How to extend flight time and battery life of quadcopters and industrial drones

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Farnell Webinar

Agenda

- High-Speed Sensorless-FOC for drone ESC
- Battery Pack for drone

High-Speed Sensorless-FOC for drone ESC

Agenda

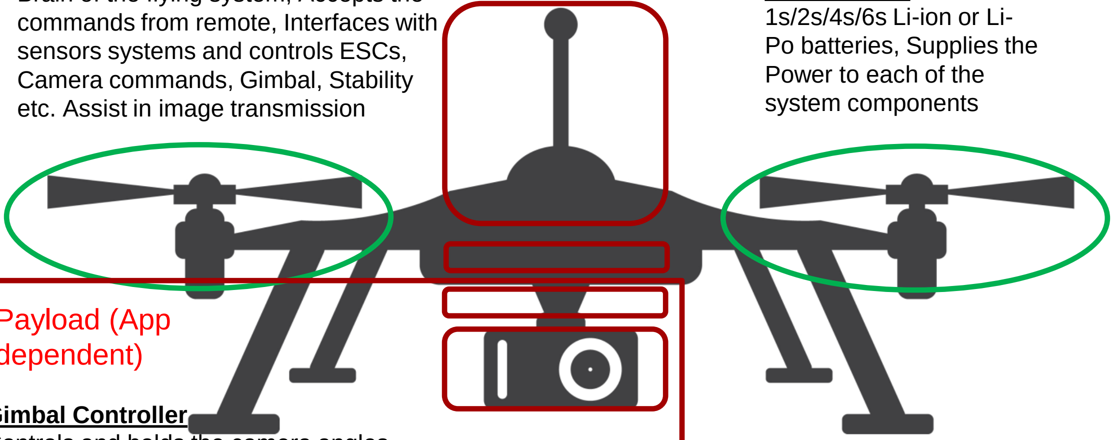
- Overview of a Drone
- Trapezoidal vs Sinusoidal considerations
- Software considerations
- Test results and setup
- Design Overview

Non – Military Drones – Subsystems

Flight Controller
Brain of the flying system, Accepts the commands from remote, Interfaces with sensors systems and controls ESCs, Camera commands, Gimbal, Stability etc. Assist in image transmission

Battery Pack
1s/2s/4s/6s Li-ion or Li-Po batteries, Supplies the Power to each of the system components

ESC – Electronic Speed Controller
Typically 4 or more, Brushed DC or Brushless DC motor, Speed control for thrust and direction change



Payload (App dependent)

Gimbal Controller
Controls and holds the camera angles in 1/2/3 axis

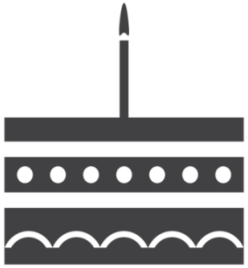
Camera Module
Captures the Images / Videos per received commands, sends the data to remote system or stores in SD card.

Flight

Vision and Sensor systems
Multiple Sensors (Ultrasonic/ LiDar / IR / Accelero / Gyro) for collision detection, Landing assist , stability, all interfaced to main controller . GPS for navigation

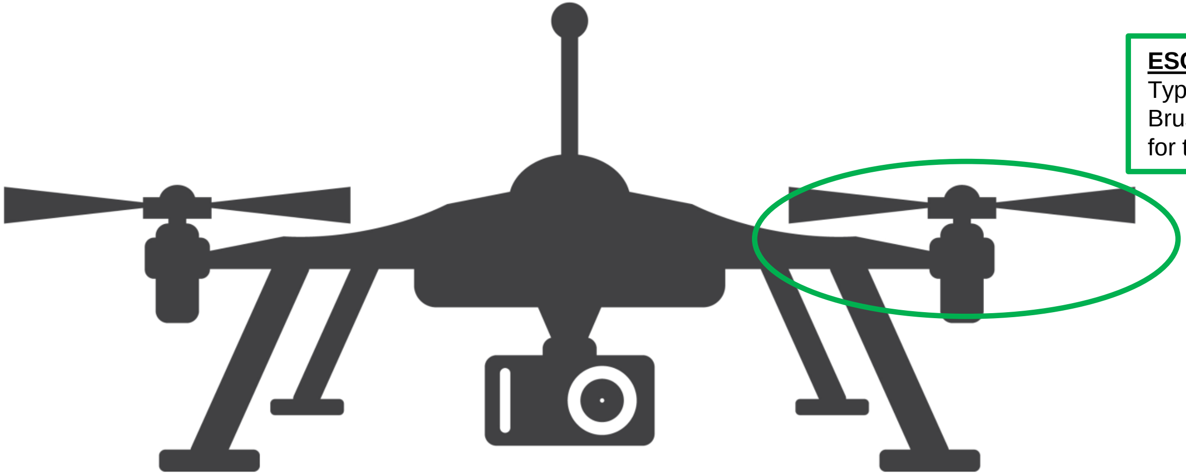
Remote Controller
Takes the inputs (flight control/capture) from user and sends the commands to Flight controller, optional Screen interface (maybe phone / tablet as well)

Remote



Battery Pack
1s/2s/3sLi-ion or Li-Po batteries, Supplies the Power to remote controller

System Description & Problem Statement



ESC – Electronic Speed Controller
Typically 4 or more, Brushed DC or Brushless DC motor, Speed control for thrust and direction change

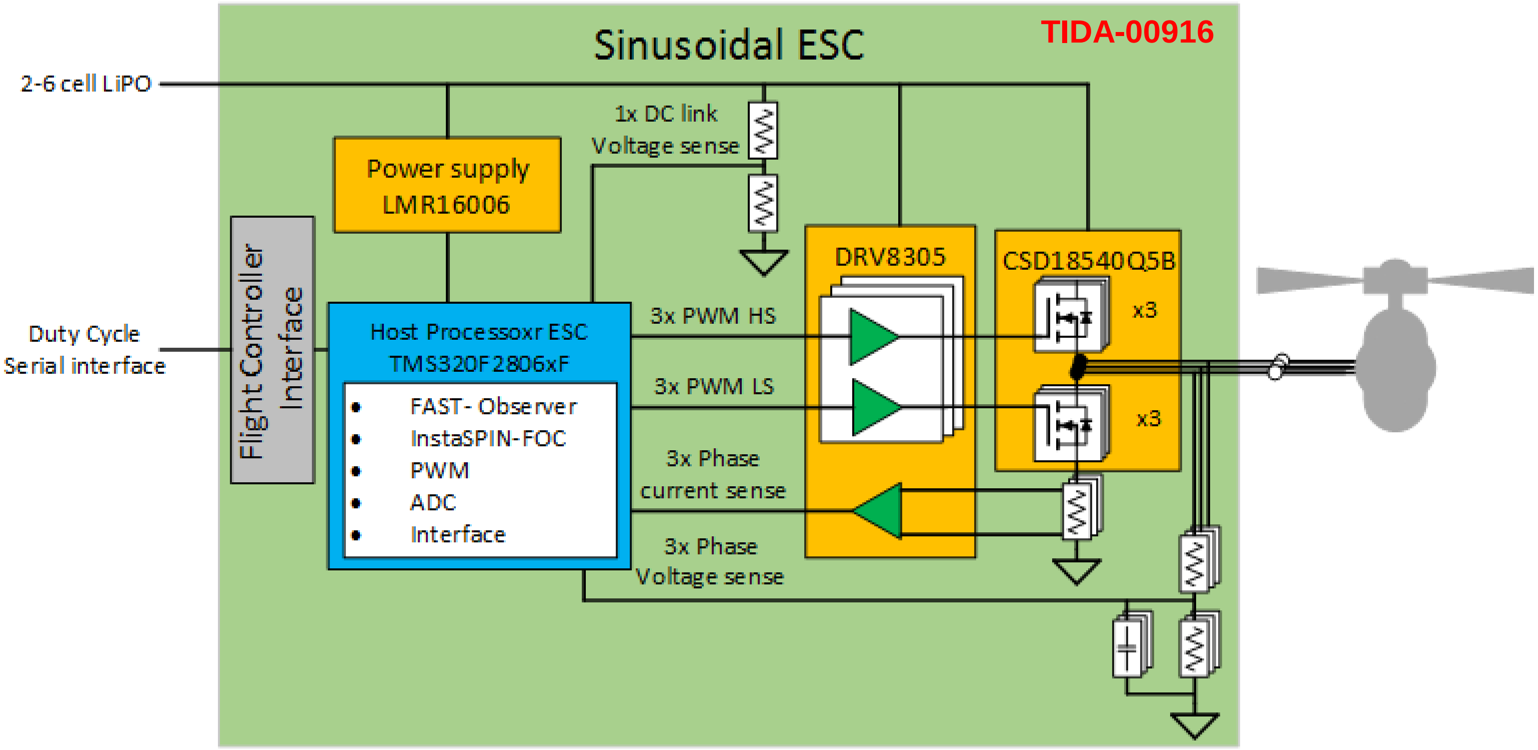
This limits the efficiency of the motor and the speed performance due to torque ripple caused by the Control, the control also limits the dynamic performance of the speed change which causes the drone to react slower then by FOC control

Changing the Trapezoidal Control to FOC(Field Oriented Control) would remove the torque ripple which would create a more smooth motor movement, hence improving efficiency

One issue with FOC control is the need for an accurate angle, hence the sensor is expensive

Therefore FOC control is only interesting if it can be done sensorless

High-Speed Sensorless-FOC for drone ESC/
Block Diagram Trapezoidal vs Sinusoidal



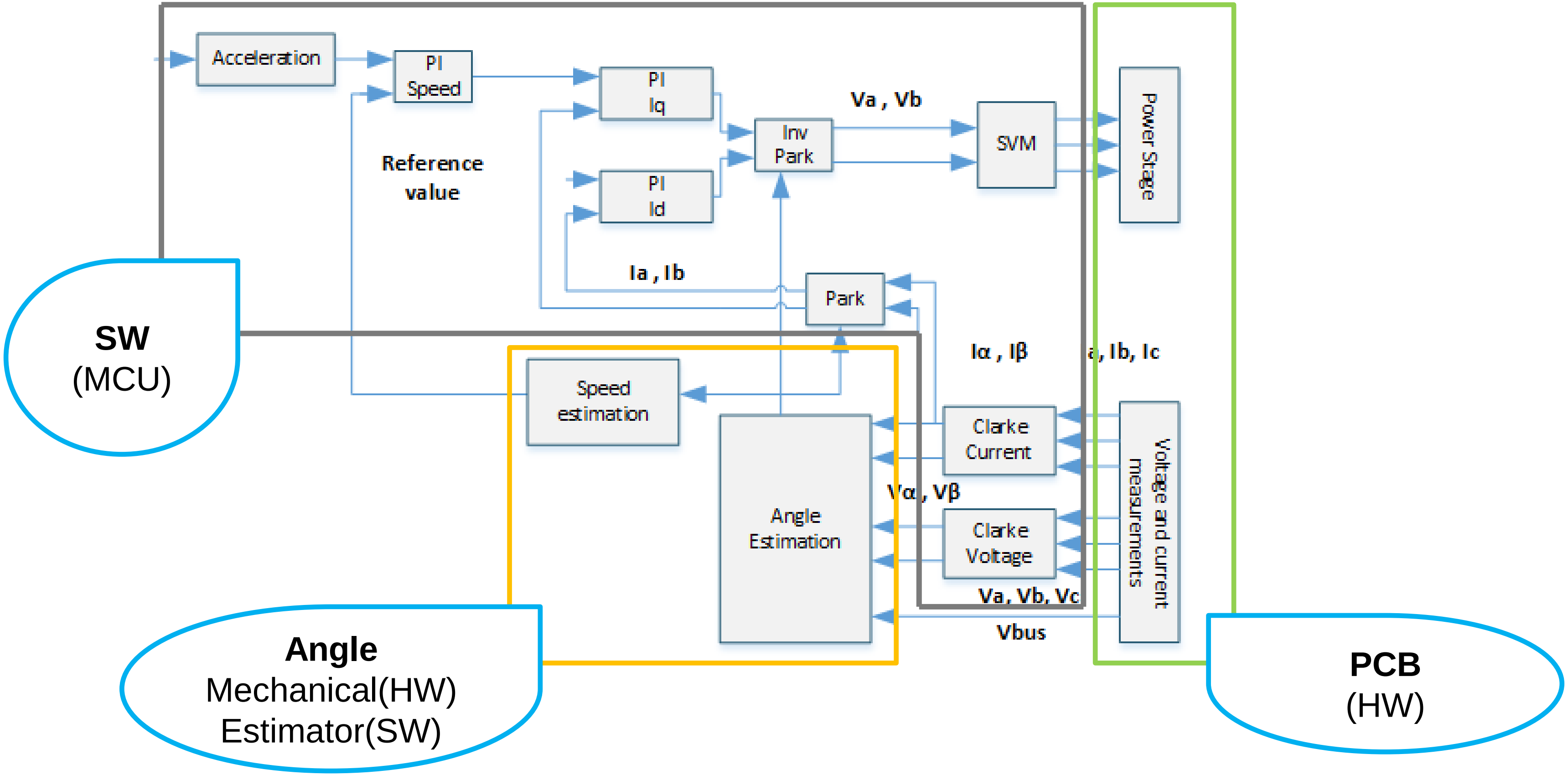
High-Speed Sensorless-FOC for drone ESC/
Trapezoidal vs Sinusoidal

TIDesigns

	Trapezoidal(BLDC)		Sinusoidal(FOC)	
Commutation of Motor	Block commutated control 60 Degree angle measurement		Field Oriented Control Real time accurate angle measurement	
Sensorless Control Technique(Bemf based)	Zero Crossing Technique	InstaSPIN™-BLDC	Sliding Mode Observer(SMO)	InstaSPIN™-FOC TI FAST Algorithm
Voltage Sense	3x Vph	3x Vph	DC-Bus	3xVph + DC-Bus
Current Sense	Optional 1-shunt	Optional 1-shunt	1-3 shunt or phase	2-3 shunt or phase
Performance Speed	Poor dynamics	Robust with load Better Dynamics	Poor low speed Medium dynamics Hard to tune	Best low to high speed Best dynamics Self Tuning
Performance Torque	High Torque, but Torque Ripple; slower dynamics		Ideal torque control, low noise, smooth operation, best dynamics	
Motor	Trapezoidal wound		Sinusoidal wound	
System Cost	Same		Sense additions	

High-Speed Sensorless-FOC for drone ESC/

Challenges of FOC control



SW

- PWM features
- ADC sampling
- Electrical speed of motor
- Tuning of PI controllers
- Startup from zero speed

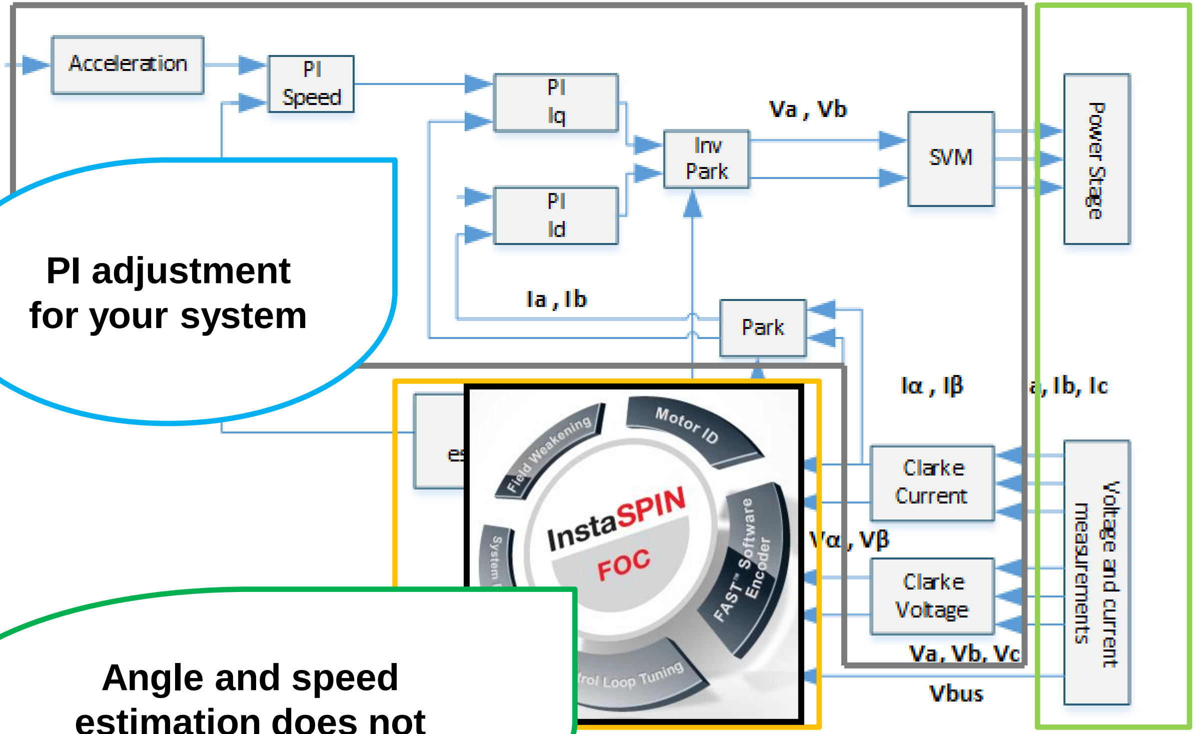
HW

- Voltage and Current sensing
- FET ratings
- Efficiency(Conduction and switching)
- Protection(OC, Short, OT)

gle

- Mech
- Estim
  - Tu m for entire speed range
  - M

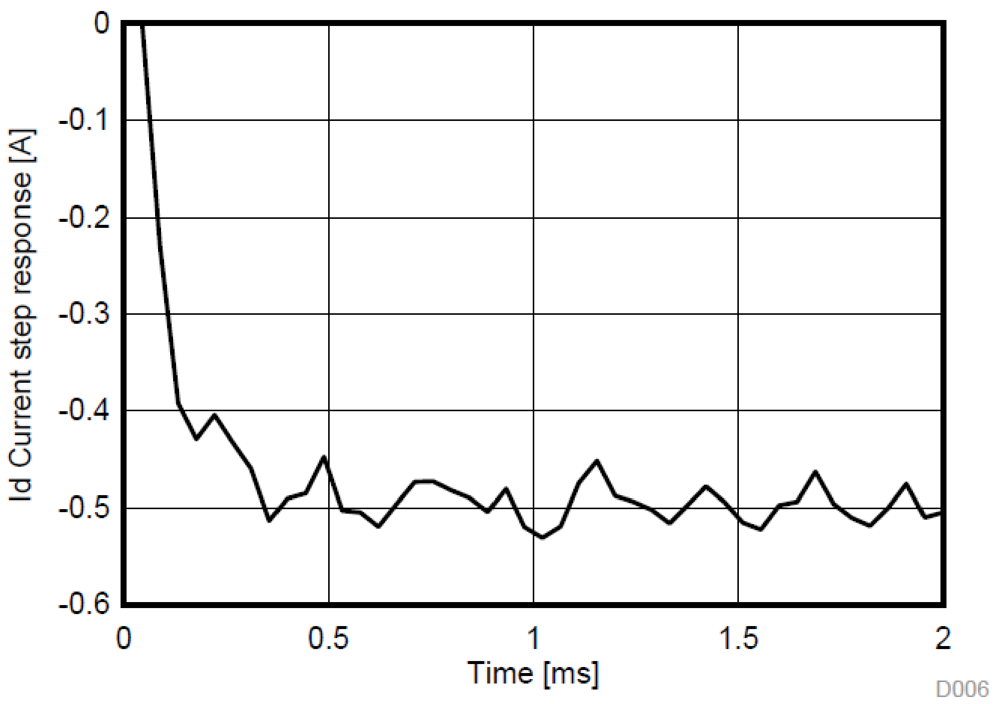
High-Speed Sensorless-FOC for drone ESC/
Challenges of FOC control



PI adjustment for your system

Angle and speed estimation does not need any more tuning

High speed motor
1200Hz equals 833us
Fast current loop
Current loop running at 22.5kHz equals 44us
Enables
Step response change is equal to approx. 400us

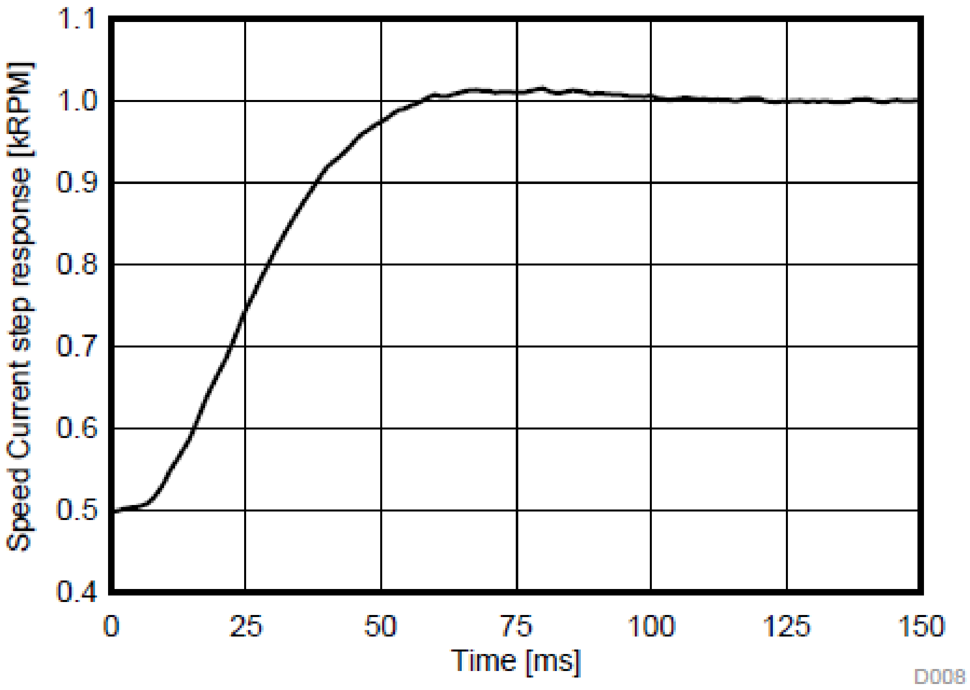


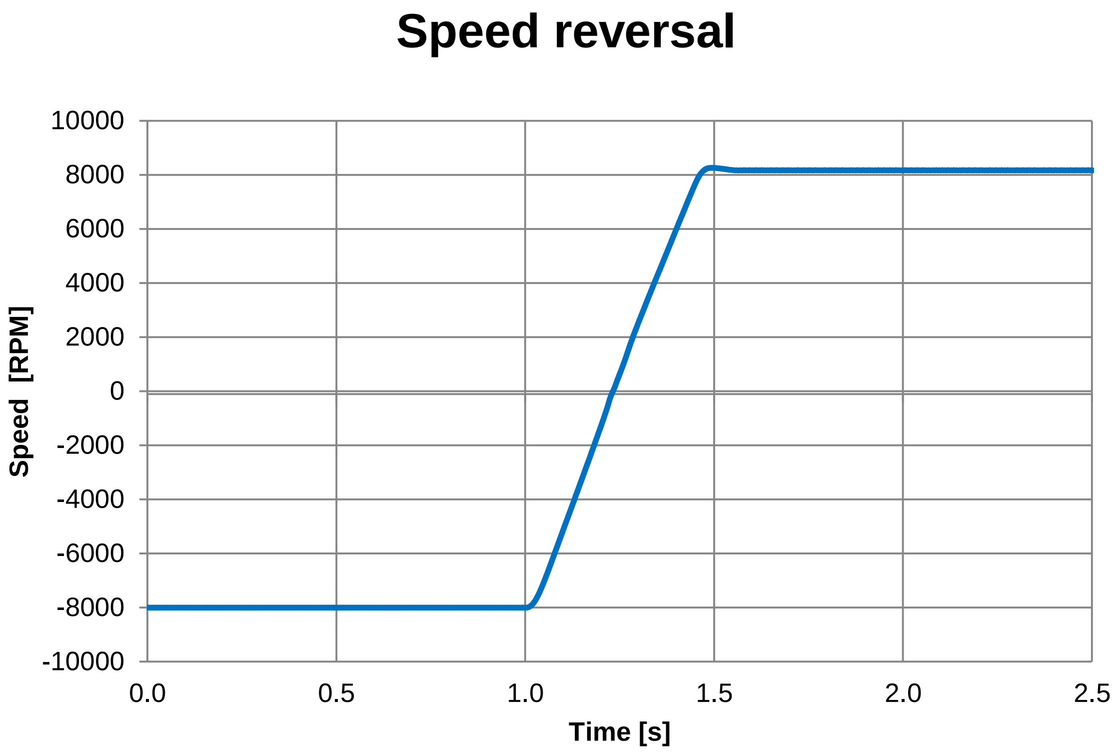
Meaning you can do approx. two speed changes
per stable step response of the electrical frequency of the motor

High-Speed Sensorless-FOC for drone ESC/ *Speed Controller Step Response*

Customer defined speed performance
Enable customer to differentiate with
their specific speed profiles and dynamics response

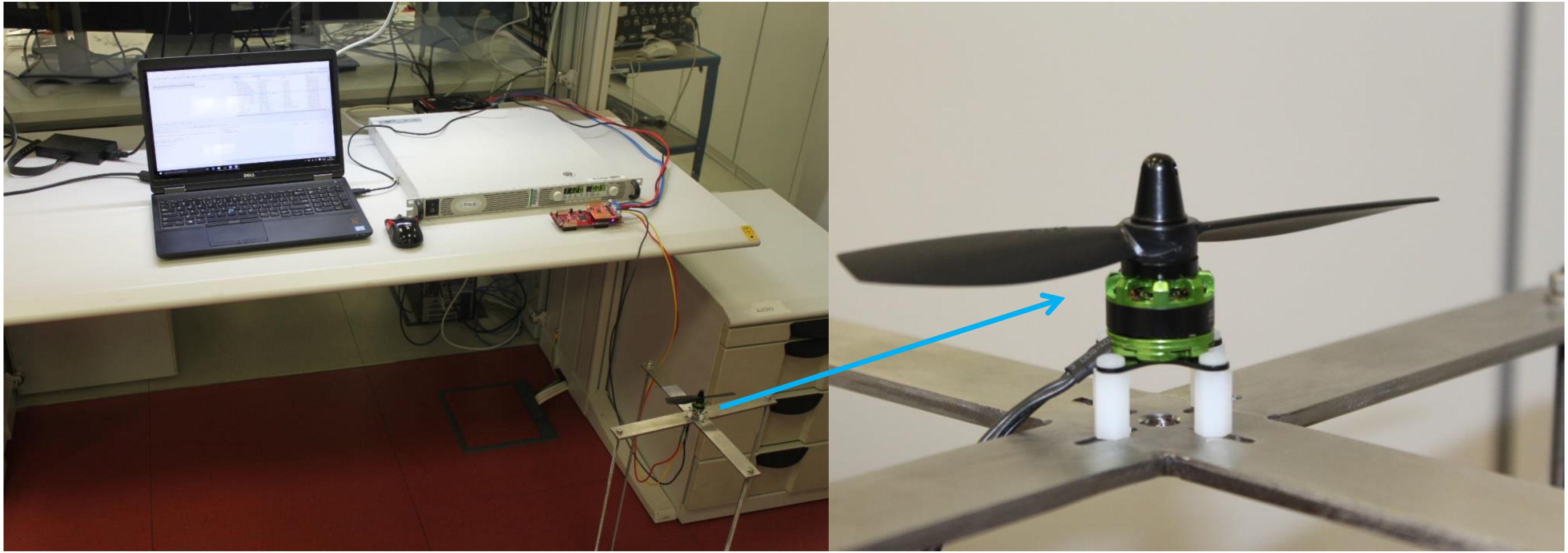
Step response shown
Showing the step response chosen for high speed signal





High dynamic performance during speed reversal with acceleration of 36,000 RPM/s

High-Speed Sensorless-FOC for drone ESC/ *Test setup*



Motor Size:
(DiameterxHeight): **21 x 15.5 mm**

High-Speed Sensorless-FOC for drone ESC/ *TI Design TIDA-00916*

Features

- High performance system solution for drone ESC using InstaSPIN™-FOC
- Sensorless high speed FOC control using TI's FAST™ software observer
- High dynamic speed performance 1krpm to 10krpm(100Hz to 1kHz) in <0.2 s
- Tested motor speed of 1.2kHz Electrically (12000rpm with 11.2V battery with a 6 pole pair motor)
- Leveraging InstaSPIN-Motion C2000 LaunchPad and DRV8305 BoosterPack
- Easy example firmware for C2000 LaunchPad using MotorWare
- Supports 2 cell to 6 cell LiPo as typically used in drones
- Phase currents rating of 15A (Peak 20A)

Benefits

- Avoids interference with ultrasonic sensor due to capability to run PWM above 45kHz
- High efficiency FOC allows longer flight time
- Faster time to market due to no tuning of sensorless algorithm required stable from zero to maximum speed
- No need to know and measure motor parameters enables cost reduction
- Fast speed reversal capability for roll movement
- Fast acceleration for high performance yaw and pitch movement

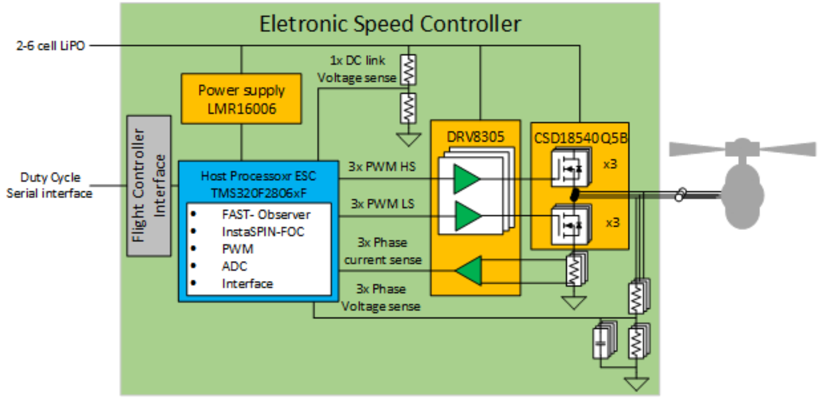
Target Applications

Non-military Drones
High speed low inductance, low voltage 3-phase brushless motors

Tools & Resources

Board Image

- **TIDA-00916 and Tools Folder**
- **Design Guide**
- **Design Files:** Schematics, BOM, Gerbers, MotorWare™, and more
- **Device Datasheets:**
  - DRV8305, TMS320F28069M, LMR16006, CSD18540Q5B



Battery Pack for drone

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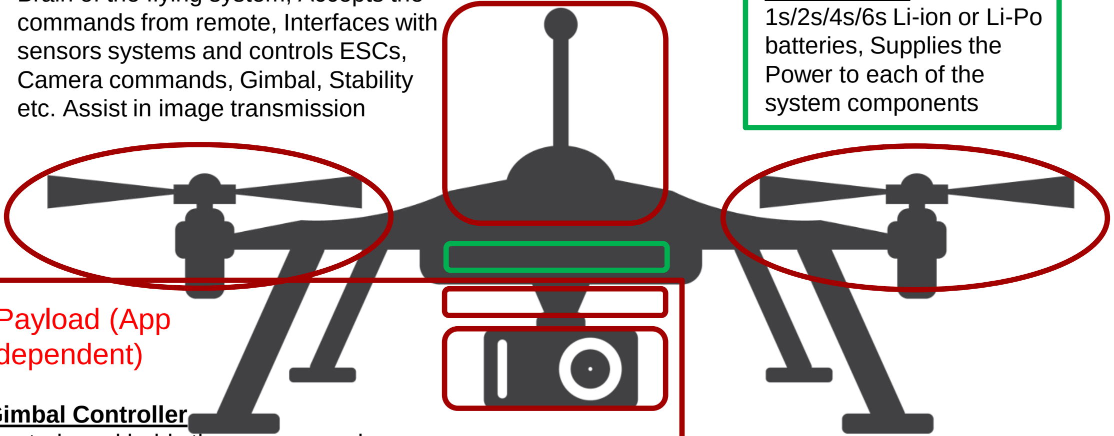

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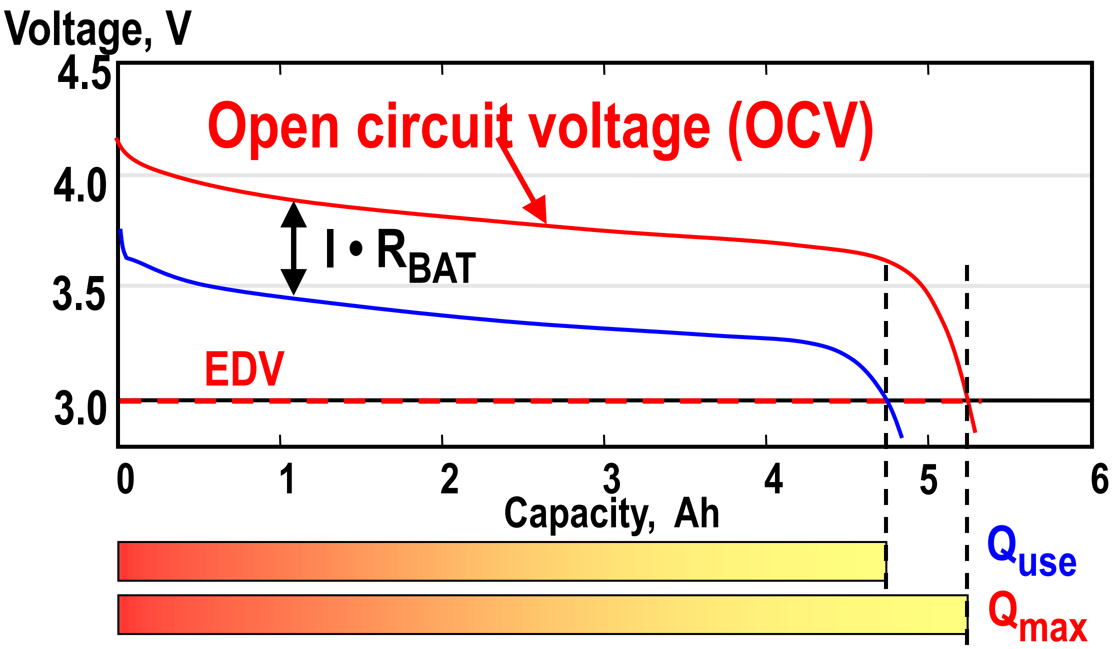
Basic remainder

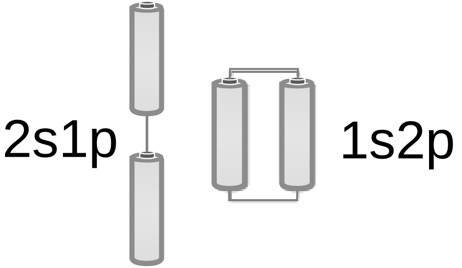


- External battery voltage (blue curve) $V = V_{0CV} - I \cdot R_{BAT}$
- Higher C-rate → EDV is reached earlier (higher $I \cdot R_{BAT}$)

C-rate:

Current to discharge a fully charged Battery to EDV in one hour

SOC= State Of Charge



CEDV= Compensated End Of Discharge

Basic remainder

- Safety
  - Over Voltage
  - Over Current
  - Over Temperature
- User experience
  - Under Voltage
  - Cell Imbalance

What are the problematic for Drones Battery Pack

- Small form factor
- Low cost
- Difficulty to have a accurate gauge du to high discharge rate (3 to 5C)
  - CEDV good from 1C to 25-50C
  - Possibility to use Impedance Track
- 2S-4S platform
- Easy to evaluate

What is in the TIDA-00984

- Battery Charger
- CEDV Battery Fuel Gauging (P2P with Impedance Track)
- Battery Protection
- Battery Pack Cell Balancing
- Onboard State of Charge (SOC)
- SMBUS Communications for Advanced Status Updates

Key Spec Charger

PARAMETER	SPECIFICATION	VALUE	UNIT
Charger efficiency	24V, 812-mA input -13.971 V, 1301-mA output	93	%
Charge voltage	Measured charge voltage	16.73	V
Charge current max	Measured charge voltage at max	1.311	A
Charger input minimum	Minimum voltage the charger would turn on	18	VDC
Charger input maximum	Maximum voltage the charger preformed to spec	28	VDC
Thermal test charger unit	(ambient 23.8°C) 1.3-A charge cycle	43	°C
Pre-charge complete	Comes out of pre-charge	3	V
Pre-charge minimum voltage	Minimum pre-charge voltage	2	V

Key Spec Protection

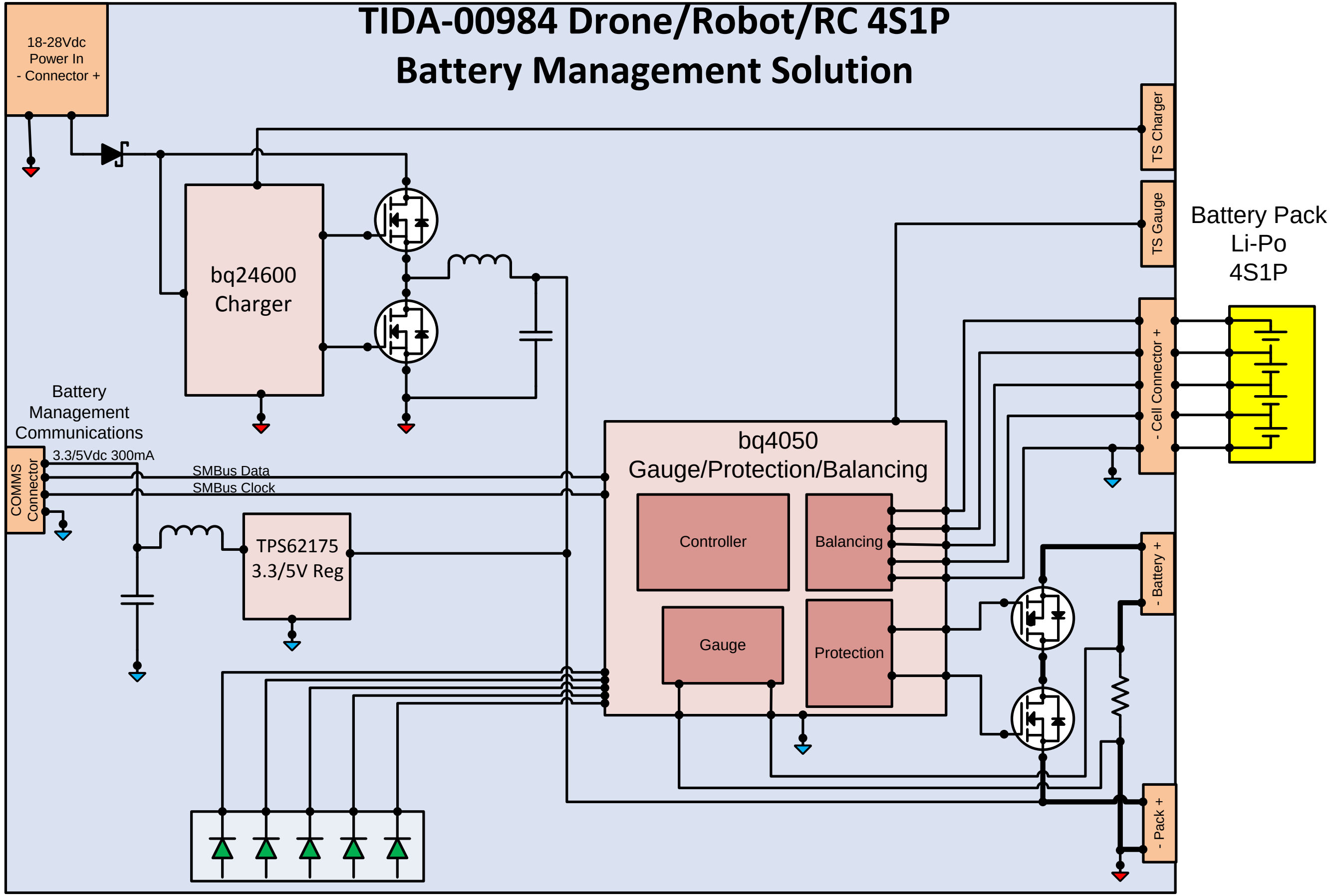
TIDesigns

PARAMETER	SPECIFICATION	VALUE	UNIT
OCD1 limit	Overcurrent limit during discharge	15000	mA
OCD1 delay	Overcurrent delay during discharge	20	S
OCD2 limit	Overcurrent limit during discharge	2,0000	mA
OCD2 delay	Overcurrent limit during discharge	10	S
AOLD limit	Analog front-end current overload limit	24	A
AOLD delay	Analog front-end current overload delay	15	mS
ASCD1 limit	Analog front-end short current limit 1	33	A
ASCD1 delay	Analog front-end short current delay 1	1,028	μs
ASCD2 limit	Analog front-end short current limit 2	44	A
ASCD2 delay	Analog front-end short current delay 2	244	μs

Key Spec other

PARAMETER	SPECIFICATION	VALUE	UNIT
Idle current for the gauge with regulator	Gauge active, MOSFETs on, gauge current for each cell, with a 3.3-V regulator	1.32	µA
Voltage regulator	Voltage of the 3.3-V regulator	3.31	VDC
Series impedance	Batt connector to pack connector series impedance, including MOSFET RDS's	0.0325	Ω
Thermal test under current for PCB	(ambient 23.8°C) 10-A constant current load	72	°C

Block Diagram



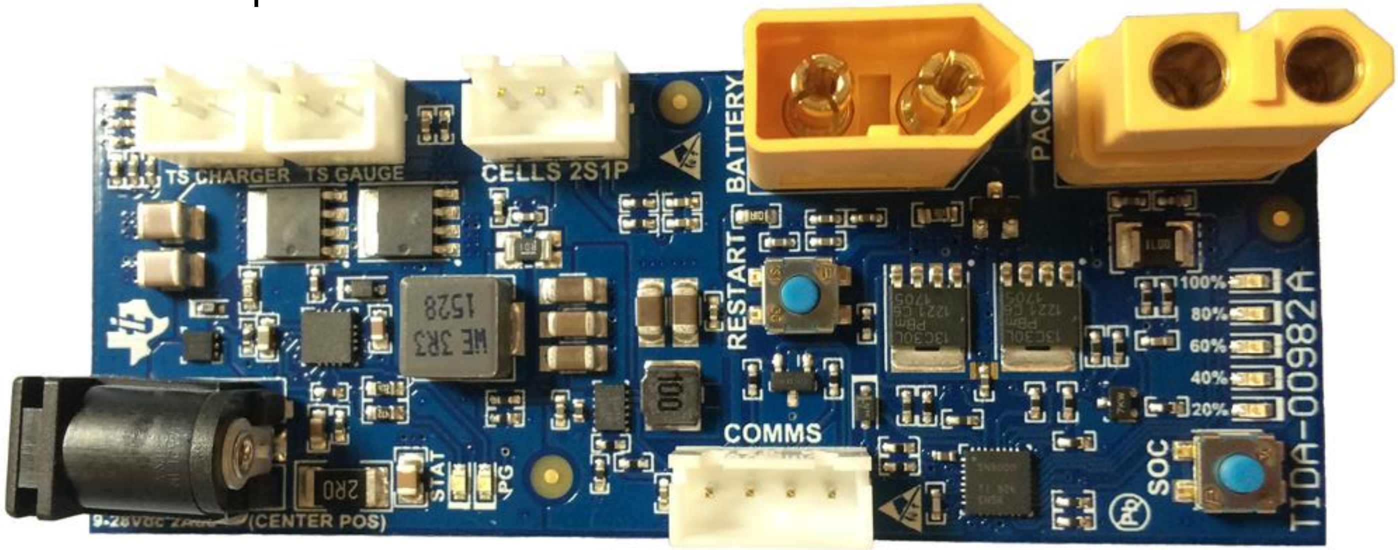
Board Picture

Charger and Gauge external temperature sensor input

Battery cells connector

Batteries High current connector

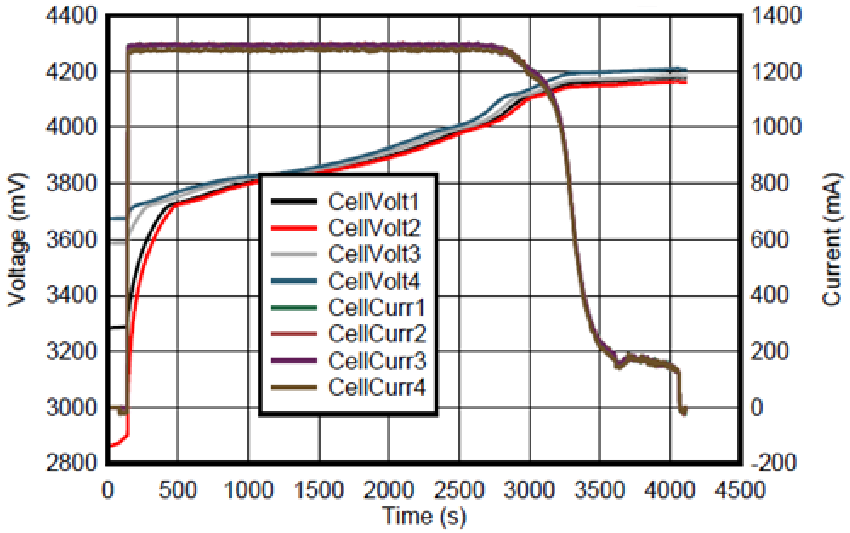
Pack High current connector



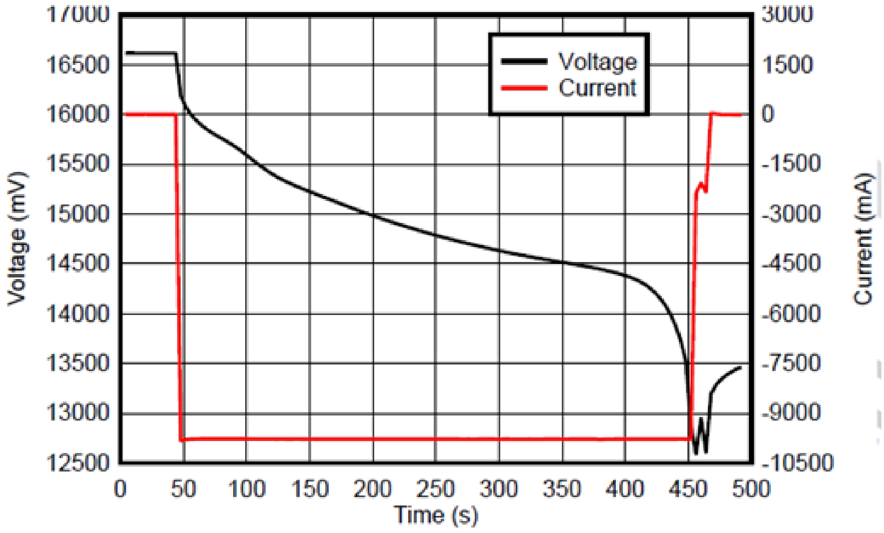
18 to 28VDC input

SMBus Communications and external supply

Charge and Discharge cycle

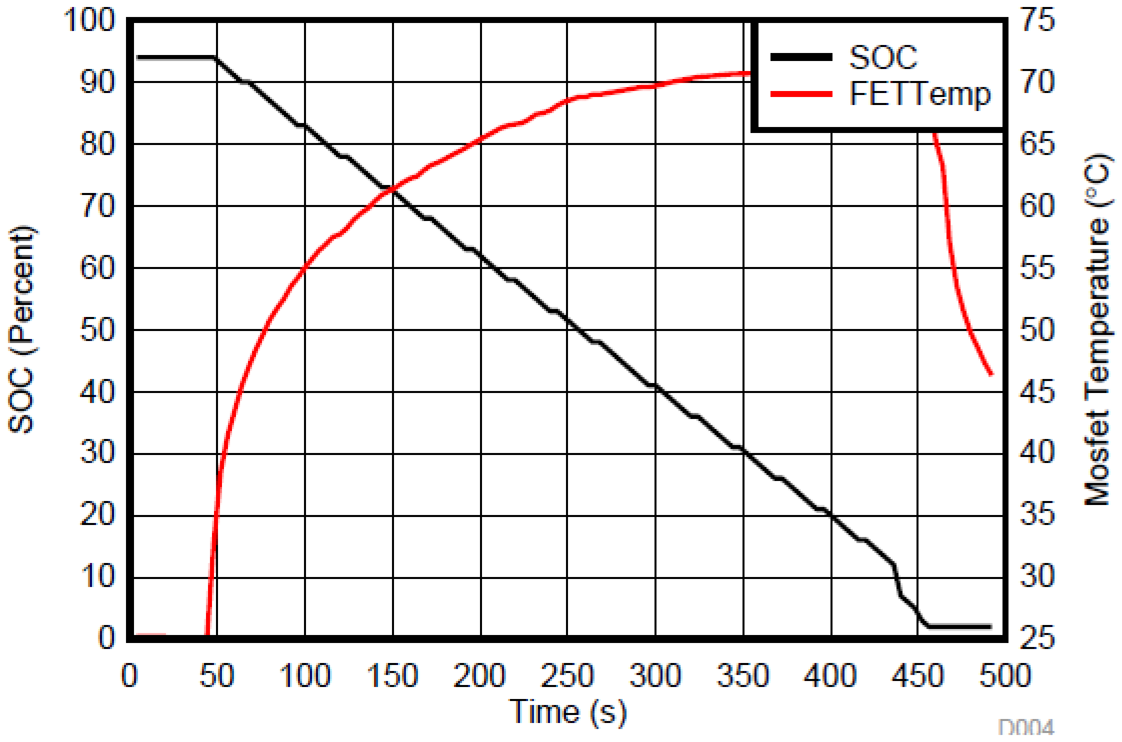


Charge Cycle

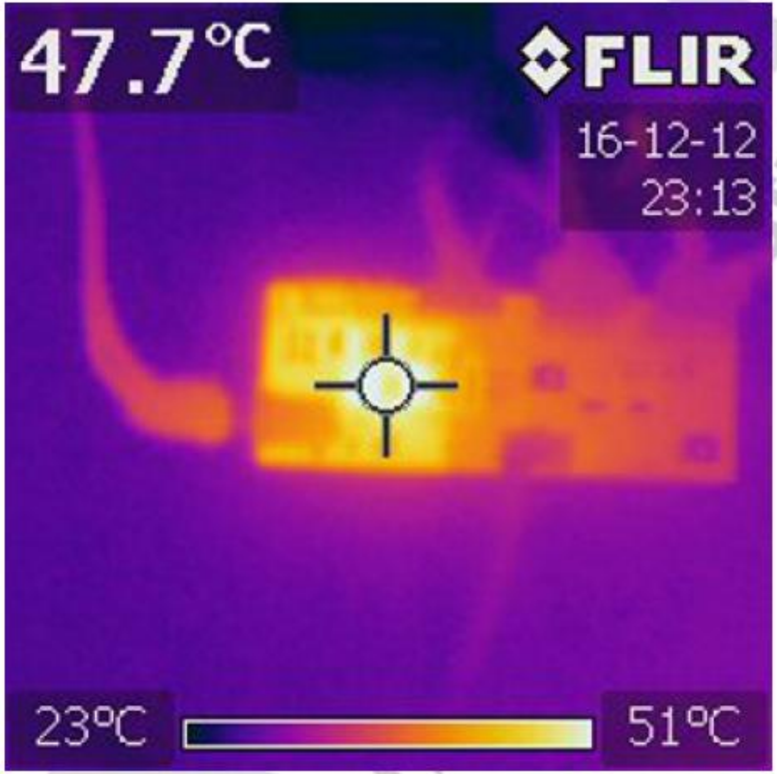


Discharge Cycle

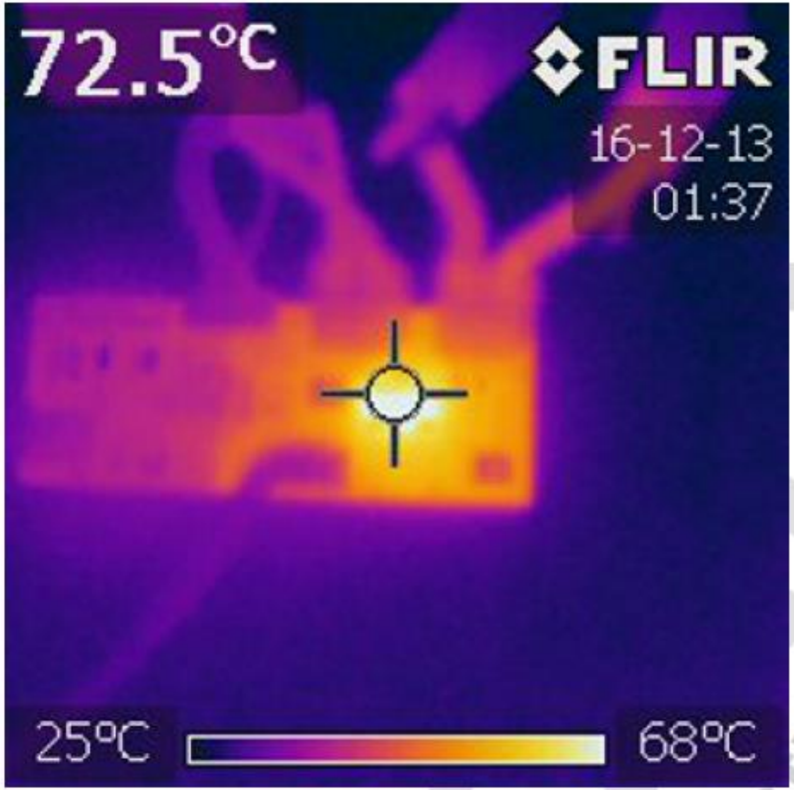
MOSFet temperature and SOC during a 10A Discharge



Thermal



1C Charge



10C Discharge

Non-Military Drone / Robot / RC 4S1P Battery Management Solution Reference Design *: TIDA-00984*

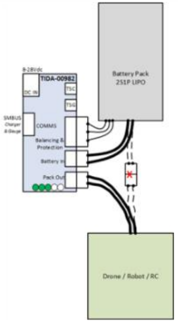
Features

- Subsystem for a 4S1P Battery Management Solution for Non-Military Drone, Robot or RC projects and designs
- bq24600 Charger
- bq4050 Gauge, Protection and Balancing
- TPS62175 Adjustable Switching Regulator

Target Applications

- Non-Military Drone, Robot, RC (Radio Controlled) Car, Airplane, Helicopter
- Alternate applications using the bq40Z50: Portable audio, Medical, IoT and other portable devices that use a 4S battery solution

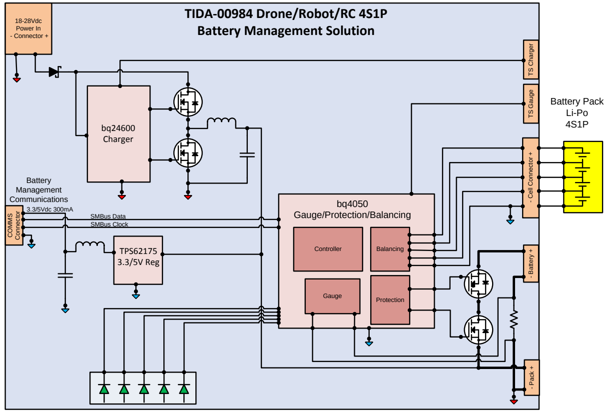
Tools & Resources



- **TIDA-00984 and/or Tools Folder**
- **Design Guide**
- **Design Files:** Schematics, BOM, Gerbers, Software, and more
- **Device Datasheets:**
  - bq4050 Product Folder
  - bq24600 Product Folder
  - TPS62175 Product Folder

Benefits

- Compensated end of discharge voltage (CEDV) gas gauge accurately measures available charge in Li-Ion and Li-Polymer batteries
- Integrated cell balancing while charging
- Programmable protection features for voltage, current, temperature, charge time out, CHG/DSG FETs and AFE
- Diagnostic lifetime data monitor and black box recorder for your battery
- On board 3.3V/5V 300mA regulator to run an external controller



Thank you for your attention!

References:
TI Designs showing 3 phase ESC:
TIDA-00916
TIDA-00643
For product selection on 3 phase ESC motor drivers:
TI 3 phase motor drivers
InstaSPIN-FOC:
Link
For more details on Motor Control:
Motor Control Compendium

References:
TI Designs for Drone Battery Pack:
TIDA-00982 – 2S
TIDA-00984 – 4S
TIDA-00553 - Multi-Cell Battery Manager Unit

Other TI Designs:
TIDA-00449 – 10s Battery Pack