EECE72545

Project Functional Requirements

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REVISION HISTORY

Revision	Description of Change	Effective Date
1.0	Initial Release	Jan 18, 2019
1.1	Updated Topics	Feb 15, 2019
1.2	PCB Layout Completion Update	Mar 8, 2019

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Document Scope

This project will consist of designing and building a controller board for a robot, to interface and control various actuators on the robot platform. The project will take about eight weeks, with 6 weeks devoted to designing schematics, and 2 weeks on PCB layout. The result will be a PCB with all components soldered, and ready to start programming.

This document outlines all the requirements for each component on the controller board, as well as the component chosen, the pins used to interface, any configuration options, and any necessary calculations for power, temperature, current, etc.

Cost Targets

The target cost for manufacturing of the PCB, parts, and soldering is $200CDN max. The cost of one PCB is $66USD.

Configuration Options

The controller board should include as many configurable options as possible to aid in debugging.

Hardware Description

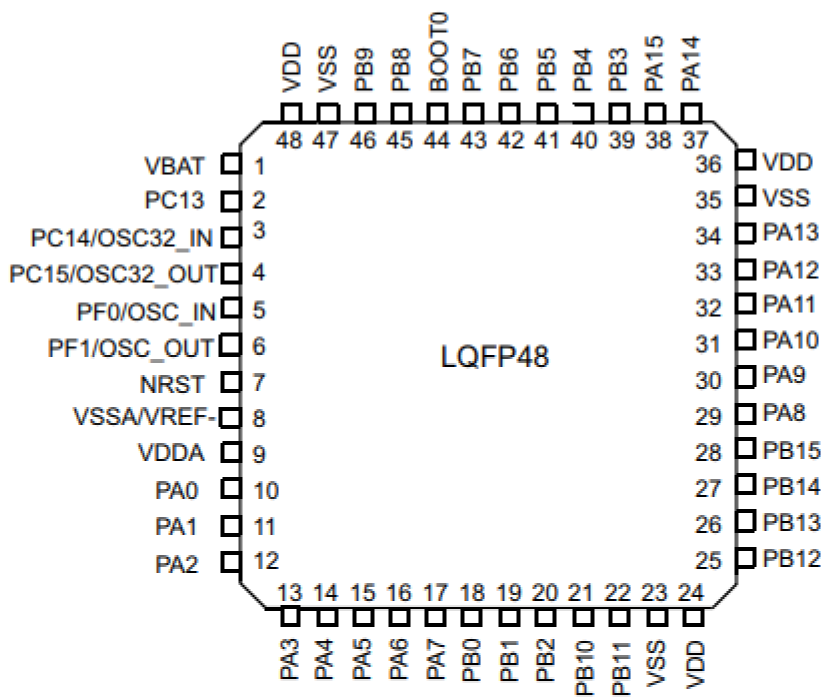
STM32F303RE Nucleo

The STM32F303RE Nucleo Development board includes the main processor for the controller board. It includes a programming interface, local power regulation, and breakouts for many of its pins. These pins interface with the rest of the Embedded Controller Board, and the pins include:

- Serial
- CANbus
- SPI
- I2C
- Timers
- ADC
- Power

Pin Table

The following described each pin of the STM32F303, and its function on the embedded controller board.



Pin	Function	Alternate Function	Description
PA0	CTS	USART2_CTS	Serial CTS (Clear to Send)
PA1	RTS	USART2_RTS	Serial RTS (Request to Send)
PA2	TX	USART2_TX	Serial TX (Transmit)
PA3	RX	USART2_RX	Serial RX (Receive)
PA4	LCD_RS		LCD RS signal
PA5	IO1		GPIO
PA6	TEMP1		NTC temperature sensor for DRV8814 DC motor driver
PA7	TEMP2		NTC temperature sensor for DRV8884 stepper motor driver
PA8	ENCL	TIM1_CH1	Left DC motor encoder
PA9	ENCR	TIM1_CH2	Right DC motor encoder
PA10	STP_FLT		DRV8884 fault output. Active-low LED
PA11	CAN_RX	CAN_RX	CANbus RX (Receive)
PA12	CAN_TX	CAN_TX	CANbus TX (Transmit)
PA15	SERVO	TIM2_CH1 or TIM8_CH1	Servo motor signal
PB0	LCD_E		LCD E signal

PB1	LIML		Left stepper motor limit switch
PB2	LIMR		Right stepper motor limit switch
PB3	STP_EN		DRV8884 enable
PB4	STP_DIR		DRV8884 direction
PB5	STP_STEP	TIM3_CH2 or TIM17_CH1	DRV8884 step
PB6	SPI_SS_SD		SD card SPI slave select(2)
PB7	BL_PWM	TIM4_CH2 or TIM3_CH4	LCD backlight PWM signal
PB8	I2C_SCL	I2C1_SCL	I^2C Serial Clock
PB9	I2C_SDA	I2C1_SDA	I^2C Serial Data
PB10	IO_INT		MCP23S08 interrupt signal
PB11	CAN_STBY		MCP2542 standby
PB12	SPI_SS	SPI2_NSS(1)	SPI slave select
PB13	SPI_SCK	SPI2_SCK	SPI Serial Clock
PB14	SPI_MISO	SPI2_MISO	SPI Master In Slave Out
PB15	SPI_MOSI	SPI2_MOSI	SPI Master Out Slave In
PC0	LCD_DATA1		LCD Data bit 1
PC1	LCD_DATA2		LCD Data bit 2
PC2	LCD_DATA3		LCD Data bit 3
PC3	LCD_DATA4		LCD Data bit 4
PC4	STP_SLP		DRV8884 sleep
PC5	DC_PHASEA		DRV8814 Phase A
PC6	DC_PHASEB		DRV8814 Phase B
PC7	ULTRA_SIG	TIM3_CH2 or TIM8_CH2	Ultrasonic output signal
PC8	DC_ENA	TIM3_CH3 or TIM8_CH3	DRV8814 enable A
PC9	DC_ENB	TIM3_CH4 or TIM8_CH4	DRV8814 enable B
PC10	DC_RST		DRV8814 reset
PC11	DC_SLP		DRV8814 sleep
PC12	DC_FLT		DRV8814 fault output. Active-low LED
PC13	RTC	RTC_OUT	Real-Time Cock output
PC14	ULTRA_TRIG		Ultrasonic trigger signal
PD2	HEARTBEAT		Heartbeat LED
RESET	RESET		STM32F303 & MCP23S08 reset signal. Active low
VBAT			RTC battery
AGND			Analog ground
GND			Ground

(1) SPI slave select can also be a GPIO pin. It is required to be a GPIO is there are more than one devices on the bus.

(2) Not connected to hardware SPI module. Slave select signal must be formed with GPIO

Serial

Serial communications will be used to control and receive messages from the Embedded Control Board. It will also aid in debugging. The serial communications will use 3V3 logic levels from the STM32 to a RS232 transceiver. The requirements for the serial transceiver are:

- 3-5V Supply Voltage
- Minimum 100Kbps data rate
- Minimum of 2 TX/RX pins (one of each); recommended 4 (two of each)
- Accepts ±25V RS232-levels
- Small package, SMD, ceramic charge-pump capacitors
- Leaded SMD package

Utilized device: ICL3232

The ICL3232 is a low power, 3-5.5V, RS232 transceiver with dual-transmitters and dual-receivers. The ICL3232 uses charge-pumps for RS232 voltage level generation, compatible with 0.1µF capacitors for PCB space reduction.

Critical specifications include:

Specification	Value	Condition
V_{CC}	3.3V	
Input Logic Threshold High	2V min.	VCC = 3.3V
Transmitter Output Voltage	±5V min.	
Transmitter Output Short Circuit Current	±60mA max.	
IC Package	16 TSSOP	
Number of Supporting Components	9 approx.	

The ICL2323 does not have significant thermal dissipation.
There are no hardware configuration options for serial.

Pin configuration:

- PA2 – This is the TX pin. It has an active-low LED
- PA3 – This is the RX pin. It has an active-low LED
- PA0 – This is the CTS pin
- PA1 – This is the RTS pin

There are 2 external connections for the serial module.

- DB9 connector – This connection is a standard Serial DB9 connector with TX, RX, CTS, DTS and GND
- Header – This connection is a 6-pin, 2.54mm header with TX and RX connections. This header is intended to interface with a HC-10 Bluetooth module.

CANbus

The Embedded Control Board will eventually connect to a CANbus network. A CANbus transceiver will interface to the integrated CAN controller in the STM32 via 3.3V logic levels. The requirements for the CANbus transceiver are:

- Compatible with 3.3V logic levels
- Integrated ESD and fault protection
- Low current standby
- High-speed CAN capable
- Leaded SMD package

Utilized device: MCP2542

The MCP2542 is a high-speed CANbus transceiver. The MCP2542 supports multiple CAN data rate standards (2.0 and FD), has separate logic and CANbus voltage supplies, and has several CANbus and self-protection features. Protections include ground fault, thermal, voltage transient, and unpowered bus disconnect protection, as well as meeting automotive EMC requirements.

Critical specifications include:

Specification	Value	Condition
V_{DD}	5V	
V_{IO}	3.3V	
Maximum Supply Current	140mA max.	Fault Condition
Transmitter Output Short Circuit Current	±115mA max.	
IC Package	8 SOIC	
Number of Supporting Components	9 approx.	

The MCP2542 does not have significant thermal dissipation when V_{DD} = 5V.

There are no hardware configuration options for CANbus.

Pin configuration:

- PA12 – This is the CANbus TX pin
- PA11 – This is the CANbus RX pin
- PB11 – This pin controls the MCP2542 standby (ON/OFF)

There are 1 external connection1 for the CANbus module.

- There is one, 4-pin 2.54mm headers for CANbus TX, CANbus Rx, 5V and GND

DC Motor

The Embedded Control Board will control two brushed DC motors, each with a IR LED-based encoder. The DC motor driver must be able to drive both DC motors, independently, in both directions. Protection systems are a requirement. The motor driver must operate at the maximum battery voltage. Low $R_{DS(ON)}$ for cooler operation is a desirable feature. The requirements for the DC motor driver are:

- Compatible with 3.3V logic levels
- Integrated over-current, thermal and fault protection
- Low current standby
- 14.8V supply voltage capable
- $R_{DS(ON)}$ <=500mΩ
- Leaded, thermally enhanced SMD package

Utilized device: DRV8814

The DRV8814 dual H-bridge DC motor driver, with a phase/enable interface, programmable decay and current control, sleep mode, and 1.75A RMS output current per H-bridge. The DRV8814 includes over-current protection, thermal protection, and an open-drain fault output. The operating voltage of the DRV8814 is 8-45V.

Critical specifications include:

Specification	Value	Condition
V_{VM}	14.8V max.	
Continuous Output Motor Current	2.5A peak/1.75A RMS	25°C
Logic Level Input High	2V min	
RDS(ON) HIGH/LOW	0.25Ω/0.25Ω max.	25°C
Operating Junction Temperature	150°C max.	
IC Package	28 HTSSOP w/ PowerPad	
Number of Supporting Components	19 approx.	

Worse case power dissipation (V_M = 14.8V, I_{OUT} = 1.5A, 25°C):

$$P_{RDS(ON)} = (2)\left(R_{DS(ON)HS+LS}\right)\left({I_{OUT}}^2\right) = (2)(0.525\Omega)(1.5A^2) = 2.36W$$

$$P_{SW} = (V_M)(I_{OUT})\left(t_{F,R}\right)(f_{SW}) = (14.8V)(1.5A)(300ns)(50KHz) = 0.333W$$

$$P_{IVM} = (V_M)(I_{IVM}) = (14.8V)(5mA) = 0.074W$$

$$P_{LDO} = (V_M - V_{LDO})(I_{LDO\ OUT}) = (14.4V - 3.3V)(1mA) = 0.0115W$$

$$P_{TOTAL} = P_{RDS(ON)+}P_{SW} + P_{IVM}+P_{LDO} = \mathbf{2.775W}$$

Worse case IC temperature:

$$T_J = T_A + (P_{TOTAL})(R_{\theta JA}) = 25°C + (2.775W)\left(31.6\ {}^{°C}/_{W}\right) = \mathbf{112.7°C}$$

112.7°C is well below the max operating junction temperature for the DRV8814 of 150°C.

Hardware configurations:

- AI1 – This jumper sets one of two current limit bits for H-bridge A of the DRV8814
- AI2 – This jumper sets two of two current limit bits for H-bridge A of the DRV8814
- BI1 – This jumper sets one of two current limit bits for H-bridge B of the DRV8814
- BI2 – This jumper sets two of two current limit bits for H-bridge B of the DRV8814

Pin configurations:

- PC8 – This is the Enable input pin for H-bridge A. It will be configured as a PWM on TIMx, and activates or deactivates the DC motor
- PC5 – This is the Phase input pin for H-bridge A. It controls the direction of the DC motor
- PC9 – This is the Enable input pin for H-bridge B. It will be configured as a PWM on TIMx, and activates or deactivates the DC motor
- PC6 – This is the Phase input pin for H-bridge B. It controls the direction of the DC motor
- PC10 – This is the Reset input pin for the DRV8814
- PC11 – This is the Sleep input pin for the DRV8814
- PC12 – This is the Fault output pin of the DRV8814. This pin has an active-low LED

There are 2 external connections for the DC motor.

- There are two, 2-pin 2.54mm headers. Each for a DC motor
- There is a test pin on the VREF pin

The motor encoders use LED interruption to create a signal proportional to the speed of the DC motors. The maximum frequency of the signal will be approx. 2Khz. A low-pass RC filter will filter out higher-frequency noise, and an inverting Schmitt trigger will provide signal conditioning and additional noise filtering.

Utilized device: 74LVC2G14
The 74LVC2G14 is a dual-inverting Schmitt trigger, compatible with 3V and 5V logic devices.

Critical specifications include:

Specification	Value	Condition
$\mathbf{V_{CC}}$	14.8V max.	

Logic Level Input Low	0.55V max.	V_{CC} = 3V
Logic Level Input High	2.3V min.	V_{CC} = 3V
Hysteresis	0.73V typ.	V_{CC} = 3V
Total Power Dissipation	250mW max.	
IC Package	SOT-363	

The 74LVC2G14 does not have significant thermal dissipation.

There are no hardware configurations for the 74LVC2G14.

Pin configurations:

- PA8 – This is the left encoder signal. It is an input to the STM32F303
- PA9 – This is the right encoder signal. It is an input to the STM32F303

There are 2 external connections for the serial module.

- There are two, 3-pin 2.54mm headers. Each has an encoder signal, 3V3 with current limiting resistor, and a GND pin

Camera Module

The camera module includes the servo motor, stepper motor, and limit switches.

Servo

The servo motor needs a PWM signal for operation. The STM32F303 can provide this signal without any external ICs and minimal components.

Pin configuration:

- PA15 – This is the signal for the servo motor. It will be configured as a PWM on TIMx

There are 2 external connections for the servo motor.

- There is one, 3-pin 2.54mm headers. The header has 5V, signal and GND
- There is a test pin on the signal pin

Stepper Motor

The Embedded Control Board will control a stepper motor, with two limit switches to indicate the rotational limits in both directions. The stepper driver must be able to drive a unipolar motor. Protection systems are a requirement. The stepper driver must operate at the maximum battery voltage. Low RDS(ON) for lower temperature operation is a desirable feature. The requirements for the stepper motor driver are:

- Compatible with 3.3V logic levels
- Step/direction controls • Integrated over-current, thermal and fault protection
- Low current standby
- 14.8V supply voltage capable • RDS(ON) <=1Ω
- Mixed decay mode
- Leaded, thermally enhanced SMD package

Utilized device: DRV8884

The DRV8884 is a quad half H-bridge stepper motor driver, with step/direction control, with programmable microstepping, programmable decay, sleep mode, and 700mA RMS output current per bridge. The DRV8884s step/direction has an integrated step pattern. The DRV8814 includes over-current protection, thermal protection, and an open-drain fault output. The operating voltage of the DRV8814 is 8-37V.

Critical specifications include:

Specification	Value	Condition
V_{VM}	14.8V max.	
Continuous Output Motor Current	1A peak/700mA RMS	25°C
Logic Level Input High	1.6V min	
RDS(ON) HIGH/LOW	0.798Ω/0.749Ω max.	25°C
Operating Junction Temperature	150°C max.	
IC Package	24 HTSSOP w/ PowerPad	
Number of Supporting Components	14 approx.	

Worse case power dissipation (V_M = 14.8V, I_{OUT} = 0.4A, 25°C):

$$P_{RDS(ON)} = \left(R_{DS(ON)HS}\right)\left({I_{OUT}}^2\right) + \left(R_{DS(ON)LS}\right)\left({I_{OUT}}^2\right)$$

$$= (0.798\Omega)(0.4A^2) + (0.749\Omega)(0.4A^2) = 0.247W$$

$$P_{SW} = (V_M)(I_{OUT})\left(t_{F,R}\right)(f_{SW}) = (14.8V)(0.4A)(100ns)(50KHz) = 0.029W$$

$$P_{IVM} = (V_M)(I_{IVM}) = (14.8V)(5mA) = 0.074W$$

$$P_{TOTAL} = P_{RDS(ON)} + P_{SW} + P_{IVM} = \mathbf{0.35W}$$

Worse case IC temperature:

$$T_J = T_A + (P_{TOTAL})(R_{\theta JA}) = 25°C + (0.35W)\left(31.6\ {}^{°C}/_{W}\right) = \mathbf{36.0°C}$$

36.0°C is well below the max operating junction temperature for the DRV8884 of 150°C.

Hardware configurations:

- M1, M2 – These jumpers set the microstepping setting for the DRV8884

Pin configurations:

- PB3 – This is the Enable input pin. It activates or deactivates the stepper motor
- PB5 – This is the Step input pin. It steps the stepper motor. It will be configured as a PWM on TIMx
- PB4 – This is the DIR input pin. It controls the direction of the stepper motor
- PC4 – This is the Sleep input pin for the DRV8884
- PA10 – This is the Fault output pin of the DRV8884. This pin has an active-low LED

There are 2 external connections for the serial module.

- There is one, 4-pin 2.54mm header
- There is a test pin on the VREF pin

The limit switches activate when the camera module reaches either the left or right rotational limits. Limit switches exhibit switch bounce on activation A low-pass RC filter, and an inverting Schmitt trigger will provide switch debouncing.

Utilized device: 74LVC2G14
For a description of the 74LVC2G14, see the DC Motor section of this document.

There are no hardware configurations for the 74LVC2G14.

Pin configurations:

- PB1 – This is the left limit switch. It is an input to the STM32F303
- PB2 – This is the right limit switch. It is an input to the STM32F303

There is 1 external connection for the stepper motor.

- There are two, 2-pin 2.54mm headers. Each has a signal, and a GND pin

LCD

The LCD module will display information in text form. It must be powered by 3.3V or 5V, and use a low pin-count interface. A backlight would be beneficial. The requirements for the LCD are:

- HD44780 compatible interface
- Compatible with 3.3V logic levels
- Low pin-count interface
- Through-hole, 0.1” pin header connection

Utilized device: 0216K1Z by Newhaven Display

The 0216K1Z is a low power, 16x2, FSTN negative, LED backlight LCD module. It is HD44780 compatible, and will be used in 4-bit parallel, write only mode. The LCD has contrast control, and a blue LED backlight, with PWM dimmable interface.

Critical specifications include:

Specification	Value	Condition
V_{DD}	5V	
Logic Level Input High	$0.7V_{DD}$ min.	
LED Backlight Voltage	5V typ.	
LED Backlight Current	8mA typ.	
Number of Supporting Components	7 approx.	

The 0216K1Z does not have significant thermal dissipation.

Hardware configurations:

- R16 – This potentiometer sets the contrast for the LCD

Pin configurations:

- PA4 – This is the RS input pin for the LCD
- PB0 – This is the E input pin for the LCD
- PC0, PC1, PC2, PC3 – These are the data pins for the 4-bit interface of the LCD
- PB7 – This is the backlight PWM signal for the LCD. It is connected to the gate of a N-MOSFET to increase the current available.

There are 3 external connections for the LCD module.

- There is one, 16-pin 2.54mm header
- There is a test pin on the LCD contrast pin
- There is a test pin on the Backlight PWM pin

IO Expander

An IO expander will provide 8 additional digital GPIO, as the STM32F303RE does not have many free IO pins left. The IO expander should utilize a bus – either SPI or I^2C. The requirements for the IO expander are:

- Utilizes SPI or I^2C bus
- Compatible with 3.3V logic levels
- Leaded, thermally enhanced SMD package

Utilized device: MCP23S08

The MCP23S08 is an 8 port, SPI interface IO expander. It also has two address pins, and an interrupt pin that triggers on pin change.

Critical specifications include:

Specification	Value	Condition
V_{DD}	3.3V	
Max SPI Clock	10MHz	
V_{DD} Current	125mA max.	
Pin Current	25mA max.	
Number of Supporting Components	5 approx.	

The MCP23S08 does not have significant thermal dissipation.

There are no hardware configurations for the MCP23S08.

Pin configurations:

- PB12 – This is the Slave Select input pin for the MCP23S08
- PB13 – This is the Serial Clock input pin for the MCP23S08
- PB14 – This is the Master In, Slave Out pin for the MCP23S08
- PB15 – This is the Master Out, Slave In pin for the MCP23S08
- RESET – This is the Reset pin for the MCP23S08. It is directly connected to the Reset pin on the STM32F303
- PB10 – This is the IO Interrupt pin output for the MCP23S08

There are 3 external connections for the MCP23S08:

- There is 1, 20-pin, dual row, 2.54mm header. It has 8 pins for the MCP23S08 GPIO, and also breaks out SPI, RESET, RTC (PC13), I^2C, 5V, 3V3, and GND
- There is 1, 2-pin 2,54mm header for an additional GPIO from the STM32F303 (PA5)
- There is a test pin on the Reset pin

Temperature Sensors

Each motor driver has a NTC thermistor for it. While both motor drivers have thermal protection, there are also benefits to knowing and monitoring the temperature of the motor drivers. Prolonged high temperatures can have long-term, detrimental effects on ICs. Knowing the temperature, and the slope of temperature change can help predict and diagnose problems. The expected temperatures are from 10°C - 150°C. A lower resistance tolerance (<= 1%) is preferred.

Critical specifications include:

Specification	Value	Condition
Resistance	10KΩ	25°C
Temperature Range	-40°C to 180°C	
B25/85	3500K typ.	

POWER

There are several external components at the input of the battery voltage. These components protect the circuitry on the PCB. These components are:

- Reverse protection diode – This is a low V_f Schottky diode that protects against VBAT and GND being accidentally swapped at the input terminals.
- There are two input terminals: a 2.1mm(ID) x 5.5mm(OD) barrel jack, and a 2-pin, 3.5mm screw terminal. Both can be used for VBAT, and the unused can be used as an auxiliary VBAT output
- There are two ceramic capacitors as close to the input terminals as possible for input noise reduction.

Critical specifications for the Schottky diode include:

Specification	Value	Condition
V_f	500mV	@ 8A
$V_{DC\ REVERSE}$	40V	
$I_{AVERAGE\ RECTIFIED}$	8A max.	
IC Package	DO-214AB, SMC	

Power Budget

The Embedded Controller Board will use two power supply voltages, in addition to the battery voltage. The 3V3 power rail will be supplied by the 5V rail. The linear conversion from 5V to 3V3 is assumed to be 50% efficient. The following is the power budget (worse case) for the 5V and 3.3V rails, with 20% extra calculated:

Rail	Budget (+20%)	Power
3V3	32mA	106mW
5V	557mA	2.919W
Total		**3.025W**

5V Switching Power Supply

The 5V power supply will power many parts of the Embedded Controller, as well as the servo motor. A switching power supply will provide efficient power conversion. The requirements for the 5V switching power supply are:

- 5V output voltage
- Greater than 14.8V maximum input voltage
- Minimum 700mA output current
- Better than 85% efficiency at >100mA output current
- Compatibility with low-ESR ceramic output capacitors
- Small, leaded SMD package

Utilized part: TPS562201

The TPS562201 is a 2A, synchronous buck converter. The TPS562201 provides fast transient response, has internal compensation, is compatible with low-ESR output capacitors, and has high efficiency at small loads. The TPS562201 also has soft-start, output over-current protection, under-voltage lockout, and thermal shutdown protection. The TPS562201 has an input voltage of 4.5-17V. The 580KHz operating frequency of the TPS562201 is sufficiently far from the 50KHz internal PWM frequency of the motor drivers.

Hardware configuration:

- There is a single jumper on the output of the TPS562201 that disconnects it from the rest of the board

Pin configuration:

- The output of the TPS562201 is connected to an inductor, which is connected to an active-high LED

There are no external connectors for the TPS562201.

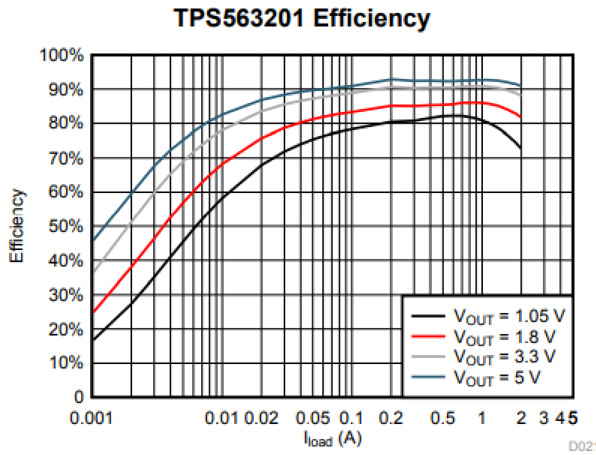


Figure 1: TPS562201 efficiency. ***5V output voltage***

Critical specifications include:

Specification	Value	Condition
V_{INPUT}	4.5-17V	
V_{OUTPUT}	0.76-7V	
Internal Current Limit	4A max.	
Switching Frequency	580KHz	L_1 = 2.2µH
RDS(ON) HIGH/LOW	0.14Ω/0.084Ω typ.	25°C
IC Package	6-SOT-23 THIN	
Number of Supporting Components	11 approx.	

The design parameters for the 5V switching power supply are:

Parameter	Value
Input Voltage	12-14.8V
Output Voltage	5V
Output Current	1A

Worse case power dissipation (I_{OUT} = 1A, 25°C):

The following method was taken from TI: Application Report AN-1566 "Techniques for Thermal Analysis of Switching Power Supply Designs"

$$P_{BIAS} = I_q \times V_{IN} = 750\mu A \times 14.8V = 0.011W$$

$$P_{COND} = Duty \times \left[\left(R_{DS(ON)HS} \times {I_{OUT}}^2\right) + \left(R_{DS(ON)LS} \times {I_{OUT}}^2\right)\right]$$
$$= 35\% \times [(0.14\Omega \times 1A^2) + (0.084\Omega \times 1A^2)]$$
$$= 0.078W$$
$$P_{SW} = \frac{(I_{OUT} \times V_{IN})}{2} \times f_{SW} \times (t_R + t_F)$$
$$= \frac{(1A \times 14.8V)}{2} \times 580KHz \times (50ns) = 0.215W$$
$$P_{TOTAL} = P_{BIAS} + P_{COND} + P_{SW} = 0.31W$$

Worse case IC temperature:

$$T_J = T_A + (P_{TOTAL})\left(R_{\theta JA}\right) = 25°C + (0.31W)\left(90.8\ {}^{°C}/_{W}\right) = \mathbf{53.1°C}$$

53.1°C is well below the max operating junction temperature for the TPS562201 of 125°C. *Using the TI WEBENCH online tool, the power dissipation of the TPS562201, using the same conditions, was calculated to be 0.35W, with a junction temperature of 46°C, however, it uses a Θ_{JA}=60°C/W. This value is different than the value in the datasheet, which was used in the above calculation.*

Component selection calculations:

Output Voltage Resistors:

$$V_{OUT} = 0.768 \times \left(1 + \frac{R5}{R6}\right)$$

Choosing R6 = 10K, gives

$$R5 = \left(\frac{10000V_{OUT}}{0.768}\right) - 10000 = \mathbf{56K}\Omega$$

The inductor value and output capacitor(s) value(s) were chosen from Table 2 of the TPS562201 datasheet.

The inductor peak-to-peak current is:

$$I_{P-P} = \frac{V_{OUT}}{V_{IN(MAX)}} \times \frac{\left(V_{IN(MAX)} - V_{OUT}\right)}{L_O \times f_{SW}}$$
$$= \frac{5V}{14.8V} \times \frac{(14.8V - 5V)}{4.7\mu H \times 580KHz} = \mathbf{1.21A}$$

The inductor peak current is:

$$I_{PEAK} = I_O + \frac{I_{P-P}}{2} = 1A + \frac{1.21A}{2} = \mathbf{1.60A}$$

The RMS inductor current is:

$$I_{RMS} = \sqrt{{I_O}^2 + \frac{1}{12}{I_{P-P}}^2} = \mathbf{1.12A}$$

Utilized part: **74404064047**

Using TI WEBENCH, the following parameters were calculated:

Parameter	Value (Ideal)
Duty Cycle	35.02%
Efficiency	93.1%
$V_{OUT\ P-P}$	7.72mV

3V3 Linear Power Supply

The 3V3 power supply will power several lower power parts of the Embedded Controller. While the Nucleo has its own 3V3 regulator, an external regulator will have greater current capacity for external devices. It could also have better regulation and noise characteristics, and thermal regulation. Powering devices from 3V3 can simplify interfacing between devices, as no level converters are needed. The requirements for the 3V3 power supply are:

- 3V3 output voltage
- 5V input voltage
- Minimum 100mA
- Small, leaded SMD package with good thermal dissipation

Utilized part: CAT6219

The CAT6219 is a 500mA low-dropout linear regulator. The CAT6219 is compatible with low-ESR output capacitors and has a 300mV dropout voltage. The CAT6219 also has a quick-start feature, under-voltage lockout, current limit, and thermal protection.

Critical specifications include:

Specification	Value	Condition
V_{INPUT}	2.3-5.5V	
V_{OUTPUT}	3V3	
Internal Current Limit	500mA max.	
PSRR	>54dB	10nF bypass cap
IC Package	TSOT-23	
Number of Supporting Components	7 approx.	

Power dissipation:

$$P_D = (V_{IN} - V_{OUT}) \times I_{OUT} = (5.0 - 3.3) \times 32mA = 4.89mW$$

Worse case IC temperature:

$$T_J = T_A + (P_{TOTAL})(R_{\theta JA}) = 25°C + (0.00489W)\left(235\,{}^{°C}/_{W}\right) = 26.15°\boldsymbol{C}$$

Hardware configuration:

- There is a single jumper on the output of the CAT6219 that disconnects it from the rest of the board

Pin configuration:

- The output of the CAT6219is connected to an inductor, which is connected to an active-high LED

There are no external connectors for the CAT6219.

Power Monitor

In order to monitor voltage and current from the batteries, a power monitor IC will be used. The power monitor should be accurate at low current and should use low value current sense resistors to minimize power consumption. The power monitor should use the SPI or I^2C bus. The requirements for the 3V3 power supply are:

- Minimum 14.8V input voltage
- Minimum 4A current sensing
- Small, leaded SMD package

Utilized part: INA219

The INA219 is an I2C current and power monitor. The INA219 has programmable averaging, gain amplifiers, and calibration registers. The INA219 uses the voltage drop across a low-value current sense resistor, along with the sensed voltage to monitor voltage, current and power. For increase thermal dissipation, two resistors are used in parallel. There is a low-pass filter on each input, consisting of a 10R series resistor and a 100nF capacitor.

Critical specifications include:

Specification	Value	Condition
V_{SENSE}	0-26V	
V_{SUPPLY}	3-5V	
Current Sense Error	<2.0% @ >100mA >0.6% @ >1A	25°C, 0.025Ω Sense Resistor
IC Package	SOT-23-8	
Number of Supporting Components	6 approx.	

The INA219 does not have significant thermal dissipation.
Error values calculated using TI website INA219 Error Analysis Tool.

Hardware configuration:

- JMP3 – This jumper sets the address bit A1. It connects to either 3V3 or GND

Pin configurations:

- PB8 – This is I^2C Serial Clock input to the INA219. It has a 3K3 pullup resistor
- PB9 – This is I^2C Serial Data input to the INA219. It has a 3K3 pullup resistor

Extras

There are several “extras” implemented on the embedded controller board. There are also GPIO, SPI, and I^2C pins on headers for interfacing with other external modules.

Ultrasonic Sensor

There is a header for a HC-SR04 ultrasonic sensor.

Bluetooth Module

There is a header for a HC-5/6/10 Bluetooth module. This will be capable of sending and receiving serial over Bluetooth.

LED Indicators

Many circuits on the embedded controller board have LEDs to show status, data, or other necessary information. A table of LEDs, their description, and their associated current-limiting resistor value is shown:

LED	Description	Resistor Value
5V Power	Green. Indicates 5V power is on.	470Ω
Heartbeat	Blue. Indicates STM32F303 is running main loop.	470Ω
TX	Green. Indicates Serial TX activity.	1.2KΩ
RX	Red. Indicates Serial RX activity.	680Ω
DC Fault	Red. Indicates DC motor driver in fault state.	1KΩ
Stepper Fault	Red. Indicates DC motor driver in fault state.	1KΩ

Configuration Jumpers

Configuration jumpers on the embedded controller board set many functions. A table of jumpers, their description, and their associated default setting is shown:

Jumper(s)	Description	Default Indicator
AI0, AI1	Selects current limit for DC H-Bridge A. 11 = disabled, 10 = 38%, 01 = 71%, 00 = 100%	00
BI0, BI1	Selects current limit for DC H-Bridge B. 11 = disabled, 10 = 38%, 01 = 71%, 00 = 100%	00
M1, M2	Selects microstepping setting for stepper motor. 00 = Full Step, 01 = 1/16 Step, 10 = ½ Step, 11 = ¼ Step	00
5V	Enables 5V power.	-
3V3	Enables 3V3 power.	-
JMP3	Selects bit 1 of INA219 address.	0

Environmental Requirements

The embedded controller board must be able to work reliably in temperatures from 10°C to 40°C.