TEXAS INSTRUMENTS

Application Report
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Hardware Design Considerations for an Electric Bicycle Using a BLDC Motor

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ABSTRACT

A traditional bicycle is a two-wheel vehicle that is propelled by the rider who delivers muscle power through pedals that rotate one of the two wheels. The rider steers the front wheel to create a force that returns and maintains the vehicle center of gravity into a stable zone whenever necessary, thus keeping the bicycle upright. An electric bicycle carries batteries that deliver electric power to a motor that is coupled to either wheel. In most electric bicycles the rider can chose to use muscle power to deliver all, part, or none of the propulsion power required to maintain an adopted travel speed. Some models even sense pedal pressure and command the motor to deliver more power whenever the rider pedals harder.

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1 Introduction

A controller for an electric bicycle must deliver power that varies from zero to the rated peak of the propulsion-motor, at motor speeds corresponding to bicycle speeds from zero to 48 km per hour (30 mph). With DC propulsion motors, power can be controlled with pulse-width modulated (PWM) transistors. AC motors need variable frequency. Hardware requirements for design of an electric-bicycle control are postulated and basic blocks along with their usage are shown.

An electric bicycle has a conventional bicycle frame, pedals, cranks, chain, and freewheel assembly. Electric propulsion replaces or supplements muscle power. This adds to the bicycle an electric motor, gear reducer, battery, and power control. The following defines the requirements of an electric bicycle:

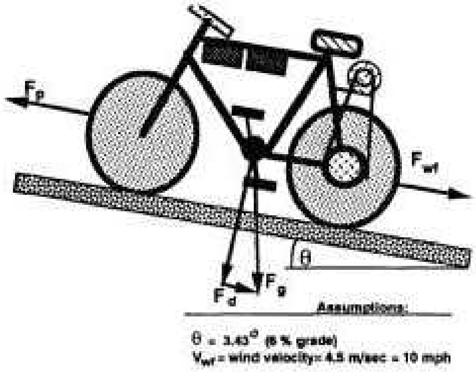
- The complete bicycle must have the lowest practical mass. All mass must be hauled over hills with energy supplied by the battery. Lower mass gives more range between recharging of the battery.
- Bicycle stability is another important requirement. Total mass need not affect stability, but the placement of mass is important.

Table 1 lists the range of mass that is considered to be propelled.

Table 1. Range of Mass

COMPONENT	MASS IN KG
Bicycle assembly	10
Motor and gear	6
Power control	1
Battery	6
Cyclist	80
Total weight	106

Figure 1 shows the required power to develop the necessary wheel torque for the indicated travel conditions:



F_{wf} = windage and friction drag

F_d = downhill force from gravity

F_P = propulsion force = $F_{wf} + F_d$

V_b = bicycle speed = 20 km/hr

F_d = m sin x = 106 kg × 0.06 × 9.8 = 63 N

$P_d = F \times V_b$ = 63 × 5.56 m/s = 350 W

Headwind speed = 25 km/hr, adds 30-W power to propel

Figure 1. Range of Mass

Hence the power required by the motor to propel the bicycle and rider is 380 W.

2 Motor Selection

Table 2 lists the comparisons of the different DC Motors available.

Table 2. DC Motors

TYPE	ADVANTAGES	DISADVANTAGES	TYPICAL APPLICATION	Typical Drive
Stepper DC	Precision positioning Stepper DC High holding torque	Slow speed Requires a controller	Positioning in printers and floppy drives	Multiphase DC
Brushless DC electric motor	Long lifespan Low maintenance High efficiency	High initial cost Requires a controller	Hard drives CD/DVD players Electric vehicles	Multiphase DC
Brushed DC electric motor	Low initial cost Simple speed control	High maintenance (brushes) Limited lifespan	Treadmill exercisers Automotive starters Toys	Direct (PWM)

Based on Table 2, a BLDC motor can be selected for its advantages.

Brushless Direct Current (BLDC) motor is a type of synchronous motor, where magnetic fields generated by both stator and rotate have the same frequency. The BLDC motor has a longer life because no brushes are needed. Apart from that, it has a high starting torque, high no-load speed and small energy losses. The BLDC motor can be configured in 1-phase, 2-phase, and 3-phase. Three-phase motors are the most popular among all the configurations and are widely used in e-bikes.

The structure of a BLDC motor is divided into two parts:

- Moving part called the rotor, represented by permanent magnet
- Fixed part called the stator, represented by phase windings of magnetic circuit

3 Stator

The stator of a BLDC motor consists of stacked steel laminations with windings placed in the slots that are axially cut along the inner periphery. Traditionally, the stator resembles an induction motor; however, the windings are distributed in a different manner. Most BLDC motors have three stator windings connected in star fashion. Each winding is constructed with numerous coils that are interconnected to form a winding. One or more coils are placed in the slots and they are interconnected to make a winding. Each winding is distributed over the stator periphery to form an even number of poles.

4 Rotor

The rotor is made of permanent magnet and can vary from two to eight pole pairs with alternate North (N) and South (S) poles

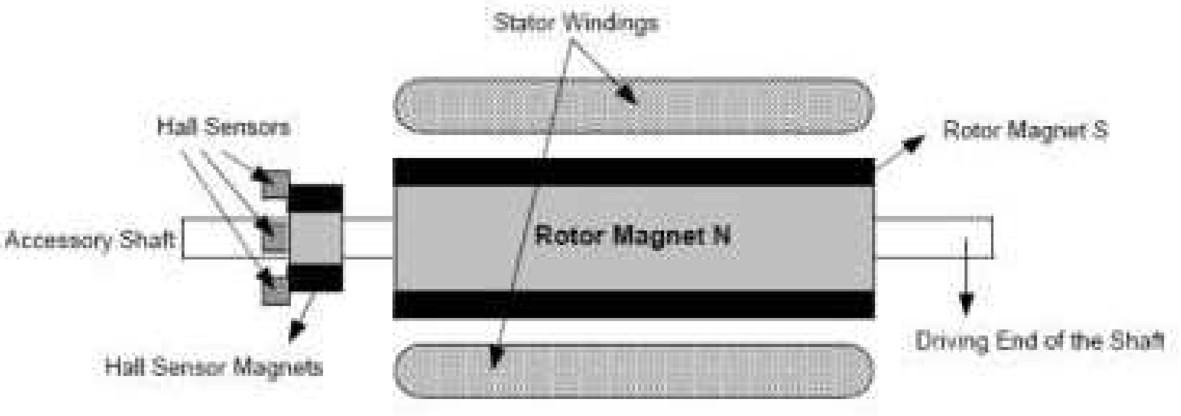


Figure 2. BLDC Motor Mechanical Structure

Unlike a brushed DC motor, BLDC motor can be controlled electronically. To rotate the BLDC motor, the stator windings must energized in a special sequence. The rotor position must be known in order to understand which winding will be energized next. The rotor position is sensed using Hall Effect sensors that are embedded in the stator.

Most BLDC motors have three Hall sensors embedded in the stator on the non driving end of the motor. Whenever the rotor magnetic poles pass near the Hall sensors, they generate a high or low signal, which indicates that N or S pole is passing near the sensors. Based on the combination of these Hall Sensor signals, the exact sequence of commutation can be determined.

Because of the increasing popularity of ebikes, motors designed specifically for ebike applications are now commercially available. These motors vary a great deal in how they are mounted to a bicycle and in how the power is applied to them

The following power train and motor types have multiple examples in the market today:

Belt-drive transmission—a specially designed motor is mounted low in the frame, and drives the rear wheel by use of a belt

Direct drive (in-line chain-drive)— this method has the motor working with the primary bicycle chain—the same chain that the rider uses when pedaling. Gearing for the motor varies with each manufacturer.

Frame-mounted motor with dedicated chain drive—another common method is to mount a motor to the bicycle frame near the hub of the rear wheel, often on one side. The motor has its own small chain that drives a planetary gear on the rear wheel. This specialized chain is separate from the primary bicycle chain that remains in use with the bicycle pedals. Gearing remains specific to the manufacturer or aftermarket motor conversion kit.

Wheel-mounted disk motor—this is a *pancake* or *dish plate* motor, sometimes even called a *Frisbee motor*, installed on one or both wheels. These motors can be placed on both wheels, effectively doubling the power available to the rider. However, these motors increase weight and centrifugal force on wheels.

Hub motor—ideally, the term *hub motor* refers to a motor that replaces the hub of a wheel. Sometimes this can be a flat disk motor, other times it is not a disk motor. In either case, the motor is the hub—instead of being mounted beside it or near it.

Friction-based shaft—this type of electric drive installs the motor very close to one wheel. A shaft extends from the motor, and this rotating shaft drives the wheel by spinning in direct contact with it. The motor does not interact with the chain. Multiple gears for the motor are rarely supported.

Geared transmission-style shaft drive—this type of electric drive is like a shaft-driven motorcycle. The cycle does not have a chain. The motor and the pedals apply power to a sealed and protected shaft that has bevel gears in front and back. Multiple gears (speeds) are supported.

Table 3 summarizes of the previously describe drive train types.

Table 3. Types of Drive Train

POWERTRAIN TYPE	ADVANTAGES	DISADVANTAGES
Belt-drive transmission	• Allows for a great deal of customization in design • Silent operation	Might reduce the performance of pedaling when motor is not used
Direct drive (conventional in-line chain)	• No additional chain needed • Monocoque frames can hide the motor with great protection • The motor might inherit as many gears as are available to the rider. • Low center of gravity	• Perceived (standard) drag upon the chain • Chain remains visible, perhaps vulnerable to dirt • Potential for noise
Frame-mounted motor with dedicated chain	• A dedicated chain can attain good power transfer without complications • A dedicated chain can attain good power transfer without complications	• A second chain and planetary gear are required • Multiple gears for the motor may or may not be available. • Multiple gears for the motor may or may not be available.
Wheel-mounted disk motor (pancake motor)	• The most efficient approach so far • No planetary gears or spinning shafts are needed for power • Retains good protection from elements	• Places a great deal of weight in the wheels, with potential handling issues at higher speed. • Multiple gears for the motor may or may not be present.
Hub-motor (non-disk)	• No interaction with the primary bicycle chain required • No additional transmission required	• Adds weight to the wheel • Torque factors can enter operational considerations. • Un-sprung weight or mass
Friction-based shaft drive	• Inexpensive • Easy to mount • By far the most mechanically simple concept	• Inefficient—no gearing • Friction wears out tires. • Pressure against the shaft might strain motor functions over time. • Motor must sustain very high RPMs at higher cycle speeds.
Geared transmission-style shaft drive	• Multiple gears are common • Multiple gears are common	Changing tires and reinstalling the wheel may become more demanding than with other methods

Based on the information listed in Table 3, a 500-W rear hub motor is selected with the following performance details:

- Model: HBS36R
- Rear Hub Motor Voltage: 36 V (brushless)
- Power Rate: 500 W
- Weight: 5 Kgs

Table 4.

DESCRIPTION	U (V)	I (A)	P1 (W)	M (Nm)	n (RPM)	P2 (W)	EFFICIENCY (%)
No load	36.11	1.521	54.93	0.28	343.5	10.07	18.3
Maximum efficiency	35.9	10.92	392.4	10.24	298.3	319.8	81.4
Maximum output power	35.78	18.43	659.7	18.24	266.1	508.1	77
Maximum torque	35.78	18.43	659.7	18.24	266.1	508.1	77
End	35.78	18.43	659.7	18.24	266.1	508.1	77

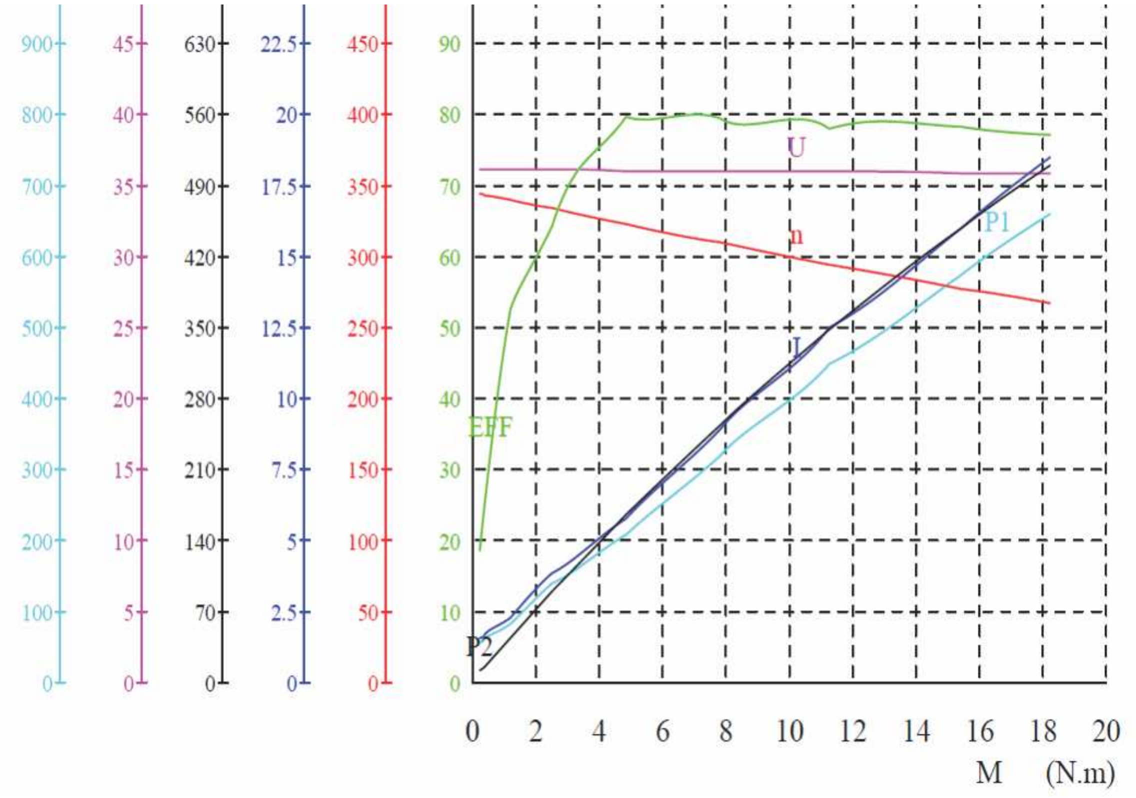


Figure 3.

Table 5.

Number	U (V)	I (A)	P1 (W)	M (Nm)	n (RPM)	P2 (W)	EFFICIENCY (%)
1	36.11	1.521	54.93	0.28	343.5	10.07	18.3
2	36.11	1.504	54.32	0.28	343	10.05	18.5
3	36.11	1.534	55.4	0.36	343	12.92	23.3
4	36.1	1.706	61.6	0.44	342.4	15.77	25.6
5	36.1	1.864	67.3	0.61	341.7	21.82	32.4
6	36.1	1.935	69.89	0.86	340.9	30.69	43.9
7	36.09	2.27	81.94	1.21	339	42.94	52.4
8	36.09	2.532	91.38	1.44	338.2	50.98	55.7
9	36.06	3.314	119.5	2.02	335.1	70.87	59.2
10	36.05	3.829	138	2.54	333.5	88.69	64.2
11	36.04	4.231	152.5	3.29	329.4	113.4	74.3
12	36.01	5.016	180.6	3.89	326.6	133	73.6
13	36	5.731	206.3	4.87	321.9	164.1	79.5
14	35.97	6.746	242.6	5.69	318.2	189.5	78.1
15	35.94	7.715	277.3	6.88	312.6	225.1	81.1
16	35.92	8.87	318.6	7.83	308.7	253	79.4
17	35.9	10.16	634.8	8.78	304.8	280.1	76.7
18	35.9	10.92	392.4	10.24	298.3	319.8	81.4
19	35.88	1.44	446.4	11.28	294.2	347.4	77.8
20	35.87	13.42	481.6	12.8	287.7	385.5	80
21	35.86	14.64	525	13.89	283.5	412.2	78.5
22	35.83	15.99	573.1	15.46	276.7	447.8	78.1
23	35.81	17.11	612.9	16.61	273.1	474.9	77.4
24	35.78	18.43	659.7	18.24	266.1	508.1	77

Figure 4.

4.1 Battery Selection

See the following equations to calculate the range from amperage and voltage:

$$\text{Ah (Amp hours)} \times \text{V (volts)} = \text{Wh (Watt hours)} \quad (1)$$

Select a 48-V, 10-AH battery with 480 Wh.

$$\text{P (power)} = \text{Work / t (time)} \quad (2)$$

$$\text{P} \times \text{t} = \text{Work} = \text{Force} \times \text{distance} \quad (3)$$

$$\text{Force} = \text{mass} \times \text{acceleration} \quad (4)$$

$$\text{Distance} = \text{Wh / Force} \quad (5)$$

$$\text{Distance} = \text{Wh / Force} \quad (6)$$

Electric bicycles are often restricted to a speed of 30 km/h across level ground. A larger wattage increases the range and can increase the uphill torque, however, a larger wattage does not typically increase the maximum speed which is restricted.

From the previously listed equations, a 480-Wh battery can roughly provide a range of total 55 km.

Table 6 lists a comparison of the different battery types available.

Table 6. Available Battery Types

POWER TRAIN TYPE	ADVANTAGES	DISADVANTAGES
Lead-Acid (sealed)	• Inexpensive and simple to manufacture • Mature, reliable and well-known technology • Low self-discharge—the self-discharge rate is among the lowest in rechargeable batteries. Capable of high discharge rates. • Low self-discharge—the self-discharge rate is among the lowest in rechargeable batteries. Capable of high discharge rates.	• Not to be stored in a discharged condition • Low energy density—poor weight-to energy density • Environmentally unfriendly—the electrolyte and the lead content can cause environmental damage.
Lithium-Ion	• Highest energy density to weight ratio • Eliminates need for periodic care for a long life • Has no memory effect • Achieves a better cost-performance ratio for battery packs in series than for single cell • Is arguably better for the environment, from a raw materials viewpoint, to other options • • Li-ion-Cobalt is the most developed Li-ion technology, with flexible shape options	• All lithium-ion technologies require a protection circuit to prevent overheating • All lithium-ion technologies require a protection circuit to prevent overheating • Can damage easily by over charge or discharge
NiCD	• Fast and simple charge—even after prolonged storage • High number of charge and discharge cycles—if properly maintained • Good load performance—the NiCD allows recharging at low temperatures • Long shelf life in any state-of-charge • Forgiving if abused—the NiCD is one of the most rugged rechargeable batteries • Economically priced — the NiCD is the lowest cost battery in terms of cost per cycle. • Available in a wide range of sizes and performance options	• Relatively low energy density when compared with newer systems • Memory effect—the NiCD must periodically be exercised to prevent memory • Environmentally unfriendly—the NiCD contains toxic metals • Some countries are limiting the use of the NiCD battery • Has relatively high self-discharge—needs recharging after storage

Table 6. Available Battery Types (continued)

POWER TRAIN TYPE	ADVANTAGES	DISADVANTAGES
NiMH	• 30%-40% higher capacity over a standard NiCD. The NiMH has potential for yet higher energy densities. • Less prone to memory than the NiCD. Periodic exercise cycles are required less often • Environmentally friendly—contains only mild toxins; profitable for recycling • NiMH generates more heat during charge and requires a longer charge time than the NiCD • About 20% more expensive than NiCD	• Limited service life—shallow rather than deep discharge cycles preferred • Repeated discharges with high load currents reduce the battery's cycle life • High self-discharge—NiMH has about 50% less stored shelf life than NiCD • Performance degrades if stored at elevated temperatures • High maintenance—requires regular full discharge to prevent crystalline formation

Based on the information listed in Table 6, a Li-ion battery is selected. The LFP-4810S 48-V, 10-AH battery is selected with the following performance specification:

- Maximum discharge current: 35 A (12 AH) and 60 A (16 AH)
- Maximum continuous discharge current: 20 A (12 AH) an 30 A (16 AH)
- Charging cycles: >800 times

This battery are high capacity LiFePO4 battery packs specifically designed for an e-Bike application. These batteries come with a light-weight (5.5 kgs) aluminum casing and secure connector. A universal charger with the following specifications is available off the shelf

- AC input: 85 V_{AC} to 265 V_{AC}
- Charger output: 54 V at 2 A

4.2 Controller Selection

Figure 5 shows a typical block diagram for the complete control of the selected motor.

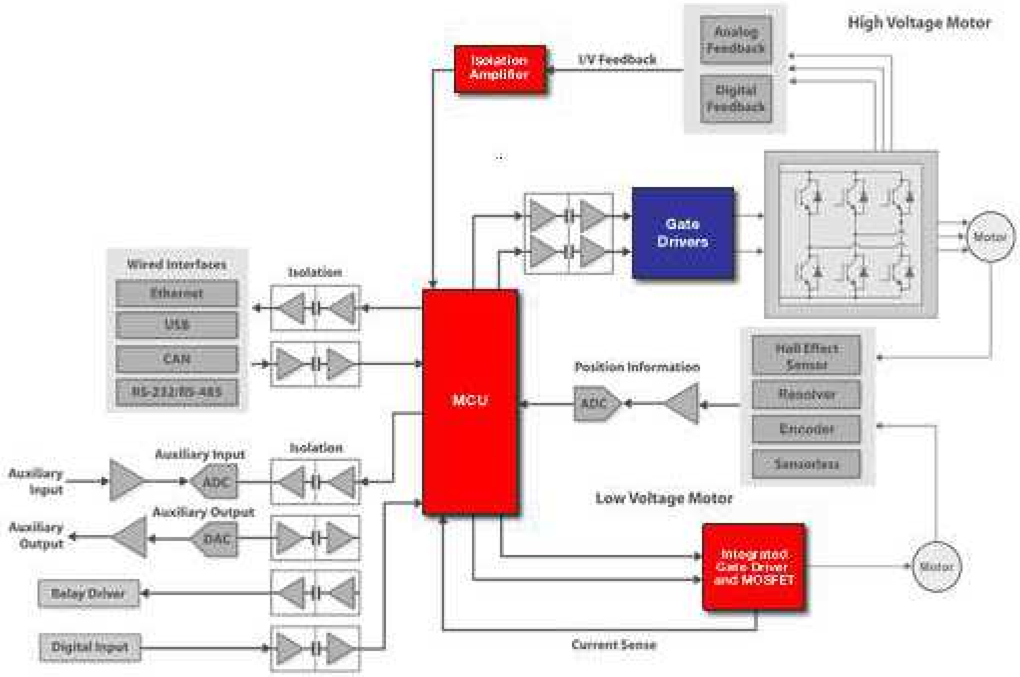


Figure 5. Typical Controller Block Diagram

5 Key Electrical Characteristics of E-Bike Controller

The following lists the key electrical characteristics of an e-bike controller:

- Rated voltage: 48 V_{DC} (Li-ion Battery pack)
- Rated power: 500 W
- Motor speed: 0 to approximately 30 km/h variable-speed by handlebar
- Speed restriction: Maximum 20 km/h (by Jumper)
- Battery undervoltage protection: 41.5 ± 0.5 V

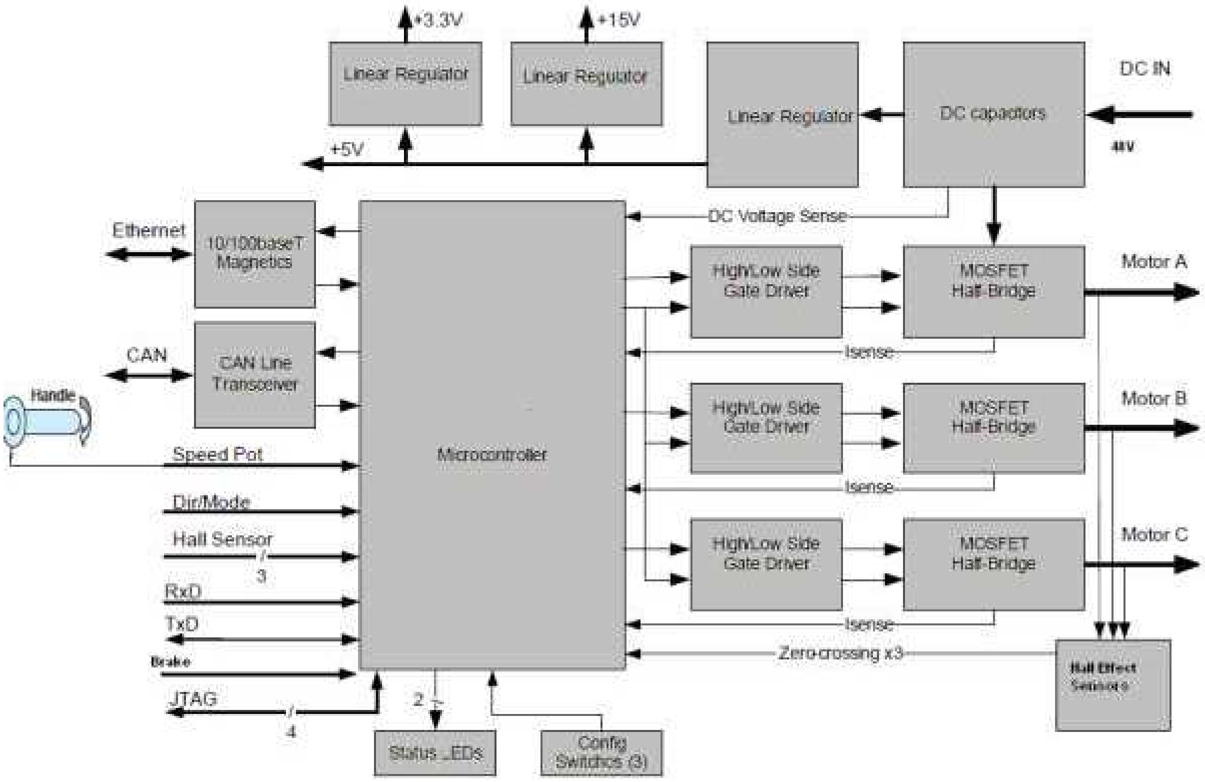


Figure 6. Hardware description

5.1 Sensing Mechanisms

	HALL-EFFECT SENSOR	SENSORLESS (BACK-EMF)
Type	Directly senses rotor field	Indirectly senses rotor field
Mounting	In or on motor	N/A
Speed range	All speeds	Medium to high
Applications	Constant and variable torque	Best suited to variable torque
Motor shakes at startup	No	Sometimes
Cost	Medium	Very low
Reliability	Medium	High

The chosen motor has Hall Effect sensors built-in.

6 Hardware Blocks

6.1 Voltage Regulating Circuit

An e-bike system has three power levels. The power levels are oriented from a 48-V battery.

- 48 V can drive the power MOSFET directly
- 15 V specifies the power supply of MOSFET driver ICs in power bridge
- 5 V specifies the power supply of microcontroller and other devices

Figure 7 shows a typical 5-V buck converter stage.

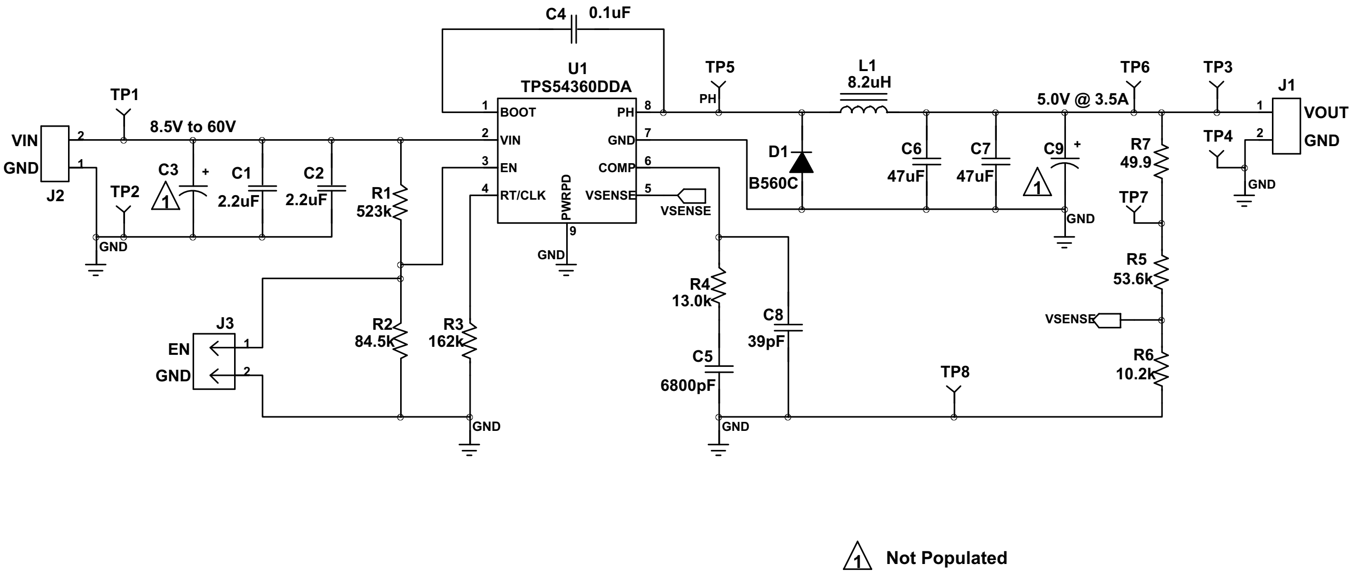


Figure 7. TPS54360 Schematic

The TPS54360 device provides input voltage transient protection, high efficiency at full load current, and light load efficiency for battery powered applications like e-bike. The high switching frequency of the device enables small passives leading to a small total solution size.

6.2 Battery Voltage Detect

The battery has a positive terminal and a negative terminal. In case of correct polarity, diode D5 is turned on and it supplies the normal power. In case of wrong polarity, diode D5 is on the reverse voltage and it does not turn on. The diode can protect other devices in system including the MCU ADC input. If the ADC result is lower than a preset value, undervoltage protection can occur. The battery in e-bike contains lead-acid. The voltage discharge cannot be too low; otherwise, the voltage discharge will cause permanent damage to the battery. The ADC should detect this voltage during normal operation. If the battery voltage is less than a certain preset value, the MCU will go into undervoltage protection mode.

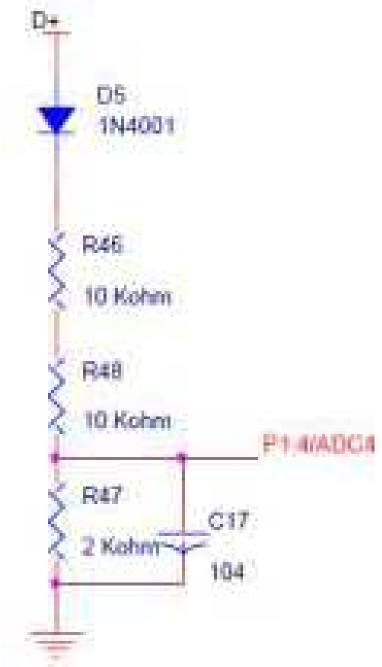


Figure 8. Battery Voltage Detection Schematic

6.3 Handbar Voltage Detection

Jumper S4 is used for speed limitation. When S4 is on connected, R61 is connected in parallel with R59, which makes the ADC input voltage much lower than the time S4 is off.

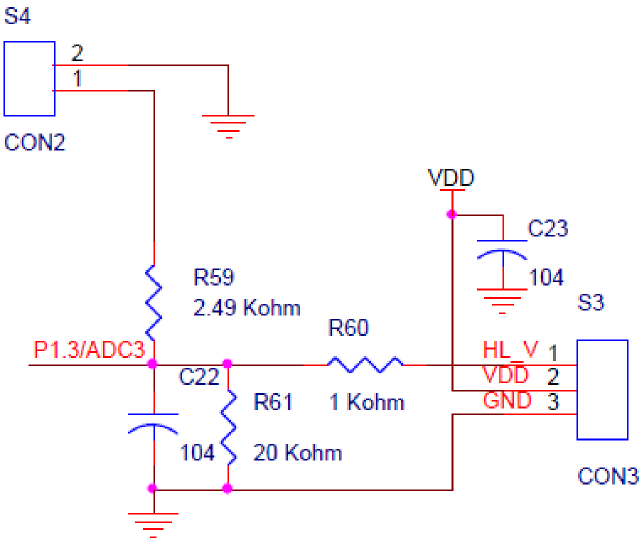


Figure 9. Handbar Voltage Detection Schematic

6.4 Feedback Current Detection

One LM358 op-amp (operational amplifier) is used for the measurement of system feedback current. Gain control resistors (R16, R17) ensure that the ADC input voltage is within the range of 0 to 5 V.

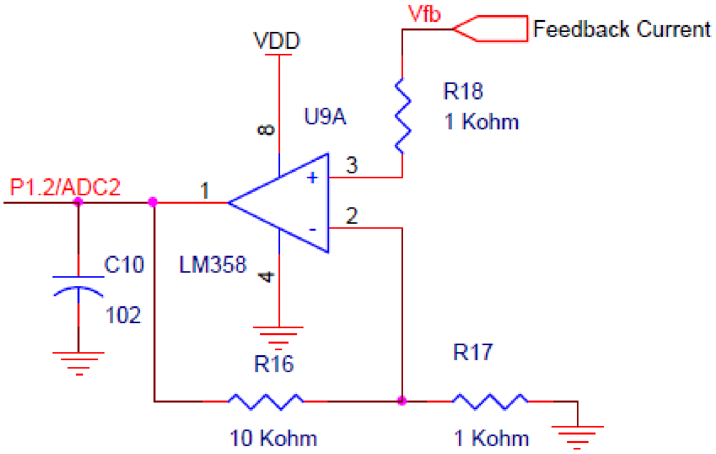


Figure 10. Feedback Current Detection Schematic

6.5 Overcurrent Detection and System Overcurrent Protection Circuit

The controller can judge over current using two types of *outside* conditions:

- Condition 1: The feedback current abruptly rises up to an unexpected value which could be caused by MOSFET short or motor rotation blockage.
- Condition 2: The current is above a preset safe value (usually 50 A), which is set for the system safety.

Condition 1 is protected by an external comparator as shown in Figure 11. Condition 2 is realized by feedback current detection.

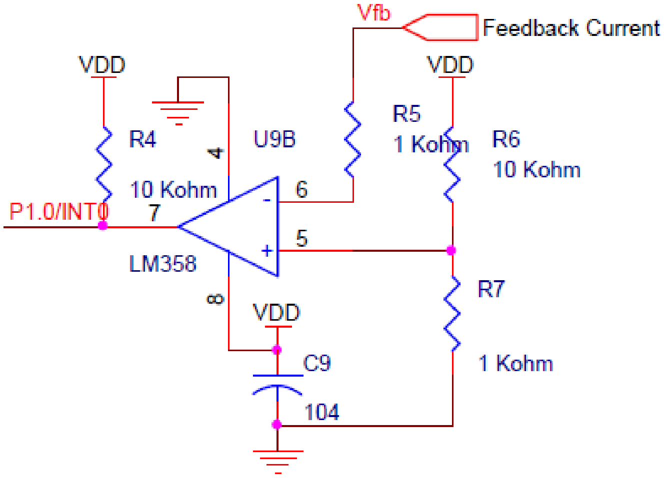


Figure 11. Overcurrent Protection Schematic

6.6 Brake Mechanism

The brake mechanism can support both high-level and low-level brake signals. The ADC has the wave form shown in Figure 12 regardless of the brake signal.

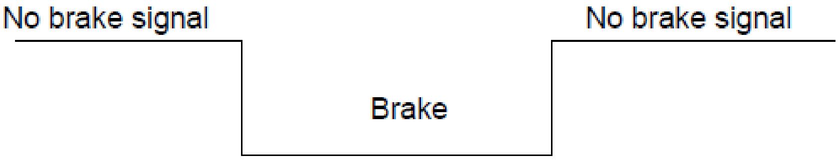


Figure 12.

Figure 13 shows the brake mechanism circuit.

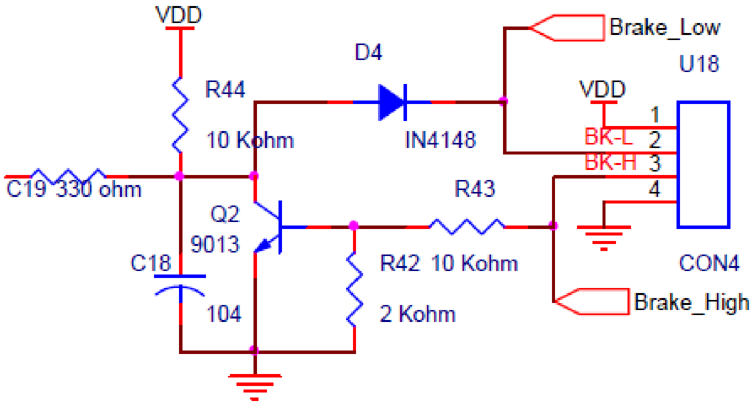


Figure 13. Brake Mechanism Schematic

7 Hall Sensor Position Detection

The synchronization between the rotor and rotating field requires knowledge of the rotor position. The BLDC motor used in this application has 3 Hall sensors.

Figure 14 shows the Hall sensor position detection circuit and velocity meter circuit.

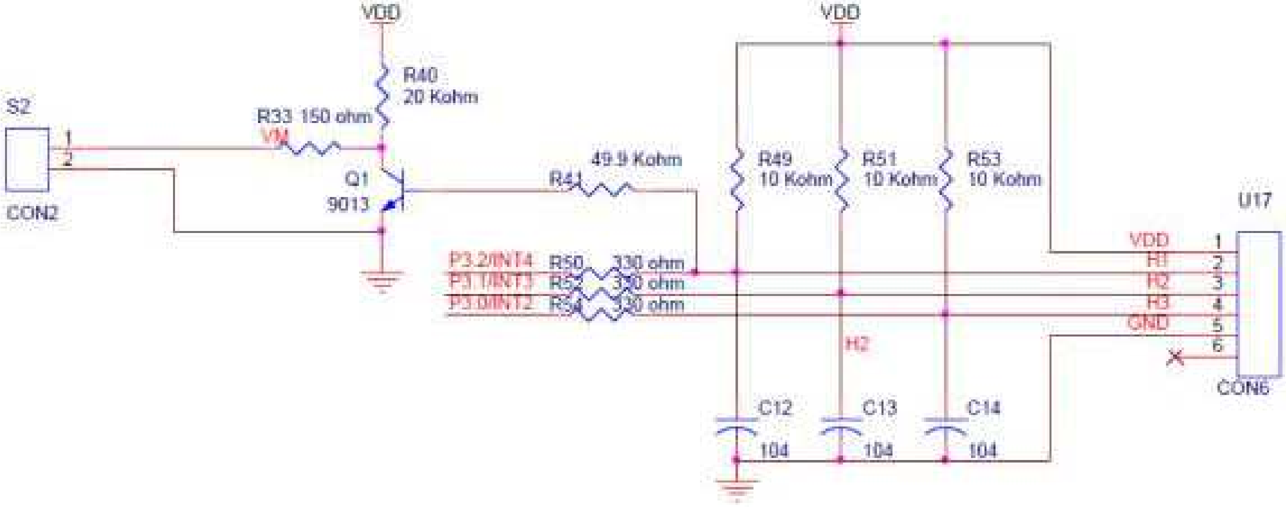


Figure 14. Hall Sensor Position Detection Schematic

Figure 15 shows the output signal flow of sensors, which describes the electrical rotor position.

Eight possible signal combinations can be used as the output of the three sensors. Two of these combinations are not valid for position detection and are usually caused by an open or short sensor line. The other six combinations will be detected by external interrupts both at the rising and falling edge.

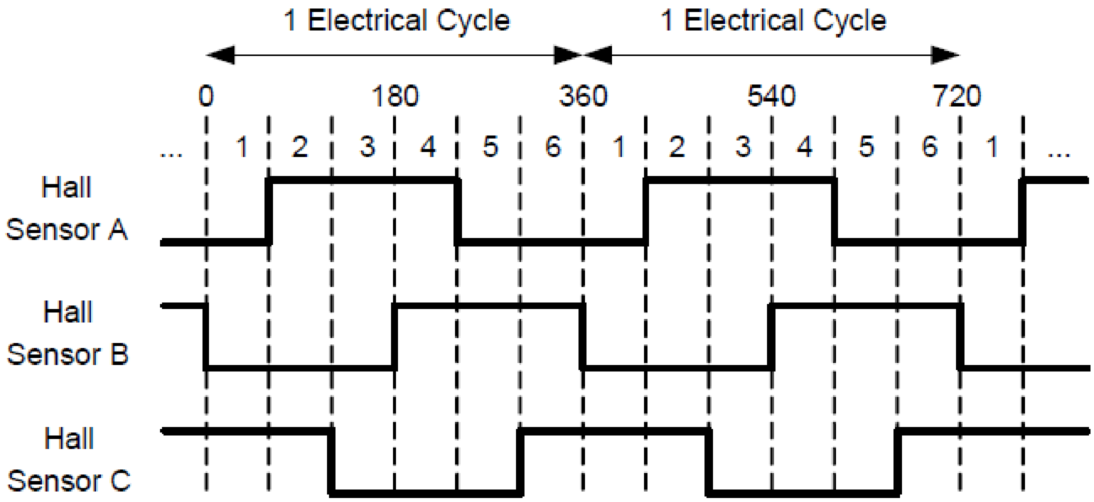


Figure 15. Hall Sensor Position Waveform Diagram

Table 7. Sequence of Forward Rotating

SEQUENCE NO.	HALL SENSOR INPUT			ACTIVE MOSFET		PHASE CURRENT		
	A	B	C	H-BRIDGE	L-BRIDGE	A	B	C
1	0	0	1	C	B	Off	DC–	DC+
2	1	0	1	A	B	DC+	DC–	Off
3	1	0	0	A	C	DC+	Off	DC–
4	1	1	0	B	C	Off	DC+	DC–
5	0	1	0	B	A	DC–	DC+	Off
6	0	1	1	C	A	DC–	Off	DC+

Table 8. Sequence of Reverse Rotating

SEQUENCE NO.	HALL SENSOR INPUT			ACTIVE MOSFET		PHASE CURRENT		
	A	B	C	H-BRIDGE	L-BRIDGE	A	B	C
1	0	0	1	B	C	Off	DC+	DC–
2	0	1	1	A	C	DC+	Off	DC–
3	0	1	0	A	B	DC+	DC–	Off
4	1	1	0	C	B	Off	DC–	DC+
5	1	0	0	C	A	DC–	Off	DC+
6	1	0	1	B	A	DC–	DC+	Off

The freewheeling function can be realized in one two ways:

- Non-synchronous rectification where current is freewheeled by body-diode of the complementary MOSFET
- Synchronous rectification where current is freewheeled directly by the complementary MOSFET

In this application, non-synchronous rectification is implemented. The PWM module can realize dead time control; hence synchronous rectification can also be supported.

In non-synchronous rectification, control of the complementary MOSFET of the MOSFET that is driven by PWM signal is not required. Thus, only two MOSFETs are in action at one time. The difference is one is driven by PWM signal for speed control, while the other is driven by full duty cycle PWM. The effect is the same as a normal IO; it is just a trick for better synchronization between the active high and low bridge. When the compare data is set for PWM module, all the PWM outputs have the same start point even if an instruction delay occurs when implemented by IOs.

7.1 P2PWMOUT Register Configuration During Non-Synchronous Rectification Mode

Table 9 lists the sequence when the BLDC motor is forward rotating.

Table 9. Sequence of Forward Rotating

SEQUENCE NO.	HALL SENSOR INPUT			P2PWMOUT REGISTER CONFIGURATION								
	A	B	C	BIT 7	BIT 6	BIT 5	BIT 4	BIT 3	BIT 2	BIT 1	BIT 0	HEX
1	0	0	1	0	0	X	0	1	X	1	0	2EH
2	1	0	1	1	0	X	0	1	X	0	0	ACH
3	1	0	0	1	0	X	0	0	X	0	1	A5H
4	1	1	0	0	0	X	1	0	X	0	1	35H
5	0	1	0	0	1	X	1	0	X	0	0	74H
6	0	1	1	0	1	X	0	0	X	1	0	66H

Table 10 lists the sequence when the BLDC motor is backward, or reverse, rotating.

Table 10. Sequence of Reverse Rotating

SEQUENCE NO.	HALL SENSOR INPUT			P2PWMOUT REGISTER CONFIGURATION								
	A	B	C	BIT 7	BIT 6	BIT 5	BIT 4	BIT 3	BIT 2	BIT 1	BIT 0	HEX
1	0	0	1	0	0	X	1	0	X	0	1	35H
2	1	0	1	1	0	X	0	0	X	0	1	A5H
3	1	0	0	1	0	X	0	1	X	0	0	ACH
4	1	1	0	0	0	X	0	1	X	1	0	2EH
5	0	1	0	0	1	X	0	0	X	1	0	66H
6	0	1	1	0	1	X	1	0	X	0	0	74H

8 Power MOSFET and Integrated Driver Circuit

TI has a wide range of motor drivers. Some devices need external FETs and other devices have internal FETs. Devices such as the DRV8312 device simplifies the design of a 3-phase BLDC motor drive efficiently.

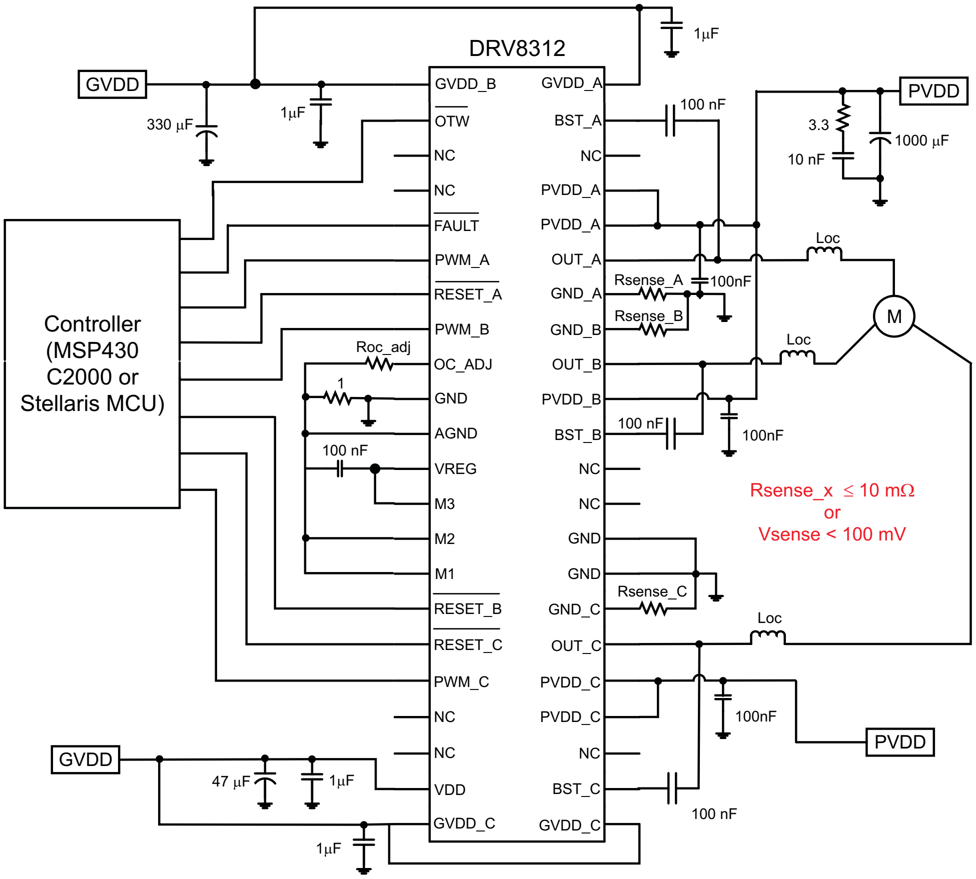


Figure 16. DRV8312 Application Diagram for Three-Phase Operation

8.1 Microcontroller

The e-bike controller system includes:

- Tthree external interrupts are used for getting position information from Hall sensors while one is used for brake mechanism
- One timer is used for counting the Hall interrupts in a fixed time to get speed information
- Three ADC channels are used for detecting battery voltage, handlebar voltage, and system feedback current
- PWM output directly controls the power bridge. Different duty cycle results in different vehicle speeds
- The remaining IO can be used as advanced function input pins or system status indicating pins

TI's Piccolo (F280xcx), Delfino (F283xx), Hercules (RM48, RM46) and Concerto (F28M35x) series of controllers easily meet all these requirements and come with additional features leading to a quick and efficient controller design. The software tools such as InstaSPIN™-BLDC further ease the process of control algorithm development

8.2 Other functions

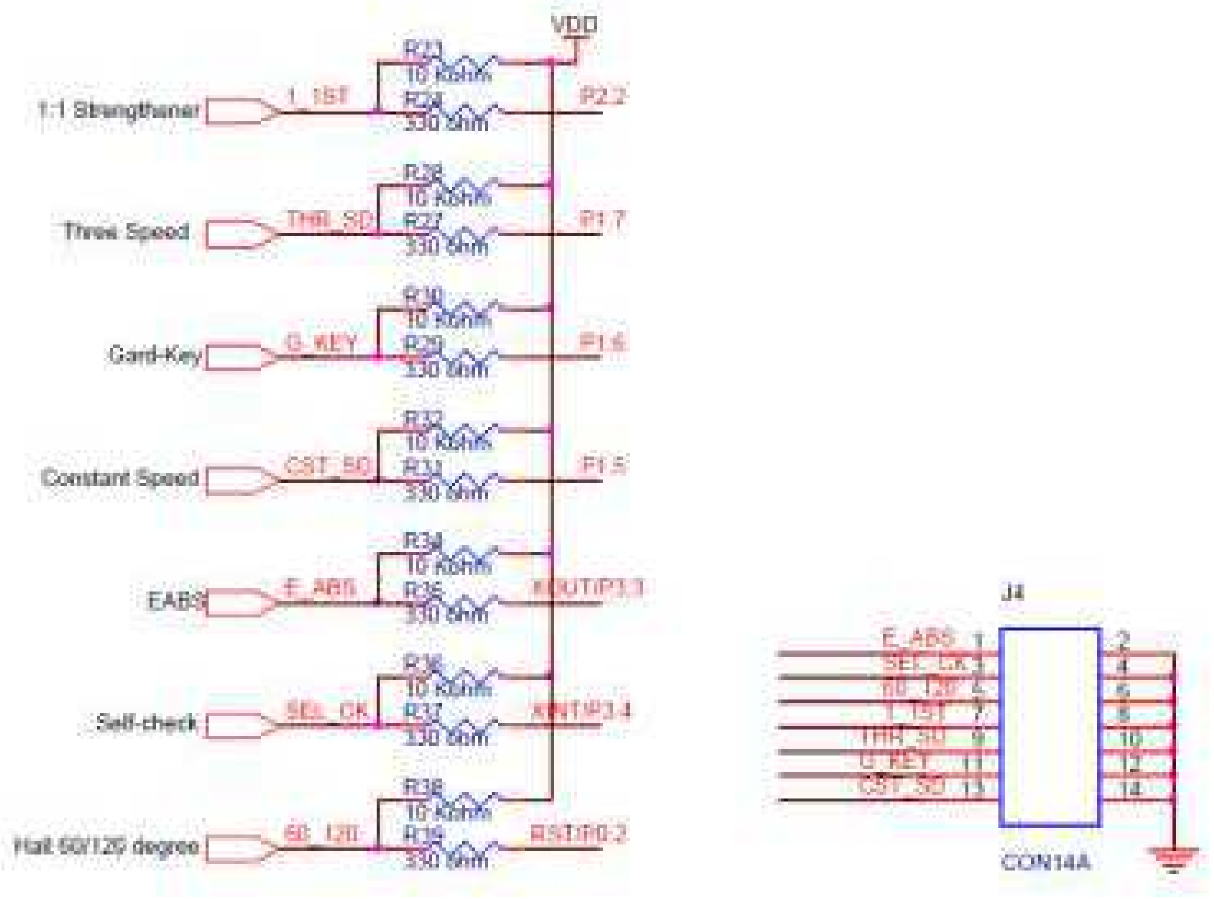


Figure 17.

8.3 Miscellaneous feature selection

8.3.1 Power Control:

Manual or throttle control—this type of power control or hand regulator can vary greatly from design to design, but in this approach, the electric power is controlled by hand or by thumb, and remains independent of whether a rider is pedaling

Pedal activation (pedelec)—advanced electronics and multiple sensors support a very different method to control power on an electric bicycle. This method uses the pedals to implement power assistance.

- Pedal hard to go fast and the bicycle adds a greater amount of electrical power.
- Pedal easy to go slow or sustain an easier speed and the power level does the same.
- To coast or slow down, the rider does not pedal at all, and the e-bicycle responds with no electric power.

This is known as the *pedelec* power-control method, short for pedal-electric, and is the most popular method in Europe, where the term pedelec originated.

Hybrid power control—this method is a combination of e-bike and pedelec power-control methods, combining manual and foot control. Details and use may vary significantly from design to design.

Efficiency Modes—many electric bicycles support two or three modes of efficiency.

Economy mode — optimizes range and sustains the battery charge for a significantly longer period of time, but at the cost of torque, acceleration, and perhaps uphill or off road performance.

The opposite mode is often called *Sport mode*, *power mode*, *performance mode*, or an equivalent. This setting enables high-performance acceleration, torque, more cargo carrying capacity, or uphill performance. The trade-off is that range is reduced.

8.3.2 Gears and Efficiency

Not all electric bicycles offer multiple gears within the electric motor. In such cases, a single gear for the motor reduces efficiency, particularly when climbing hills. Changeable gears make hill climbing easier, and extend the life and performance of your motor. A single gear on a car would make good hill climbing and efficient top speeds impossible. Adding more power to the motor when climbing hills and accelerating is possible, but this is alone not an efficient approach

A single-speed gear can require you to carry heavier and possibly a more expensive battery or set of batteries. Also, overloading an electric motor creates heat, which is wasted energy that can harm electronics and motors, and decrease the life of the product. Having gears for the motor supports better performance, creates greater efficiency, and provides a longer life for the product.

8.3.3 Regenerative Braking

Hybrid-electric or purely electric automobiles are capable of regenerative braking and harvest the gains it delivers. Such braking changes the design of an electric motor so that it can partially recharge the battery when braking is applied.

This case occurs most often when braking to stop or going downhill. Such a function can increase the range of an electric vehicle.

An electric or hybrid automobile can support regenerative braking for several reasons, primarily because these are heavier vehicles, can carry heavier loads, and they cost more.

In contrast, regenerative braking might become a different proposition for electric bicycles. Some new models incorporate regenerating braking. Consider the following factors:

- A motor must be more complex to integrate regenerative braking.
- Electronics must account for regenerative braking, making it more complex.
- Manufacturing is more intensive and components cost more.
- The price to the consumer will be higher unless other factors can help with the resulting cost.

8.3.4 Recharging Electric Bicycles With Alternative Energy

For those who are willing to invest in this approach, solar or wind technology can support the recharging of electric bicycles. This approach can be established in one of the following ways:

- Solar design is done well enough to build a custom solar recharging station
- Invest in a solar or wind energy kit, sometimes available as a recharging station specifically built for electric bicycles

8.3.5 Appropriate Brakes

Given the increased weight and speed of electric bicycles, conventional rim brakes likely do not supply sufficient stopping power, particularly when wet. Disk brakes last longer, require less maintenance, and work very well in wet conditions. Regenerative braking is partly available.

8.3.6 Battery and Motor Location

A low center of gravity can and will deliver superior handling, but it is not uncommon for some very popular bikes to have at least one battery (in a package of two) on a bike rack behind the seat. This battery is often be the smaller battery of the two.

8.3.7 Performance Suspension

The greater speed and weight of electric bicycles create the need for suspension that exceeds that of normal bicycles. A high-quality, name-brand front and rear suspension keeps the body of the rider comfortable at higher speeds and protects electronics.

8.3.8 Lights

Waterproof headlights mean you can see and be seen, and integration into a high-wattage electric bicycle increases brightness and lifetime duration over previous generations of headlights. Integration eliminates the need for separate batteries or kinetic-based light generation.

8.3.9 Composite Wheels and Rims

Light weight for as many components as possible increases the power available for rider and for payload. However, quality, strength, and safety must not be sacrificed. Consider the gains from the latest materials for wheels and hubs. Lightweight materials, when truly state of the art, can increase performance without compromising strength.

8.3.10 Readily Available BLDC Motor Control Reference Designs

Table 11. Brushless DC Motors

PART NUMBER	CONTROLLER	DRIVER	POWER RANGE	CONTROL TECHNIQUES SHOWN
DRV8301-HC-C2-KIT DRV8302-C2-KIT	Piccolo F28035	DRV8301 DRV8302	60 V, 60 A	10-kHz sensorless FOC (SMO), CL speed and torque; InstaSPIN-BLDC
DRV8312-C2-KIT	Piccolo F28069	DRV8312	50 V, 3.5 A	10-kHz sensorless FOC (SMO), CL speed and torque; InstaSPIN-BLDC
TMDSHVMTRPFCKIT	Piccolo F28035	Powerex IPM	350 V, 20 A	20-kHz sensored (CAP) and snensorless (back-EMF commutation), CL speed
DRV8301-LS31-KIT	Hercules TMS570LS3137	DRV8301	60 V, 60 A	Sensored (encoder) FOC with and redudant sensorless SMO; sensorless InstaSPIN-BLDC
DRV8301-RM48-KIT	Hercules RM48L952	DRV8301	60 V, 60 A	Sensored (encoder) FOC with redundant sensorless SMO; sensorless InstaSPIN-BLDC

9 Conclusion

This application report lists the hardware design guidelines for designing an electric bicycle. This report also lists the design criteria for an effective selection of the main components of the electric bicycle such as the motor selection, battery selection, and controller selection. Additional protection features for the controller are also listed as well as miscellaneous mechanical component selections to design an elegant electric bicycle. The microcontroller selection is left to the user. TI has many options available for this design and has the relevant applications team to support the respective TI microcontroller.

10 Reference

1. *Electric Bicycles: A Guide to Design and Use* (Morchin and Henryoman, 2005)
2. InstaSPIN™-BLDC

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