Electric Scooter Controller
SLG47115

This app note implements an Electric Scooter Controller. It describes the implemented logic, HVPAKs implementation and the obtained results of a typical scooter controller.

This application note comes complete with design files which can be found in the References section.

Contents

Terms and Definitions

IC	Integrated circuit
IR	Infrared
LED	Light-emitting diode

1. References

For related documents and software, please visit:

https://www.renesas.com/us/en/products/programmable-mixed-signal-asic-ip-products/gr eenpak-programmable-mixed-signal-products/hvpak

Download our free Go Configure Software hub [1] to open the .gp files [2] and view the proposed circuit design. Use the GreenPAK development tools [3] to freeze the design into your own customized IC in a matter of minutes. Dialog Semiconductor provides a complete library of application notes [4] featuring design examples as well as explanations of features and blocks within the Dialog IC.

[1] GreenPAK Designer Software, Software Download and User Guide, Renesas Electronics
[2] AN-CM-368 Electric Scooter Controller.hv, GreenPAK Design File, Renesas Electronics
[3] GreenPAK Development Tools, GreenPAK Development Tools Webpage, Renesas Electronics
[4] GreenPAK Application Notes, GreenPAK Application Notes Webpage, Renesas Electronics
[5] SLG47115, Datasheet, Renesas Electronics

2. Introduction

Electric and sustainable mobility applications are nowadays one of the main developments and markets for large companies and international associations due to concerns over environmental pollution and the high cost of gasoline. Electric vehicles are considered as a more sustainable and cost-effective solution because they emit fewer greenhouse gases and have lower operating costs compared to traditional vehicles. These characteristics make electric mobility an interesting method not only for urban mobility but also for industrial mobility or robotic applications.

In this context, in the last few years there have been significant progress in the development of electric vehicle technology and infrastructure. Governments and private companies are investing heavily in electric mobility, and there are now many models of electric vehicles available in the market. One of the key drivers for the growth in the use of electric vehicles is that many governments around the world are supporting electric mobility through tax incentives, subsidies, and regulatory measures. For example, some countries offer financial incentives to buy electric vehicles or exempt them from certain taxes and fees. Governments are also investing in charging infrastructure and promoting electricity-powered public transportation.

According to the International Energy Agency (IEA), global electric car sales surpassed 3 million units in 2020. Electric car sales accounted for 4.6% of total car sales in 2020, up from 2.5% in 2019.

There are several types of electric vehicles, including battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs), hybrid electric vehicles (HEVs), and fuel cell electric vehicles (FCEVs). BEVs are fully electric and rely entirely on battery power, while PHEVs have a gasoline or diesel engine as a backup power source. HEVs have both an electric motor and an internal combustion engine and do not need to be plugged in, while FCEVs use hydrogen fuel cells to generate electricity and emit only water vapor.

If battery electric vehicles are considered, several types of vehicles can be found, so not only traditional cars are included. Electric scooters are personal vehicles powered by rechargeable batteries that drive an electric motor. The motor is usually located in the front wheel hub and is controlled by a handlebar-mounted throttle. Most electric scooters have a range of around 16-32 kilometers on a single charge and can reach speeds of up to 20-40 km/h.

The main advantage of electric scooters is that they are a cost-effective alternative to traditional transportation methods taking into account not only the cost of maintenance and their size, but also the avoidance of traffic jam. Scooters are eco-friendly as they produce no emissions and require very little maintenance compared to gasoline-powered vehicles.

All these factors make electric scooters increasingly popular for short trips in urban areas. For example, in Paris, the number of electric scooters increased from 15,000 in 2018 to 20,000 in 2019, and in Los Angeles, the number of electric scooters increased from 2,500 in 2017 to 36,000 in 2018. In this context, shared electric scooter services appeared. Commercial services, such as Lime®, Lyft® or Cityscoot®, have grown rapidly in recent years. According to Statista, the number of shared electric scooters worldwide reached 881,000 in 2020, up from just 22,500 in 2017.

As a big and growing market, not only new devices are required every day, repair or replacement of existing devices is increasing. In this application note, the main controller for an electric scooter based on a GreenPAK HVPAK Device is implemented. It is designed to control the motor speed, the mechanical brake action, and the speed limit established by the driving mode selected by the user. To implement this, a High Voltage GreenPAK SLG47115 [5] is used, resulting in a low-cost and reliable solution for a scooter controller. The IC's HV capabilities allow the system to control, as a pre-driver, the DC motor, so a very-small sized controller is obtained.

3. Electric Scooter Characteristics and Requirements

As an electric vehicle, the electric scooter is a battery-powered vehicle designed for personal transportation in urban regions. Classified as a form of micro mobility, they are generally designed with a large center platform on which the rider stands.

It is generally based on an electric motor normally placed on the front wheel that is electronically controlled by a central device located on the user's front control panel. The brake system includes disc brakes on the rear wheel and the electric motor lock can also be used as an additional brake.

A typical scooter diagram is shown in Figure 1, where the main components are indicated.

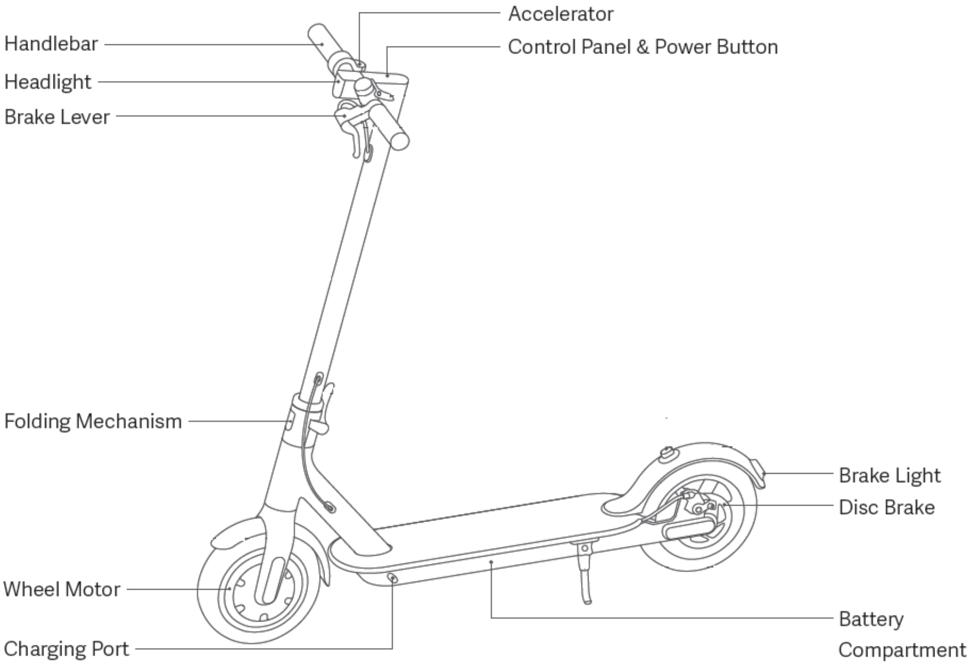


Figure 1: Electric Scooter Diagram

As mentioned before, the entire scooter control is implemented in the front panel, where power button is located, the measured speed is shown, the drive modes can be selected and some other options like turning on the headlight can be selected.

Electric scooters are usually designed to have three different driving modes with a trade-off between battery life and maximum speed. These modes are user selectable on the front panel.

The Eco drive mode is defined as the lowest speed mode. It usually reaches 10-15 km/h depending on the scooter model and is designed for energy saving and beginners.

The standard mode, or Drive as it is often called, has a top speed of 15-20 km/h and it is the recommended mode for driving in urban environments.

The Sport mode is the fastest. The top speed is limited to the maximum of the scooter (20-25 km/h typically) and is the least efficient mode in terms of battery life.

In table 1, the driving modes and the top speed are shown.

Table 1: Driving Modes

Mode	Top Speed
Eco	10-15 km/h
Drive	15-20 km/h
Sport	20-25 km/h

All these modes are selected by the user with the user button located on the front panel located on the handlebars.

In the same place, the throttle and brake lever are placed. The throttle is based on a potentiometer, so its voltage output is proportional to the user's desired speed. The brake lever moves the disc brake and, also, electronically activates the brake light located at the rear of the scooter.

4. Scooter Controller Design Diagram and Schematic

The Electric Scooter Controller described and implemented in this app note is based on the block diagram shown in Figure 2.

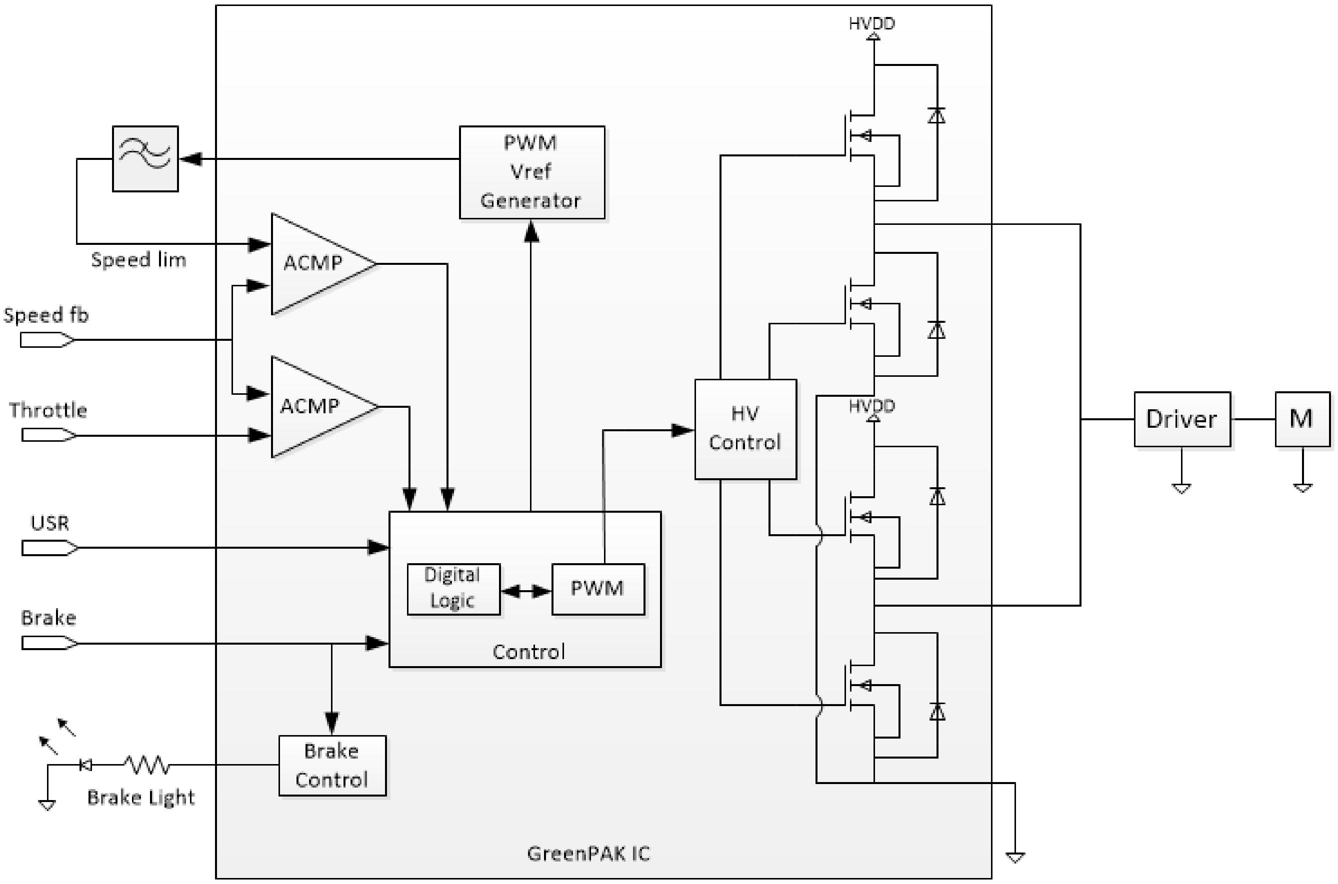


Figure 2: Electric Scooter Controller Block Diagram

A DC motor is the main actuator to be controlled. To do this, the internal HV GPIOs of the SLG47115 are configured as a double half – bridge to work as a pre-driver for external FET's that drive the motor. These pins, as the motor output controllers, define whether the motor moves forward, brake or is at coast mode.

The pins are managed with the internal HV Out control module of the GreenPAK IC, which is controlled by the implemented internal logic based on the speed sensor output (the speed feedback) and the throttle position. This control also uses a PWM, generated with one of the internals PWM modules of the GreenPAK IC, and the analog comparators connected to the actual speed, throttle position and speed limit signals. The varying duty cycle of the PWM is used to regulate the motor speed.

To set the maximum speed determined by the driving mode selected by the user, the second PWM module is applied. A PWM signal with different duty cycle is generated by means of the user selection, and it is then filtered with an external low-pass filter, thus obtaining a voltage reference signal related to the maximum speed that is used for the speed regulation.

All the scooter motion, including the internal logic and the PWM regulation, depends on the brake input signal. When it is enabled, the entire motion logic is disabled by the brake control and the corresponding light indicator is enabled.

The driving mode is selected by the user, with an external button and the corresponding deglitch filter generating edges that allow the system to switch between the different options.

The diagram shown in Figure 2 is represented, considering the required external components, in the schematic circuit shown in Figure 3.

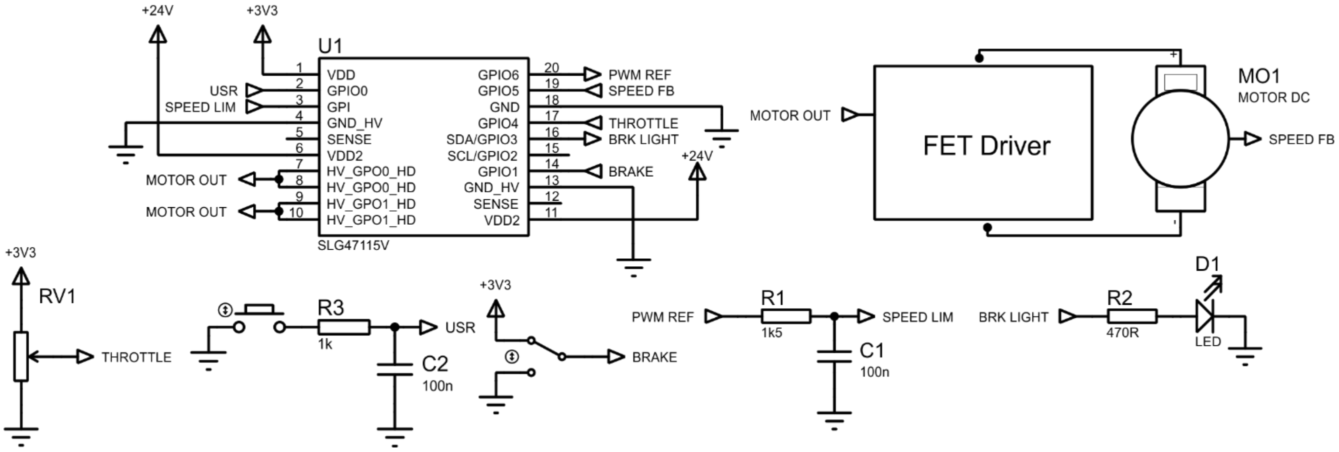


Figure 3: Electric Scooter Controller Schematic Circuit

5. Implementation and Configuration of Electric Scooter Controller

The implementation of the Electric Scooter Controller is based on a SLG47115V GreenPAK [5]. This CMIC contains internal Analog Comparators, PWM controllers, and High-Voltage Integrated H-Bridge/dual Half-Bridge functionality that can be used as a pre-driver for the DC motor with internal speed regulation, based on the user selection and throttle position.

The driving mode configuration, which determines the maximum allowed speed for the DC motor, is implemented with the internal ripple counter and the programmable delay/edge detector, as it is shown in Figure 4.

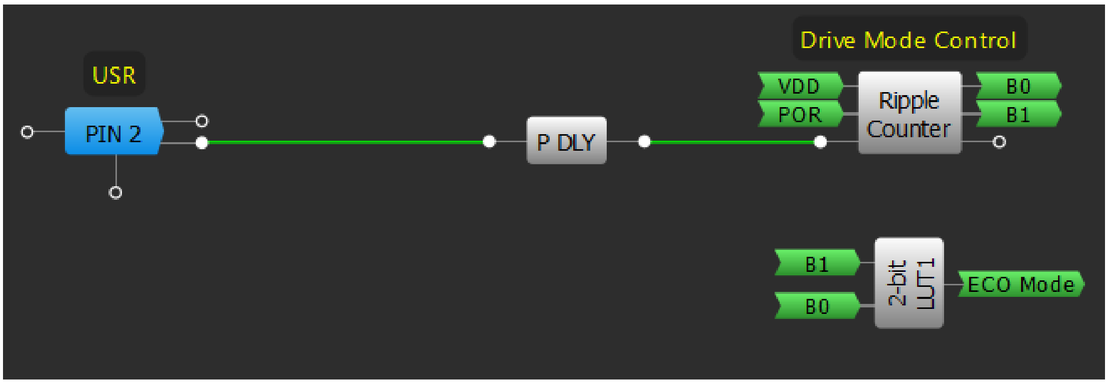
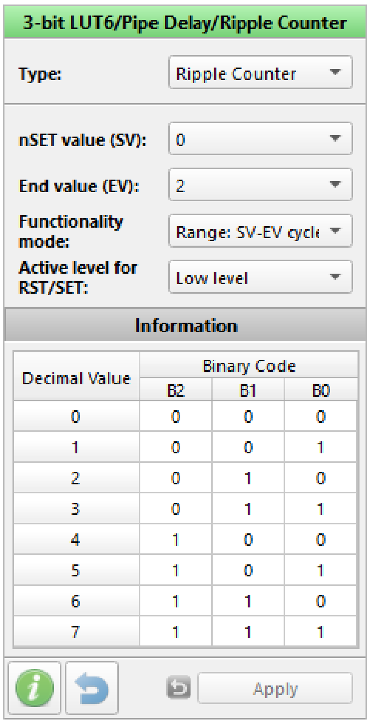


Figure 4: Driving Mode Controller

When a falling edge is detected by the P DLY module, the ripple counter increments its output, which is configured to vary between 0 and 2 (corresponding to ECO, Drive, and Sport modes respectively). The ECO mode is particularly detected with the 2-bit LUT1 output, which is used for speed control as it is described later.

The configuration of the ripple counter is shown in Figure 5.



3-bit LUT6/Pipe Delay/Ripple Counter

Type: Ripple Counter

nSET value (SV): 0

End value (EV): 2

Functionality mode: Range: SV-EV cycl

Active level for RST/SET: Low level

Information

Decimal Value	Binary Code		
	B2	B1	B0
0	0	0	0
1	0	0	1
2	0	1	0
3	0	1	1
4	1	0	0
5	1	0	1
6	1	1	0
7	1	1	1

Figure 5: Ripple Counter Configuration

The speed regulation stage of the controller is implemented by using the internal logic and analog comparators with external reference, as it can be seen in Figure 6.

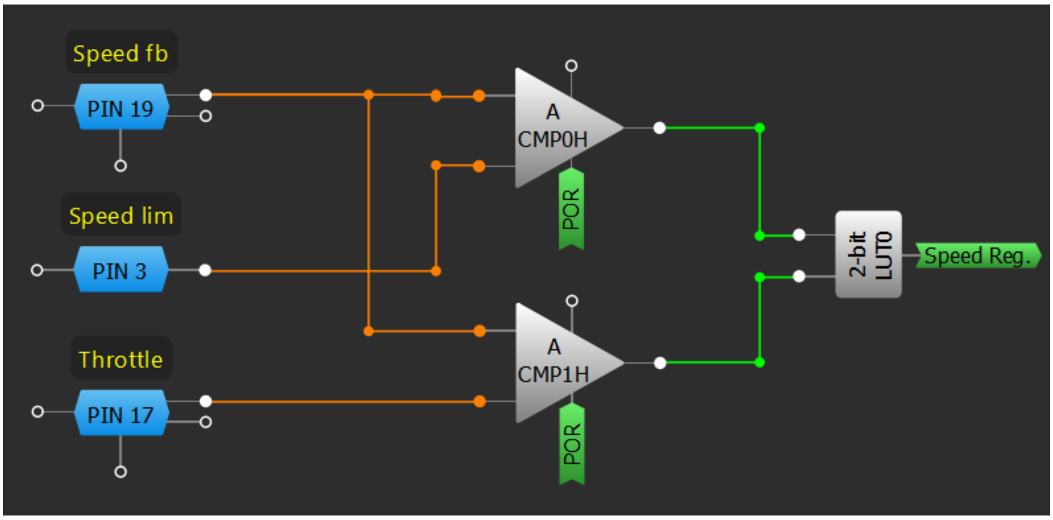


Figure 6: Speed Regulator

The throttle (an external potentiometer) and the speed limit signal are connected to analog comparators ACMP0H and ACMP1H and compared with the speed sensor output connected to PIN 19. The ACMP0H monitors the actual speed versus the speed limit (established by the user selected driving mode) while the ACMP1H controls the actual speed versus the throttle position. Both comparisons, with the corresponding logic implemented with 2-bit LUT0, determine if the DC motor speed must be increased or decreased.

2-bit LUT0 is configured to increment the DC motor speed when it is necessary only. That is, the speed will go high if the current speed (obtained from the sensor output) is lower than the required by the throttle position and if it is lower than the speed limit. If actual speed is higher than the throttle position, or it is over the speed limit, the 2-bit LUT0 output will be low in order to reduce the motor speed.

As mentioned in previous sections, the DC motor control signals are generated and regulated by a PWM connected to the HV GPIOs of the HVPAK configured as half bridge. This configuration is required to obtain the desired voltage with a high current output which is to be used as the pre-driver signal for the motor FET based driver. In order to obtain higher current drive capability, both half bridge legs are used in parallel.

Also, as the HV GPIO outputs are not used for direct motor driving, the slew rate of HV OUT Control module is configured in fast mode.The HV GPIO ports connections, and its configuration, are shown in Figure 7 & Figure 8.

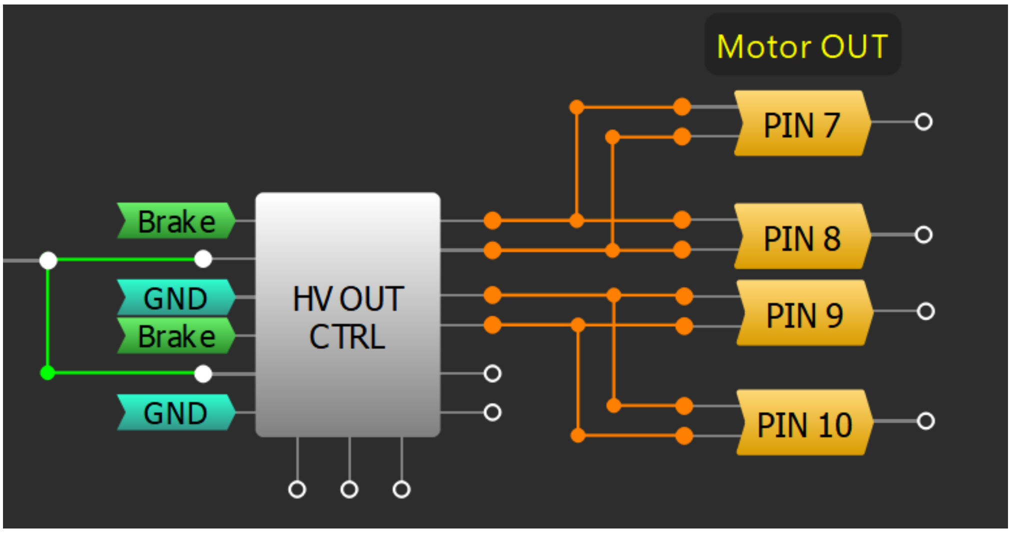
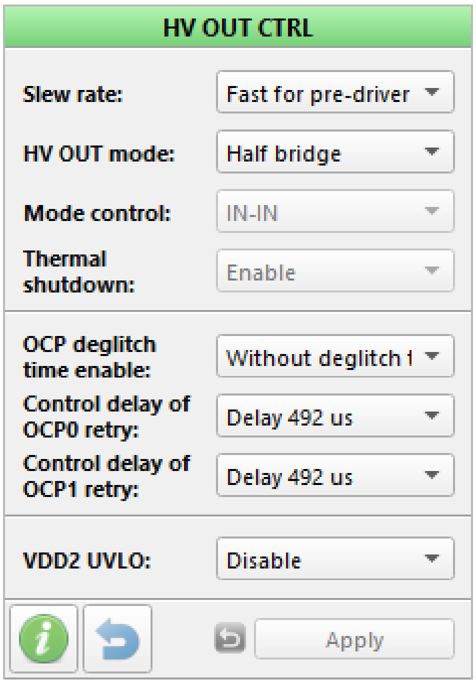


Figure 7: HV OUT Connection



Slew rate: Fast for pre-driver

HV OUT mode: Half bridge

Mode control: IN-IN

Thermal shutdown: Enable

OCP deglitch time enable: Without deglitch t

Control delay of OCP0 retry: Delay 492 us

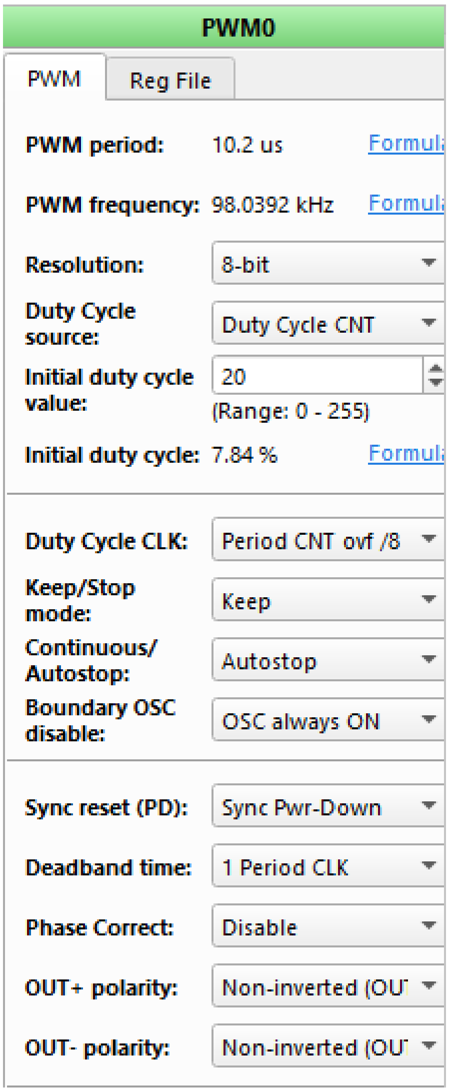
Control delay of OCP1 retry: Delay 492 us

VDD2 UVLO: Disable

Figure 8: HV OUT Configuration

To generate the PWM signal for speed regulation, PWM0 module is used. PWM is configured to have the higher frequency, 98.04 KHz, that can be generated with the high frequency internal oscillator (25 MHz internal oscillator). The duty cycle control is configured as a duty cycle counter, which can be incremented or decremented with an external control signal. This control signal is obtained from the speed regulator. When 2-bit LUT0 output is high, the speed must be incremented so the duty cycle goes high. In the other way, when 2-bit LUT0 is low, the speed must be decremented so the duty cycle goes low. The PWM is connected to the HV OUT module to control the half bridge output.

The configuration of PWM0 module can be seen in Figure 9.



PWM period: 10.2 us

PWM frequency: 98.0392 kHz

Resolution: 8-bit

Duty Cycle source: Duty Cycle CNT

Initial duty cycle value: 20 (Range: 0 - 255)

Initial duty cycle: 7.84 %

Duty Cycle CLK: Period CNT ovf /8

Keep/Stop mode: Keep

Continuous/ Autostop: Autostop

Boundary OSC disable: OSC always ON

Sync reset (PD): Sync Pwr-Down

Deadband time: 1 Period CLK

Phase Correct: Disable

OUT+ polarity: Non-inverted (OU

OUT- polarity: Non-inverted (OU

Figure 9: HV OUT Configuration

As shown previously, speed control is implemented with analog comparators ACMP1H sensing the actual speed and the throttle position, the ACMP0H connected to the speed feedback and an external reference voltage related to the speed limit. To generate the reference, the PWM1 module output signal is used, filtered with an external first order RC low pass filter. PWM 1 module is configured to generate a 98.04 KHz PWM output signal with a configurable duty cycle from the internal register file. Each time the controller changes the driving mode, the PWM receives a control pulse to change the register pointer, so the corresponding speed limit (that is, the corresponding voltage reference) is generated. These changes are made by generating a pulse in the Duty Cycle Clock Signal (when the mode changes from ECO to Drive or from Drive to Sport) or in the PWR Down signal (when Sport to ECO mode). Those pulses are triggered by an edge in the bit 0 output of the Drive Mode Control Ripple Counter or by detecting the ECO mode with the corresponding filter, respectively.

PWM output is then connected to PIN 20 and filtered externally with the RC low pass filter. The output of the filter is connected, as the reference speed, to PIN 3, the ACMP0H negative input voltage.

The connection of both PWM0 and PWM1, and the configuration of PWM1 module are shown in Figure 10 and Figure 11.

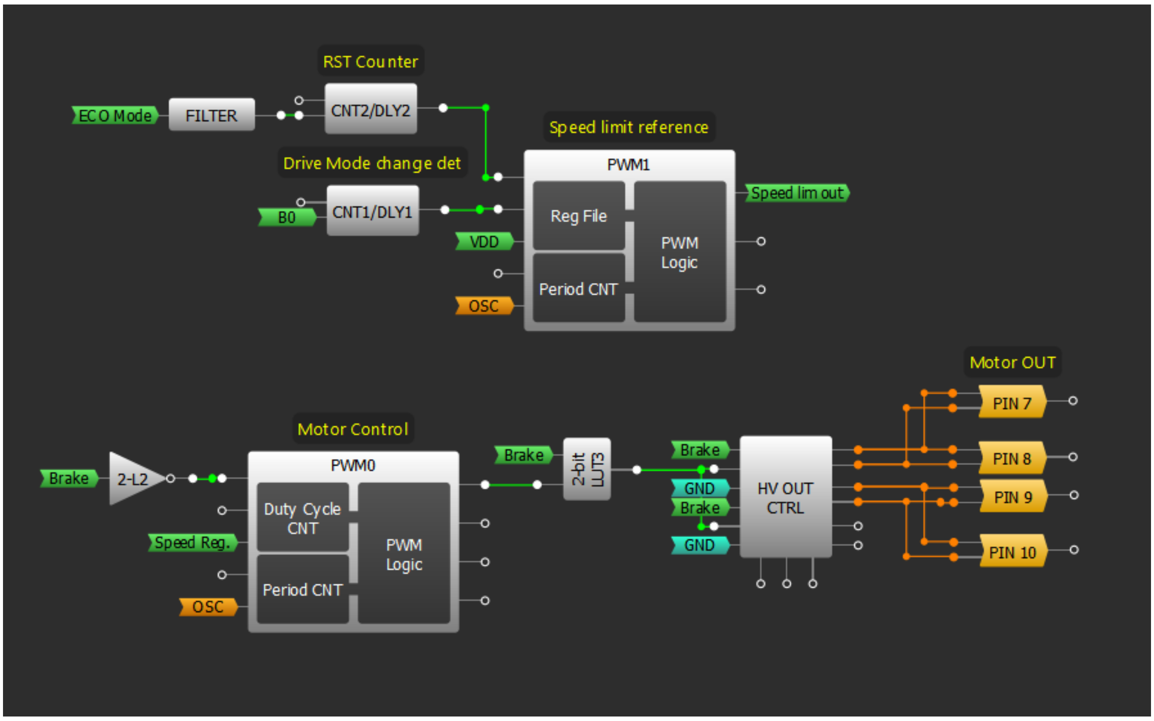
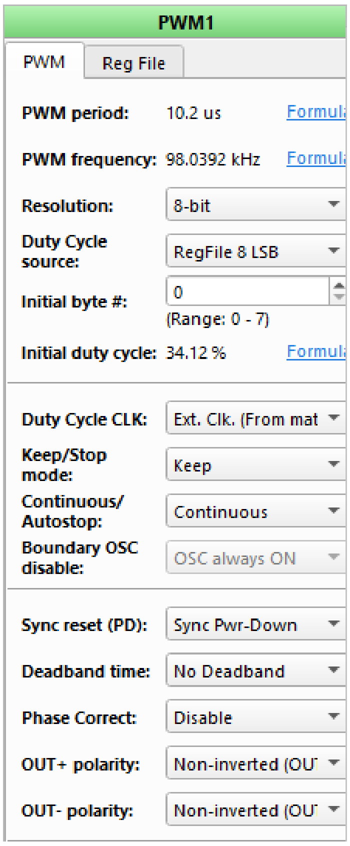


Figure 10: PWM0 and PWM1 Connection



PWM period: 10.2 us Formul

PWM frequency: 98.0392 kHz Formul

Resolution: 8-bit

Duty Cycle source: RegFile 8 LSB

Initial byte #: 0 (Range: 0 - 7)

Initial duty cycle: 34.12 % Formul

Duty Cycle CLK: Ext. Clk. (From mat

Keep/Stop mode: Keep

Continuous/ Autostop: Continuous

Boundary OSC disable: OSC always ON

Sync reset (PD): Sync Pwr-Down

Deadband time: No Deadband

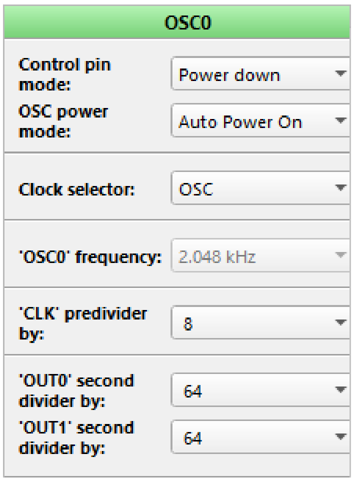
Phase Correct: Disable

OUT+ polarity: Non-inverted (OU

OUT- polarity: Non-inverted (OU

Figure 11: PWM1 Configuration

The entire motor control also depends on the brake lever signal. When low, this signal stops the PWM0 module (corresponding to the motor control), disables the HV OUT control and enables the Brake Light blinking with the OSC0 output 1 (with a frequency of 4 Hz), configured as shown in Figure 12.



OSC0

Control pin mode: Power down

OSC power mode: Auto Power On

Clock selector: OSC

'OSC0' frequency: 2.048 kHz

'CLK' predivider by: 8

'OUT0' second divider by: 64

'OUT1' second divider by: 64

Figure 12: OSC0 Configuration

The entire Electric Scooter controller implementation diagram is shown in Figure 13.

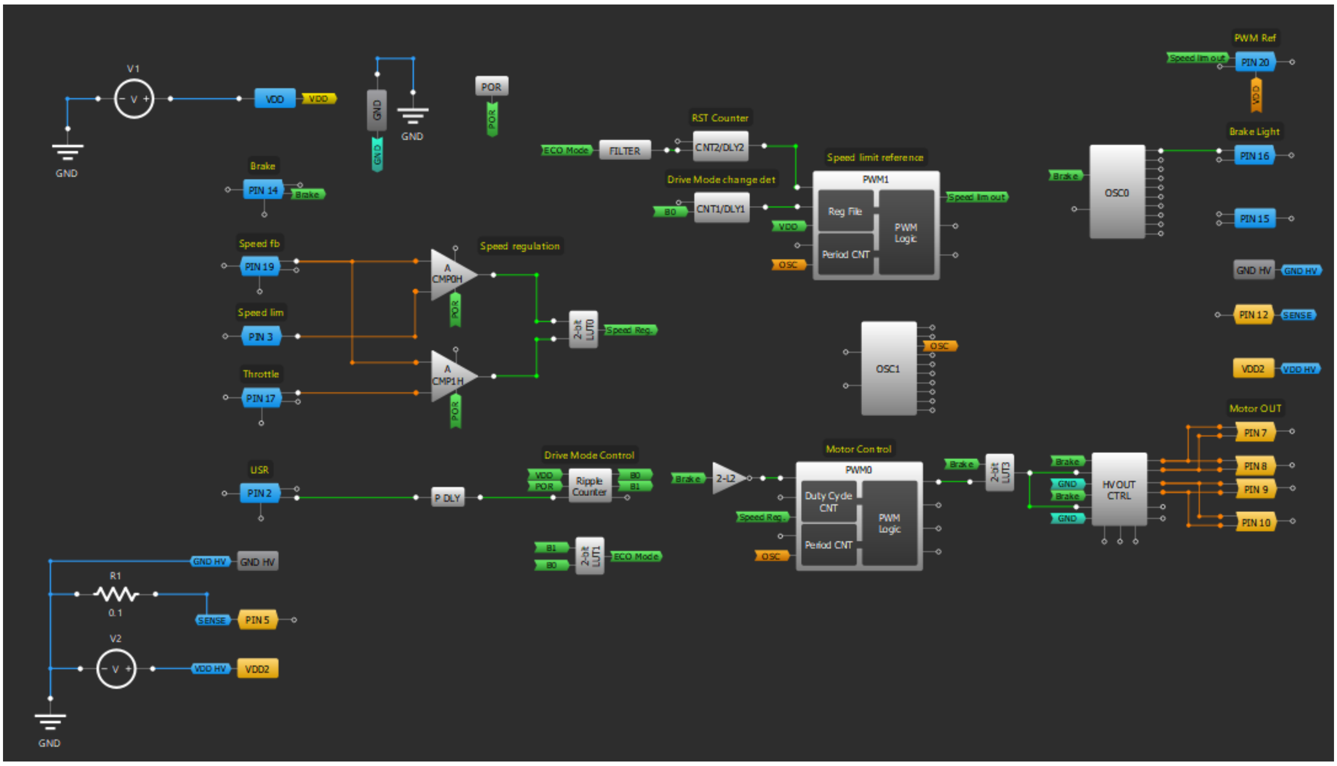


Figure 13: Electric Scooter Controller Implementation

6. Conclusion

To test the implementation, the entire system was simulated with the Go Configure Software Hub Simulator, performing several transient analyses to verify the behaviour of different parts of the design. It is important to consider that all the dynamics of the external signal were time scaled to be simulated with an acceptable execution time. This fact implies that the external signals, such as throttle output and speed feedback where much faster than the real ones, but without losing any condition about the system behavior.

To verify the speed regulation, simulated signals were injected to the corresponding pins with the custom signal generators in order to make the system vary the PWM duty cycle in the corresponding way. A constant speed limit signal and speed feedback signal were used, while the throttle speed set was varied between values lower than the current speed and higher than the current speed.

With the described conditions, it was expected that the PWM0 duty cycle will first go down and then will rise, based on the speed measurements. In Figure 14, the simulation results can be seen, showing the expected behavior.

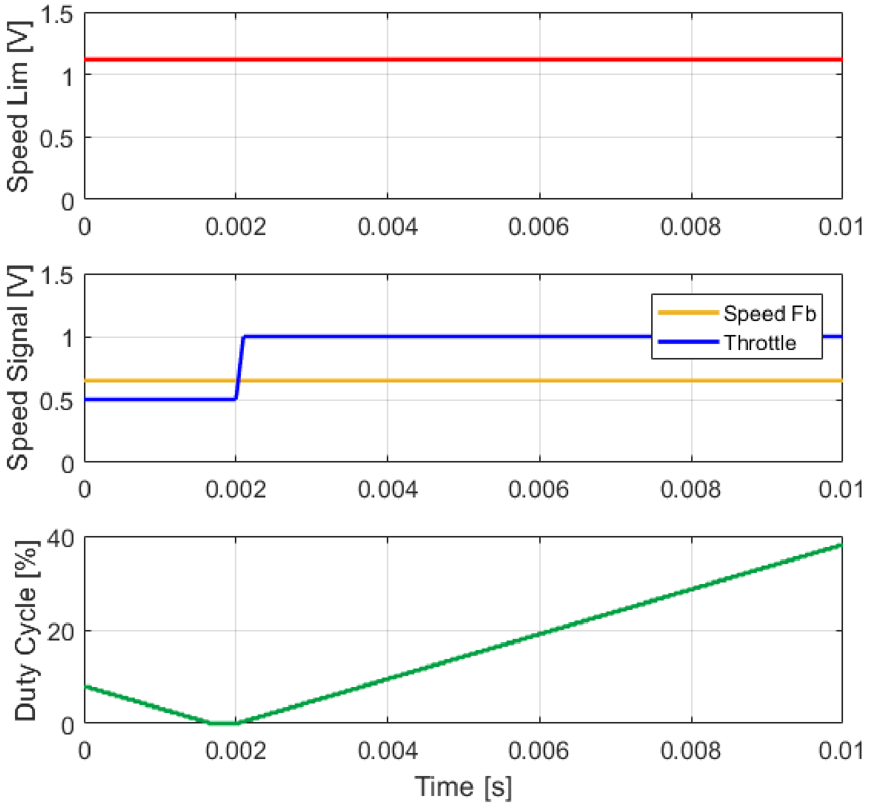


Figure 14: Speed Regulation Simulation

As the speed regulator was verified and validated, the user driving mode selector was tested. A simulated user button signal was injected to the corresponding pin, and the internal ripple counter and PWM1 duty cycle were measured. Each time a falling edge was detected, it was expected that the internal counter and the PWM1 duty changes, generating a voltage reference related to the corresponding driving mode. In Figure 15, all the input and output signals of the simulation are shown, resulting in positive results.

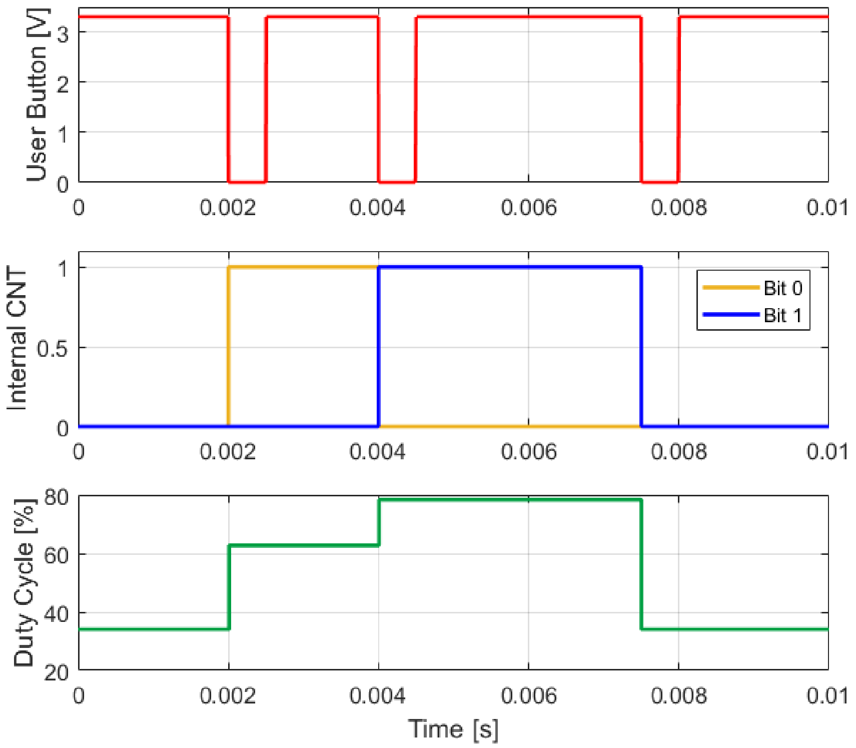


Figure 15: Driving Mode Simulation

Finally, the brake response was simulated. In this case, if the brake signal was present, the PWM0 should stop regulating (and the HV GPIO pins should be disabled). The input signal and the PWM0 duty cycle can be seen in Figure 16, showing successful results.

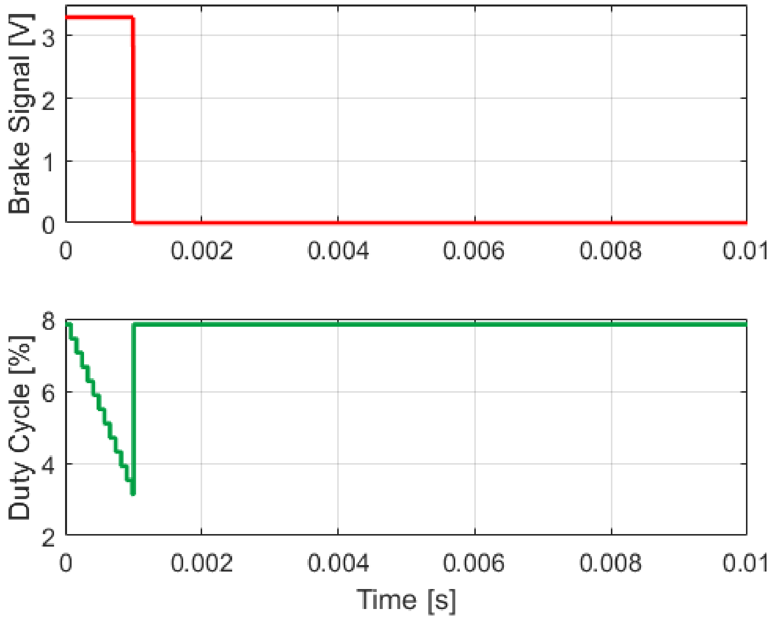


Figure 16: System Implementation

In this application note we implemented an Electric Scooter controller that can be applied for both new devices and repair used ones. Electric and sustainable mobility applications are nowadays one of the main developments and markets, so such type of controllers is highly required.

There are several methods of implementing these controllers, using different type of technologies. In this application note, an SLG47115V is used as the main device, due to the high-voltage control capability and the analog and digital resources that are available. The implementation shows how different analog features of the IC can be applied and, also, how DC motors can be controlled using the IC as the pre-driver.

The size of the entire control system is smaller than many other implementations and outlines where GreenPAK can be used and replace other commercial devices.

7. Revision History

Revision	Date	Description
1.00	Oct 4, 2023	Initial release.

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