

Boolean: Indicates if the battery can supply additional energy with rate of AtRate (mA) for at least 10 seconds.
Units: Boolean
Range: TRUE ≠ 0, FALSE = 0

Temperature() (0x08)
This read-only word returns the battery pack's internal temperature.

Output: unsigned integer. Returns the cell temperature in tenths of degrees Kelvin increments.
Units: 0.1°K
Range: 0 to +500.0°K
Accuracy: ±2°K after calibration

Voltage() (0x09)
This read-only word returns the battery pack voltage (mV).

Output: unsigned integer. Returns the battery terminal voltage in mV.
Units: mV
Range: 0 to 65,535mV
Accuracy: ±1% of DesignVoltage after calibration

Current() (0x0a)
This read-only word returns the current through the battery's terminals (mA).

Output: signed integer. Returns the charge/discharge rate in mA, where positive is for charge and negative is for discharge.
Units: mA

Range: 0 to 32,767mA for charge or 0 to –32,768mA for discharge
Accuracy: ±1% of the DesignCapacity after calibration

AverageCurrent() (0x0b)
This read-only word returns a rolling average of the current through the battery's terminals. The AverageCurrent function returns meaningful values after the battery's first minute of operation.

Output: signed integer. Returns the charge/discharge rate in mA, where positive is for charge and negative is for discharge
Units: mA
Range: 0 to 32,767mA for charge or 0 to –32,768mA for discharge
Accuracy: ±1% of the DesignCapacity after calibration

MaxError() (0x0c)
Returns the expected margin of error (%) in the state of charge calculation.

Output: unsigned integer. Returns the percent uncertainty for selected information.
Units: %
Range: 0 to 100%

RelativeStateOfCharge() (0x0d)
This read-only word returns the predicted remaining battery capacity expressed as a percentage of FullChargeCapacity (%).

Output: unsigned integer. Returns the percent of remaining capacity.
Units: %
Range: 0 to 100%
Accuracy: ±MaxError after circuit and capacity calibration

AbsoluteStateOfCharge() (0x0e)
This read-only word returns the predicted remaining battery capacity expressed as a percentage of DesignCapacity (%). Note that AbsoluteStateOfCharge can return values greater than 100%.

Output: unsigned integer. Returns the percent of remaining capacity.
Units: %
Range: 0 to 65,535%
Accuracy: ±MaxError after circuit and capacity calibration

RemainingCapacity() (0x0f)
This read-only word returns the predicted remaining battery capacity.

Output: unsigned integer. Returns the estimated remaining capacity in mAh or 10 mWh.
Units: mAh/10mWh
Range: 0 to 65,535
Accuracy: ±MaxError × FCC after circuit and capacity calibration

FullChargeCapacity() (0x10)
This read-only word returns the predicted pack capacity when it is fully charged. FullChargeCapacity defaults to the value programmed in the external EEPROM until a new pack capacity is learned. The new FullChargeCapacity is valid only if which is no less than 90 percent of the previous FullChargeCapacity.

Output: unsigned integer. Returns the estimated full charge capacity.
Units: mAh/10mWh
Range: 0 to 65,535mAh
Accuracy: ±MaxError × FCC after circuit and capacity calibration

RunTimeToEmpty() (0x11)
This read-only word returns the predicted remaining battery life at the present rate of discharge (minutes). The RunTimeToEmpty value is calculated based on Current.

Output: unsigned integer. Returns the minutes of operation left.
Units: minutes
Range: 0 to 65,534min
Invalid data indication: 65,535 indicates battery is being charged.

AverageTimeToEmpty() (0x12)

This read-only word returns the predicted remaining battery life at the present average discharge rate (minutes). The AverageTimeToEmpty is calculated based on AverageCurrent.

Output: unsigned integer. Returns the minutes of operation left.
Units: minutes
Range: 0 to 65,534min
Invalid data indication: 65,535 indicates battery is being charged.

AverageTimeToFull() (0x13)

This read-only word returns the predicted time until the Battery reaches full charge at the present average charge rate (minutes).

Output: unsigned integer. Returns the remaining time in minutes to full.
Units: minutes
Range: 0 to 65,534min
Invalid data indication: 65,535 indicates battery is not being charged.

ChargingCurrent() (0x14)

This read-only word returns the desired charging rate in mA. If ChargeMode is enabled, the JT2002 uses this command to send the desired charging rate to smart charger and SMBus Host.

Output: unsigned integer. Transmits/returns the desired charger output current in mA.
Units: mA
Range: 0 to 65,534mA

ChargingVoltage() (0x15)

This read-only word returns the desired charging voltage in mV. If ChargeMode is enabled, the JT2002 uses this command to send the desired charging voltage to smart charger and SMBus Host.

Output: unsigned integer. Transmits/returns the charger voltage output in mV.
Units: mV
Range: 0 to 65,534mV

BatteryStatus() (0x16)

This read-only word returns the battery status word.

Output: unsigned integer. Returns the bitmap of status and alarm register as shown in Table 2a.

Table 2a. Bit Definition of Battery Status

Field	Bits Used	Access	Set Condition
Alarm Bits—Over Charged	15	R	Battery is fully charged and charging is complete
Alarm Bits---Terminate Charge	14	R	Charging should be suspended temporarily
Reserved	13	R	
Alarm Bits---Over Temperature	12	R	Temperature is above pre-set limit
Alarm Bits---Terminate Discharge	11	R	Battery capacity is depleted
Reserved	10	R	
Alarm Bits---Remaining Capacity	9	R	Value of RemainingCapacity() is less than the value of RemainingCapacityAlarm()
Alarm Bits---Remaining Time	8	R	Value of AverageTimeToEmpty() is less than the value of RemainingTimeAlarm()
Status Bits---Initialized	7	R	Battery electronics are calibrated and valid EEPROM data
Status Bits---Discharging	6	R	Battery is discharging

Status Bits---Fully Charged	5	R	Battery is full and further charge is not required
Status Bits---Fully Discharged	4	R	Battery capacity is depleted
Error Codes	3-0	R	0--- No error

CycleCount() (0x17)

This read-only word returns the number of charge/discharge cycles the battery has experienced. A cycle is defined as an amount of discharge approximately equal to the value of DesignCapacity.

Output: unsigned integer. Returns the count of charge/discharge cycles the battery has experienced.
Units: cycles
Range: 0 to 65,535 cycles; 65,535 indicates battery has experienced 65,535 or more cycles.

DesignCapacity() (0x18)

This read-only word returns the theoretical capacity of a new pack. The DesignCapacity value is expressed in mAh at the nominal discharge rate.

Output: unsigned integer. Returns the battery capacity in mAh or 10mWh.
Units: mAh/10mWh
Range: 0 to 65,535

DesignVoltage() (0x19)

This read-only word returns the theoretical voltage of a new pack in mV.

Output: unsigned integer. Returns the battery's normal terminal voltage in mV.
Units: mV
Range: 0 to 65,535mV

SpecificationInfo() (0x1a)

This read-only word returns the specification revision the JT2002 supports.

ManufactureDate() (0x1b)

This read-only word returns the date the cell was manufactured in a packed integer word. The date is packed as follows: (year – 1980) × 512 + month × 32 + day.

SerialNumber() (0x1c)

This read-only word returns a serial number. This number, when combined with the ManufacturerName, the DeviceName, and the ManufactureDate, uniquely identifies the battery.

Output: unsigned integer

ManufacturerName() (0x20)

This read-only string returns a character string where the first byte is the number of characters available. The maximum number of characters is 11. The character string contains the battery manufacturer's name. For example, “J-Tek” identifies the battery pack manufacturer as J-Tek.

Output: string or ASCII character string

DeviceName() (0x21)

This read-only string returns a character string where the first byte is the number of characters available. The maximum number of characters is 7. The 7-byte character string contains the battery's name. For example, a DeviceName of “JT2002” indicates that the battery is a model of J-Tek.

Output: string or ASCII character string

DeviceChemistry() (0x22)

This read-only string returns a character string where the first byte is the number of characters available. The maximum number of characters is 5. The 5-byte character string contains the battery's chemistry. The JT2002 support Li-type battery cells only.

Output: string or ASCII character string

ManufacturerData() (0x23)

This read-only string allows access to an up to 5-byte manufacturer data string.
Output: block data – data whose meaning is assigned by the Smart Battery's manufacturer.

PackConfigure/Status (0x2f)

This read-only register returns an unsigned integer representing the pack configuration and current status of the battery pack. The MSB represents pack configuration and the LSB represents the pack status. See Table 3 and Table 4 for the bit description for PackConfigure and PackStatus.

VCELL4 (0x3c)

This read-only word returns the measured voltage of the battery cell 4.

Output: The battery cell4 output voltage in mV.
Units: mV
Range: 0 to 65,535mV
Accuracy: ±1% of DesignVoltage after calibration

VCELL3 (0x3d)

This read-only word returns the measured voltage of the battery cell 3.

Output: The battery cell3 output voltage in mV.
Units: mV
Range: 0 to 65,535mV
Accuracy: ±1% of DesignVoltage after calibration

VCELL2 (0x3e)

This read-only word returns the measured voltage of the battery cell 2.

Output: The battery cell2 output voltage in mV.
Units: mV
Range: 0 to 65,535mV
Accuracy: ±1% of DesignVoltage after calibration

VCELL1 (0x3f)

This read-only word returns the measured voltage of the battery cell 1.

Output: The battery cell1 output voltage in mV.
Units: mV
Range: 0 to 65,535mV
Accuracy: ±1% of DesignVoltage after calibration

Down load EEPROM (0xf0)

This download command is designed for writing data into *EEPROM*. Download data from Control PC through SMBus will be relayed by JT2002 to send to onboard *EEPROM* via I^2C bus. To protect data in *EEPROM* against illegal access or unintentional updating, an access code is required following the command code "0xf0". Operation procedure in detail, please refer to "Operation procedure for calibration and download".

Reset (0xf5)

This reset command provides the system user a manner to reset the pack when unexpected condition occurs. Operation procedure in detail, please refer to "Operation procedure for calibration and download".

Table 3. Bit definitions of PackConfigure

DMODE	SEAL	CSYNC	CEDV	VCOR	CHEM	LCC1	LCC0
7	6	5	4	3	2	1	0

bit 7: DMODE displays Relative capacity. Bit 7 always is 1.
1: Selects Absolute display (Not supported)
0: Selects Relative display (Default)

bit 6: SEAL
1: Sealed, Commands from ManufacturerAccess() are disabled
0: Not Sealed

bit 5: CSYNC
1: Enable RM update with charge termination
0: No RM update when charge termination condition was detected

bit 4: CEDV, Capacity compensation with EDV
1: Enable automatic compensation
0: Disable automatic compensation

bit 3: VCOR: Mid-range capacity correction with pack voltage
1: Enable mid-range correction
0: Disable mid-range correction

bit 2: CHEM.
1: Not supported
0: Li-Ion chemistry (default)

bit 1,0:LCC1/LCC0.
0, 0: Pack Stack (No cell voltage)
0, 1: 2-serial pack
1, 0: 3-serial pack
1, 1: 4-serial pack

Table 4. Bit definitions of PackStatus

—	BL	VCurr	VDP	COn	DOn	CVOV	CVUV
7	6	5	4	3	2	1	0

bit 7: Reserved.

bit 6: BL indicates that a Battery Low condition was detected
1: Battery voltage was detected below EDV2.
0: No Battery Low condition was detected.

bit 5: VCurr (Valid Charge) is detected
1: $I > I_{VALID}$.
0: $I < 0$ or $I \leq I_{VALID}$

bit 4: VDP is set when a valid discharge period is on going.
1: Valid charge period is on going
0: Not a valid discharge period

bit 3: COn (Charge FET ON) is set when charging is allowed.
1: Charge FET On
0: Charging is not allowed

bit 2: DOn (Discharge FET On) is set when the discharge from battery pack is determined to be safety
1: Discharge FET On
0: Discharge FET Off

bit 1: CVOV (Cell Voltage Over Voltage) is set when battery pack/cell voltage is detected as over predefined value
1: Over Voltage
0: Normal

bit 0: CVUV (Cell Voltage Under Voltage) is set when cell voltage is detected as beyond lower .boundary
1: Under Voltage
0: Normal

Table 5. Bit definitions of ControlMode

NDF	CB	HPE	CPE	LED	—	—	SM
7	6	5	4	3	2	1	0

bit 7: NDF: disables the digital filter during discharge if the SMBC and SMBD lines are high.
1: Digital filter enable all the time.
0: Disable digital filter, when SMD and SMC are both high.

bit 6: CB: Enable the charge balance control mechanism.
1: Adjust cell voltage while charge unbalance condition was detected during charging
0: No balance adjustment during charging.

bit 5: HPE: Enables/Disables PEC transmissions to the Smart Battery host for master mode alarm messages.
1: PEC byte on broadcasts to host (Not supported)
0: No PEC byte on broadcasts to host (default)

bit 4: CPE: Enables/Disables PEC transmissions to the Smart Battery Charger for master mode alarm messages.
1: PEC byte on broadcasts to charger (Not supported)
0: No PEC byte on broadcasts to charger (default)

bit 3: LED: The LED bit configures the JT2002 for 4 or 5 LED indication.
1: Selects the 4 LED indication mode
0: Selects the 5 LED indication mode

bit 2: Reserved

bit 1: Reserved

bit 0: SM: The SM bit enables/disables master mode broadcasts by the JT2002
1: Broadcasts to host and charger disabled
0: Broadcasts to host and charger enabled

SMBus commands to host and smart charger

The JT2002 can act as master to broadcast warning message to SMBus Host and broadcast charge commands to smart charger with write-word protocol.

Programming the JT2002

The JT2002 requires the programming of an external EEPROM for proper device operation. Each module can be calibrated for the greatest accuracy, or general default values can be used. The calibration kit (including calibration board, software, and cable) for the Windows system is available. The JT2002 uses a 24LC02 or equivalent serial EEPROM (capable of read operation to 2.0V) for storing various initial values, calibration data, and string information. Tables 6 and 7 detail the contents and show typical program value for a 3600mAh 4-series Li-Ion battery pack, using a 20mΩ sense resistor.

Table 6 Programming the EEPROM

資料名稱	位址 Low	位址 High	HEX Content Low	HEX Content High	Example Value	備註
EEPROM length	0x00		0x53		'S'	To indicate that valid data in EEPROM
EEPROM check	0x01		0x54		'T'	To indicate that external calibration has been done
Remaining Time Alarm	0x02	0x03	0x0a	00	10 min	The low time alarm value.
Remaining Capacity Alarm	0x04	0x05	0xf0	00	240mAh	The low capacity alarm threshold value.
Cycle Count	0x06	0x07	00	00	0	The number of cycles the battery has experienced.
Design Capacity	0x08	0x09	0x60	0x09	3600mAh	The theoretical capacity of the new pack.
Pack Exhausted Voltage (PEV)	0x0a	0x0b	0x20	0xd1	12000mV	Battery exhausted detection threshold level. The pack is assumed to be exhausted, when the pack output voltage is below this value. The value programmed is the two's complement of the threshold voltage in mV.
Pack Low Check Voltage (PLCV)	0x0c	0x0d	0x20	0xd1	12000mV	Battery pack voltage checkpoint beyond PEV (3%). The value programmed is the two's complement of the threshold voltage in mV.
Pack Low Voltage (PLV)	0x0e	0x0f	0x88	0xc8	14200mV	Battery pack voltage at battery low. The value programmed is the two's complement of the threshold voltage in mV.
Full Charge Capacity	0x10	0x11	0xb8	0x0b	3000mA	This value sets the estimated pack capacity. This value will be updated when a complete learning cycle is experienced.
Remaining Capacity	0x12	0x13	0xe8	0x03	1000mAh	Current battery remaining capacity. This value will be reset when pack exhausted condition is detected.
Discharge Capacity L	0x14	0x15	0	0	0mAsec	This value records the total discharged energy since last cycle count updated. This field is used internally, no description and should be programmed to zero for published document.
Discharge Capacity H	0x16	0x17	0	0		
Taper current	0x18	0x19	0xF0	00	240mA	The upper limit of charge current for Li-Ion charge termination.
ΔV_{POV}	0x1a		0x80		128mV	This value sets the voltage range for over voltage decision (w.r.t. Charge Voltage).
ΔV_{TAPER}	0x1b		0xff		255mV	This value sets the voltage range for current taper decision (w.r.t. Charge Voltage)
ΔV_{PCC}	0x1c		0xff		255mV	Voltage range (from Charge Voltage) for Constant Voltage charge. (This value also used as the pack voltage range for charge resume after fully charged)
Full-charge percentage	0x1d		0x62		98%	The ratio of the full charge capacity in RM when the JT2002 determines a full-charge termination. If RM is below this value, RM is set to this value. If RM is above this value, the RM is not adjusted.
Pack Configuration	0x1e		0x03		3	Refer to Table 3.
Control Mode	0x1f		0x00		0	Refer to Table 5.
Battery Mode	0x2a	0x2b	0x00	0x40	16384	Battery Mode, Lower byte is read only; Upper byte can be modified.
Design Voltage	0x2c	0x2d	0xd0	0x39	14800mV	Nominal battery pack output voltage
Charging Voltage	0x2e	0x2f	0xa0	0x41	16800mV	The suggested fast-charge voltage for the Smart Charger
Fast-Charging Current	0x38	0x39	0x60	0x09	2400mA	The suggested fast-charge current for the Smart charger
Pre-Charge Current	0x3a	0x3b	0x2c	01	300mA	The desired Pre-charge current before normal (fast) charge
Heavy load Current	0x3c	0c3d	0x70	0x17	6000mA	Sets the discharge current at which EDV threshold monitoring is disabled

Table 6 Programming the EEPROM (continue)

Maximum Cell Voltage	0x3e	0x3f	0x00	0x00	4200mV	
Self-Discharge Rate	0x46		0x05		0.1%	The desired self-discharge rate per day (%) at room temperature; 0.02% per unit (15 * 0.02 = 0.3)
A/D Calibration	0x47		0x00		0	A/D converter calibration data.
ΔV_{COV}	0x48		0x1e		30mV	This value sets the cell voltage range for over voltage decision (w.r.t. Maximum cell voltage)
ΔVC_{RESUME}	0x49		32		50mV	This value sets the cell voltage range for charge resume after fully charged (w.r.t. maximum cell voltage)
Timer Counter	0x4a	0x4b	0xb0	0x3c	15536	Timer1 clock count for 200ms (65536 –200000/(2*2)) For the RC inaccuracy, this value is to be tuned for precise 200ms period (pre-scale 2:1, 500kHz)
Maxi mum Temperature and DeltaT	0x4c		0x58		MaxT = 61°C DeltaT = 1.2°C	Maximum charge temperature is 69-(un*1.6) °C (un = upper nibble). The delta temperature is (ln *0.15)°C (ln = lower nibble)
BatteryLow%	0x4d		0x24		7%	Sets the battery capacity that Remaining capacity is reduced to at the Pack Low Voltage (PLV). The value equals5.12*(%RM at PLV)
Reserved	0x4e	0x4f	0x00	0x00	0	Should be programmed to zero.
Reserved	0x56	0x57	0x00	0x00	0	Should be programmed to zero.
VOC25	0x58	0x59	0x90	0x38	14480mV	Voltage of Capacity 25%
VOC50	0x5a	0x5b	0x20	0x3a	14880mV	Voltage of Capacity 50%
VOC75	0x5c	0x5d	0xf0	0x3c	15600mV	Voltage of Capacity 75%
Reserved	0x5e	0x5f	0x00	0x00	0	Should be programmed to zero.
A/D Current measurement slope	0x60	0x61	0x55	0x05		Calibration result; A/D Current slope is the number of A/D counts per Ampere.
A/D Current measurement offset	0x62	0x63	0x55	0x15		Calibration result; A/D reading for level shift voltage in current measurement, default 1500mV for 0A, which is 0x1555 for 3V(9A) full range 14-bit AD.
A/D Voltage V1 Low measurement slope	0x64			0x00		Calibration result; Lower byte of AD reading for V1 voltage slope (per Ampere)
A/D Voltage V2 Low measurement slope	0x65			0x00		Calibration result; Lower byte of AD reading for V2 voltage slope (per Ampere)
A/D Voltage V3 Low measurement slope	0x66			0x55		Calibration result; Lower byte of AD reading for V3 voltage slope (per Ampere)
A/D Voltage V4 Low measurement slope	0x67			0x00		Calibration result; Lower byte of AD reading for V4 voltage slope (per Ampere)
A/D Temperature Low measurement slope	0x68			0x08		Calibration result; The thermister bias of ADC with standard 10kΩ resistor (0x3258 for 3V full range AD reading)
A/D Voltage V1 High measurement slope	0x69			0x10		Calibration result; Upper byte of AD reading for V1 voltage slope (per Ampere)
A/D Voltage V2 High measurement slope	0x6a			0x08		Calibration result; Upper byte of AD reading for V2 voltage slope (per Ampere)
A/D Voltage V3 High measurement slope	0x6b			0x05		Calibration result; Upper byte of AD reading for V3 voltage slope (per Ampere)
A/D Voltage V4 High measurement slope	0x6c			0x04		Calibration result; Upper byte of AD reading for V4 voltage slope (per Ampere)
A/D Temperature High measurement slope	0x6d			0x12		Calibration result; The thermister bias of ADC with standard 10kΩ resistor.
A/D Current Ground measurement (offset)	0x6e	0x6f	0x55	0x15		Calibration result; A/D offset for 0A in Current measurement.
Segmental Resistance 1	0x70		2		2mΩ	Resistance between tips of Battery cell 1 and Sense Resistor

Table 6 Programming the EEPROM (continue)

Segmental Resistance 2	0x71		2		2mΩ	Resistance between tips of Battery cell 1 and cell 2
Segmental Resistance 3	0x72		2		2mΩ	Resistance between tips of Battery cell 2 and cell 3
Segmental Resistance 4	0x73		2		2mΩ	Resistance between tips of Battery cell 3 and cell 4
Sense Resistor	0x74		0x14		20mΩ	Sense resistor value in mΩ
Digital Filter current	0x75		0xa		10mA	Dead Zone Margin for A/D converter
Light Load Current	0x76		0x02		2mA	Light load current, active only when digital filter disabled.
Reserved	0x77		0x00		0	Should be programmed to zero.
Specification information	0x78	0x79	0x 10	0x10	1.1	Packed data to the version of SBD spec. JT2002 supports.
Manufacturer Date	0x7a	0x7b	0xa1	0x20	May, 1, 1996	The manufacture date of the cell pack. This value is a packed integer
Serial number	0x7c	0x7d	0x12	0x27	10002	An optional pack serial number
Reserved	0x7e	0x7f	0x00	0x00		Should be programmed to zero.
A/D Voltage V1 Low measurement bias	0x80		0x93			Calibration result; Lower byte of AD reading for V1 voltage bias (offset)
A/D Voltage V2 Low measurement bias	0x81		0x21			Calibration result; Lower byte of AD reading for V2 voltage bias (offset)
A/D Voltage V3 Low measurement bias	0x82		0xC9			Calibration result; Lower byte of AD reading for V3 voltage slope (offset)
A/D Voltage V4 Low measurement bias	0x83		0x37			Calibration result; Lower byte of AD reading for V4 voltage bias (offset)
A/D Temperature Low measurement bias	0x84		0x0C			Calibration result; Lower byte of AD reading for temperature voltage bias (offset)
Reserved	0x85					Should be programmed to zero.
Reserved	0x86	0x87				Should be programmed to zero.
A/D Voltage V1 High measurement bias	0x88		0x 04			Calibration result; Upper byte of AD reading for V1 voltage bias (offset)
A/D Voltage V2 High measurement bias	0x89		0x 05			Calibration result; Upper byte of AD reading for V2 voltage bias (offset)
A/D Voltage V3 High measurement bias	0x8a		0x 04			Calibration result; Upper byte of AD reading for V3 voltage bias (offset)
A/D Voltage V4 High measurement bias	0x8b		0x 06			Calibration result; Upper byte of AD reading for V4 voltage bias (offset)
A/D Temperature High measurement bias	0x8c		0x 09			Calibration result; Upper byte of AD reading for temperature voltage bias (offset)

Table 7 String data in EEPROM

String description	Address	0x00	0x01	0x02	0x03	0x04	0x05	0x06	0x07	0x08	0x09	0x0a	0x0b
Manufacturer name	0x20-0x29	08	S 0x53	e 0x65	n 0x6e	e 0x65	r 0x72	T 0x54	e 0x65	c 63	- 0x20		
Device name	0x30-0x37	03	J 0x4a	T 0x54	2 0x32	0 0x30	0 0x30	2 0x32	- 0x20				
Device chemistry	0x40-0x45	05	L 0x4c	i 0x69	I 0x49	O 0x4f	N 0x4e						
Manufacturer data	0x50-0x55	04	J 0x4a	T 0x54	E 0x45	K 0x4b	-						

Table 8 Recommended DC Operating Conditions

Symbol	Parameter	Minimum	Typical	Maximum	Unit	Notes
VSS	Supply Voltage	4.5	5.0	5.5	V	
REF	Reference Voltage	2.5	4.25	7	V	
I_{CC}	Normal operation	250	300	320	μA	
	Sleep mode	30	40	50	μA	
I	Voltage input in I pin	–160		80	mV	
R_{SENSE}	Sense Resistor	0.01	0.02	0.05	Ω	
V_{IH}	Logic input high	1.4		5.5	V	SDA, SCL
		0.5 × Vcc		Vcc	V	ESDA, ESCL
V_{IL}	Logic input low	–0.5		0.6		SDA, SCL
		–0.5		0.3 × Vcc		ESDA, ESCL
$I_{Pull\ Down}$	Pull down SDA, SCL		0.5		μA	
LED1..5	Output Drive Current		5	10	mA	
ILVOUTt	Vp output leakage		1		μA	

Characteristics of the SMBus

The SMBus functionality of the JT2002 complies with the System Management Bus Specification version 1.10. Some critical AC/timing characteristics are shown below.

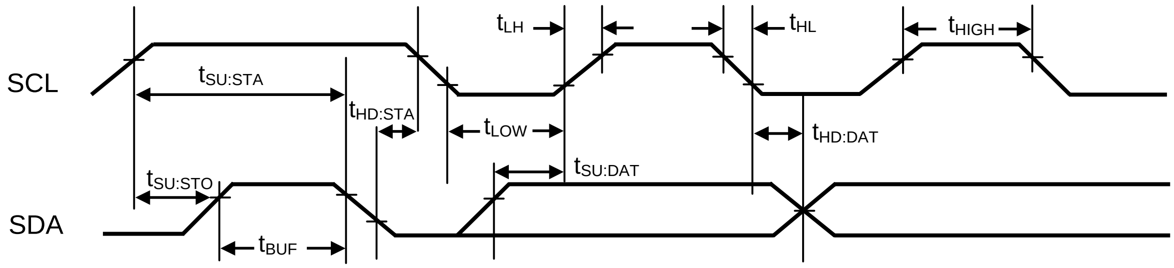


Figure 6 Timing of SMBus

Table 9 Timing parameters of the SMBus

Symbol	Description	Min	Typical	Max	Units	Notes
f_{SMB}	SMBus operation frequency	10		100	kHz	
t_{BUF}	Bus free time between stop and start conditions	4.7			µs	
$t_{HD:STA}$	Hold time after (repeated) start condition	4.0			µs	
$t_{SU:STA}$	Repeated start condition setup time	250			ns	
$t_{SU:STO}$	Stop condition setup time	4.0			µs	
$t_{HD:DAT}$	Data hold time	300			ns	
$t_{SU:DAT}$	Data setup time	250			ns	
t_{LOW}	Clock low period	4.7			µs	
t_{HIGH}	Clock high period	4.0			µs	
t_{HL}	Clock/Data fall time			300	ns	
t_{LH}	Clock/Data rise time			1000	ns	
$t_{LOW:SEXT}$	Cumulative clock low extend time (slave mode)			25	ms	see note 1
$t_{LOW:MEXT}$	Cumulative clock low extend time (master mode)			10	ms	see note 2

Note 1: $t_{LOW:SEXT}$ is the cumulative time, JT2002, in slave mode, is allowed to extend the clock cycles in one message from the initial start to the stop.

Note 2: $t_{LOW:MEXT}$ is the cumulative time, JT2002, in master mode, is allowed to extend its clock cycles within each byte of a message as defined from start-to-ack, ack-to-ack, or ack-to-stop.

Application circuit

A typical application circuits is provided in Figure 7

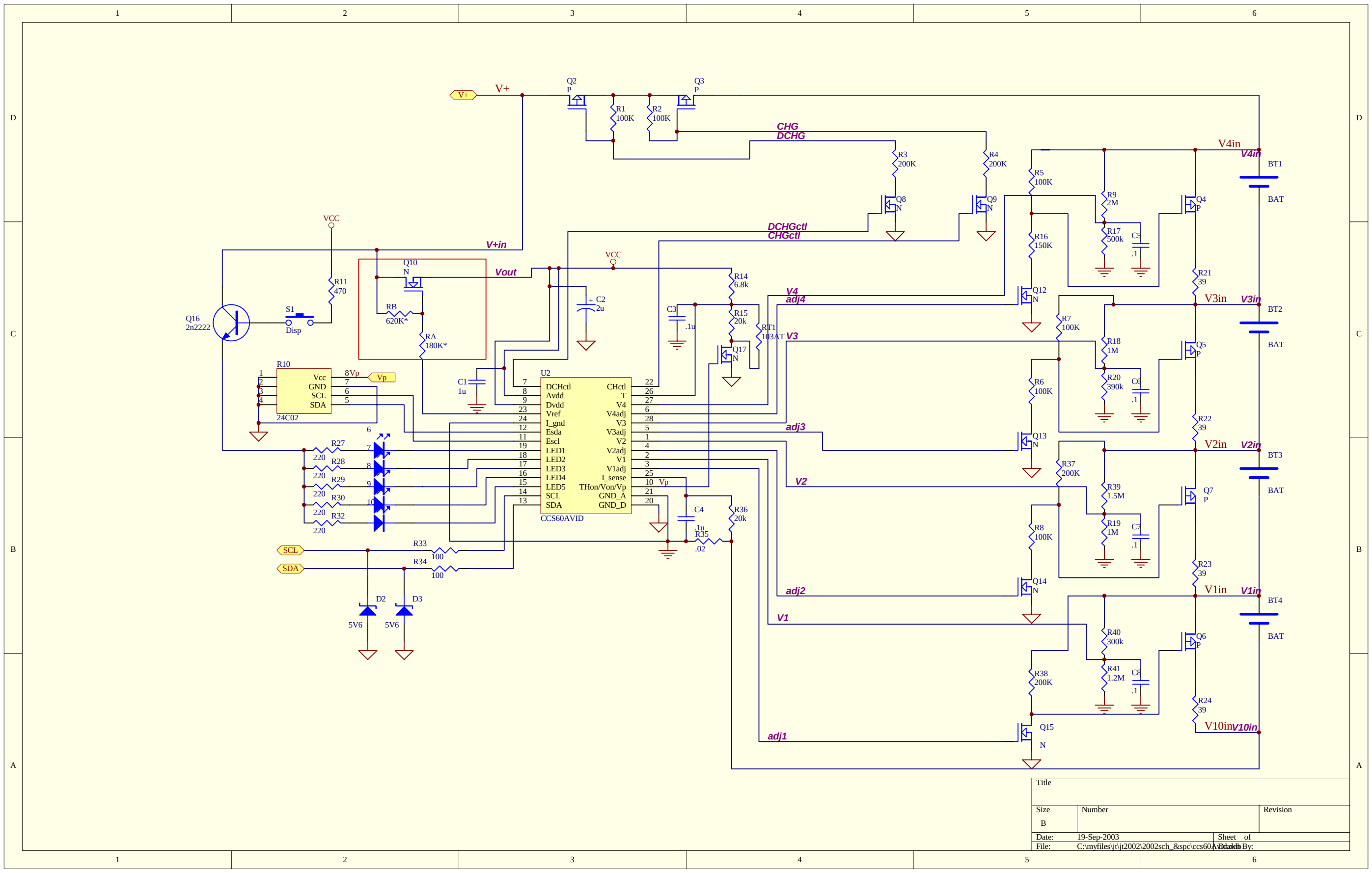


Figure 7 Typical application circuits

FET	RA	RB	Start up voltage	Regulator Voltage
2N7002	180k	620k	11.2v	8v~19v
2N7002	160k	470k	9.9v	7.5v~16v
BSS138	160k	390k	9v	7.3v~15v

Revision History

Date	Revision Number	Description of revision	Page
2003.08.16	0.0	Original	—