

TI Designs: TIDA-020010

Automotive HVAC control reference design with HMI



Description

This reference design offers a cost-effective solution for a heating, ventilation, and air conditioning (HVAC) human-machine interface (HMI) application. This reference design incorporates a synchronous step-down converter, multiple channel half-bridge motor driver for brushed DC motors (BDC), multiple channel light-emitting diode (LED) driver, high-side switch to drive various loads, ambient light sensor to measure a visible light intensity, multiple hall-sensors to measure contactless the rotation of the rotary knobs, tracking voltage regulator to supply off board sensors, multiplexer to multiplex multiple analog sensor outputs to the microcontrollers analog to digital converter (ADC). Implement control of the design using a TI LaunchPad™ Development Kit, which adjusts the dimming PWM of the LEDs according to the ambient light intensity, controls the high side switch, detects the rotation movement of the magnetic rotation knob, drives multiple BDC motors, measures the multiple analog signals from off board temperature sensors.

Features

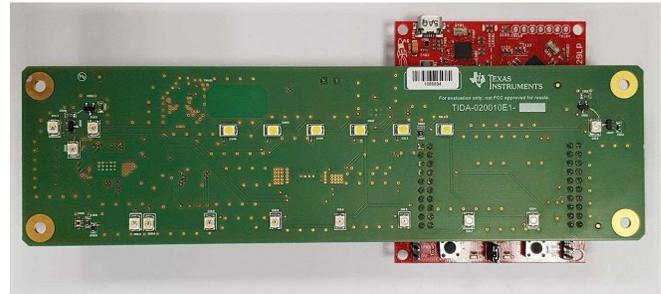
- Withstands reverse battery protection
- Drives up to 6 BDC motors
- One-chip solution to drive up to 18 LEDs with 16 individual PWM controllers in the LED driver
- LEDs do not require a current-limiting resistor for hassle-free resistor matching
- Automatic LED dimming based on ambient light intensity
- Contactless rotation detection for the rotary knobs
- High-efficiency power supply
- Fully-protected high-side power switch with accurate current sense

Applications

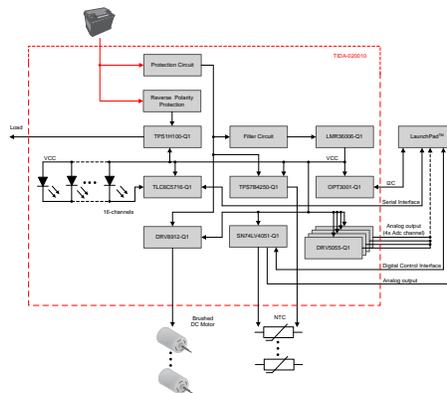
- Automotive HVAC HMI

Resources

TIDA-020010	Design Folder
LMR36006-Q1	Product Folder
OPT3001-Q1	Product Folder
DRV5055-Q1	Product Folder
TLC6C5716-Q1	Product Folder
TPS7B4250-Q1	Product Folder
SN74LV4051A-Q1	Product Folder
TPS1H100-Q1	Product Folder
DRV8912-Q1	Product Folder



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1 System Description

The HVAC control units, that are with integrated HMI, incorporate multiple devices, that are responsible not only for controlling the whole HVAC system but also control the human-machine-interface. The displays and buttons in HVAC HMIs are illuminated with a number of LEDs. The drive circuit for these LEDs is typically realized in a discreet way so that the microcontroller (MCU) drives external low-side bipolar junction transistors (BJTs), which sink the LED currents. The LED current is always limited by a series resistor. The designer must adjust the values of the current-limiting resistors to eliminate the difference in the LED light intensity caused by any small deviation between each component. The designer can use a pulse-width modulation (PWM) signal to drive these BJTs and obtain the dimming effect or they can use these BJTs like a switch (on and off). The goal of this reference design is to develop a cost-effective HVAC control with HMI, that includes an LED driver solution for 18-LEDs that can be driven without using current-limiting resistors. The designer can individually adjust the current, as well as the PWM-dimming signal, in each diode excluding those that are connected in parallel to one pin. The design includes also a multi-channel half-bridge motor driver for HVAC flaps, multiple hall-sensors to detect the rotation of the magnetic rotary knobs, the fully protected high-side switch to drive various loads, the eight channel multiplexer, tracking voltage regulator to supply off board temperature sensors and the ambient light sensor to measure the intensity of the visible light and adjust accordingly the light intensity of each LED. As a power supply in this design is used a high efficient synchronous Step-Down converter. This design includes protection features against load dump conditions and reverse battery conditions while simultaneously maintaining a small solution size and low quiescent current.

The TIDA-020010 has been designed with a focus on the following points:

- Capability to simultaneously drive 18 LEDs without current-limiting resistors
- Capability to simultaneously drive 6 BDC HVAC flap motors
- Capability to survive reverse battery condition
- Low leakage current
- Output current adjustment for all 16 outputs through one external resistor
- LED-dimming based on ambient light intensity
- Contactless rotary magnetic knobs
- Supplying multiple off board temperature sensors (Negative Temperature Coefficient NTC)
- Measure multiple off board NTC sensor outputs
- Efficient power supply with good EMI performance (Buck-Converter)
- Fully protected high-side switch for driving various loads

1.1 Key System Specifications

Table 1. Key System Specifications

PARAMETER	SPECIFICATIONS	MIN	TYP	MAX	UNIT
V_{IN}	Input supply voltage	5.5	12	20	V
V_{REV}	Reverse voltage	-	-	-60	V
POWER					
f_{SW}	Switching frequency	-	400	-	kHz
V_{OUT}	Output voltage	-	3.3	-	V
I_{OUT}	Output current	-	-	0.6	A
I_{SUPPLY}	Input supply current when in regulation	-	25	-	μ A
POWER SWITCH					
V_S	Operating voltage	5	-	40	V
$V_{S,UVR}$	Undervoltage restart	3.5	3.7	4	V

Table 1. Key System Specifications (continued)

PARAMETER	SPECIFICATIONS	MIN	TYP	MAX	UNIT
$V_{S,UVF}$	Undervoltage shutdown	3	3.2	3.5	V
$V_{UV,hys}$	Undervoltage shutdown, hysteresis	-	0.5	-	V
I_{nom}	Nominal operating current	-	-	5	mA
$I_{OFF,diag}$	Standby current with diagnostic enabled	-	-	1.2	mA
$R_{DS(on)}$	On-state resistance ($V_S > 5V$, $T_J = 150^\circ C$)	-	-	166	m Ω
$I_{lim,nom}$	Internal current limit	7	-	13	A
MOTOR DRIVER					
V_{VM}	Power supply voltage (VM)	4.5	-	20	V
V_{DD}	Logic supply voltage (VDD)	3	-	5.5	V
I_{max_total}	Total maximum current for all outputs	-	-	3	A
I_{peak}	Peak current per half-bridge	-	-	1.5	A
I_{VMQ}	VM sleep mode current	-	-	2	μA
I_{VDDQ}	VDD sleep mode current	-	-	1	μA
$R_{HS_DS(on)}$	High-side MOSFET on resistance	-	-	1.5	Ω
$R_{LS_DS(on)}$	Low-side MOSFET on resistance	-	-	1.5	Ω
VOTAGE-TRACKING LDO					
V_{IN}	Unregulated Input	4	-	40	V
V_{OUT}	Regulated output	1.5	-	18	V
ADJ/EN	Adjust input and enable input voltage	1.5	-	18	V
I_L	Output-current limitation (V_O short to GND)	100	-	500	mA
I_Q	Current consumption ($I_O = 30$ mA, $V_{ADJ} = 5V$)	-	150	350	μA
C_{OUT}	Output capacitor requirements	1	-	50	μF
ANALOG MULTIPLEXER, DEMULTIPLEXER					
V_{CC}	Supply voltage	2	-	5.5	V
I_{CC}	Supply current ($V_{CC} = 5V$)	-	-	40	μA
Input Channels	Number of input channels			8	
LED DRIVER					
V_{CC}	Supply voltage	3	-	5.5	V
I_O	Constant output sink current	-	-	50	mA
I_{CC}	Supply current	-	13.1	14	mA
OPTICAL					
Peak irradiance spectral responsivity		-	550	-	nm
Resolution (LSB)	Lowest full-scale range	-	0.01	-	lx
HALL-EFFECT SENSOR					
V_{CC}	Supply voltage	3	-	3.6	V
I_O	Output continuous current	-1	-	1	mA
I_{CC}	Supply current	-	6	10	mA
S	Sensitivity	57	60	63	mV/mT
B_L	Linear magnetic sensing range ($T_A = 25^\circ C$)	± 22			mT

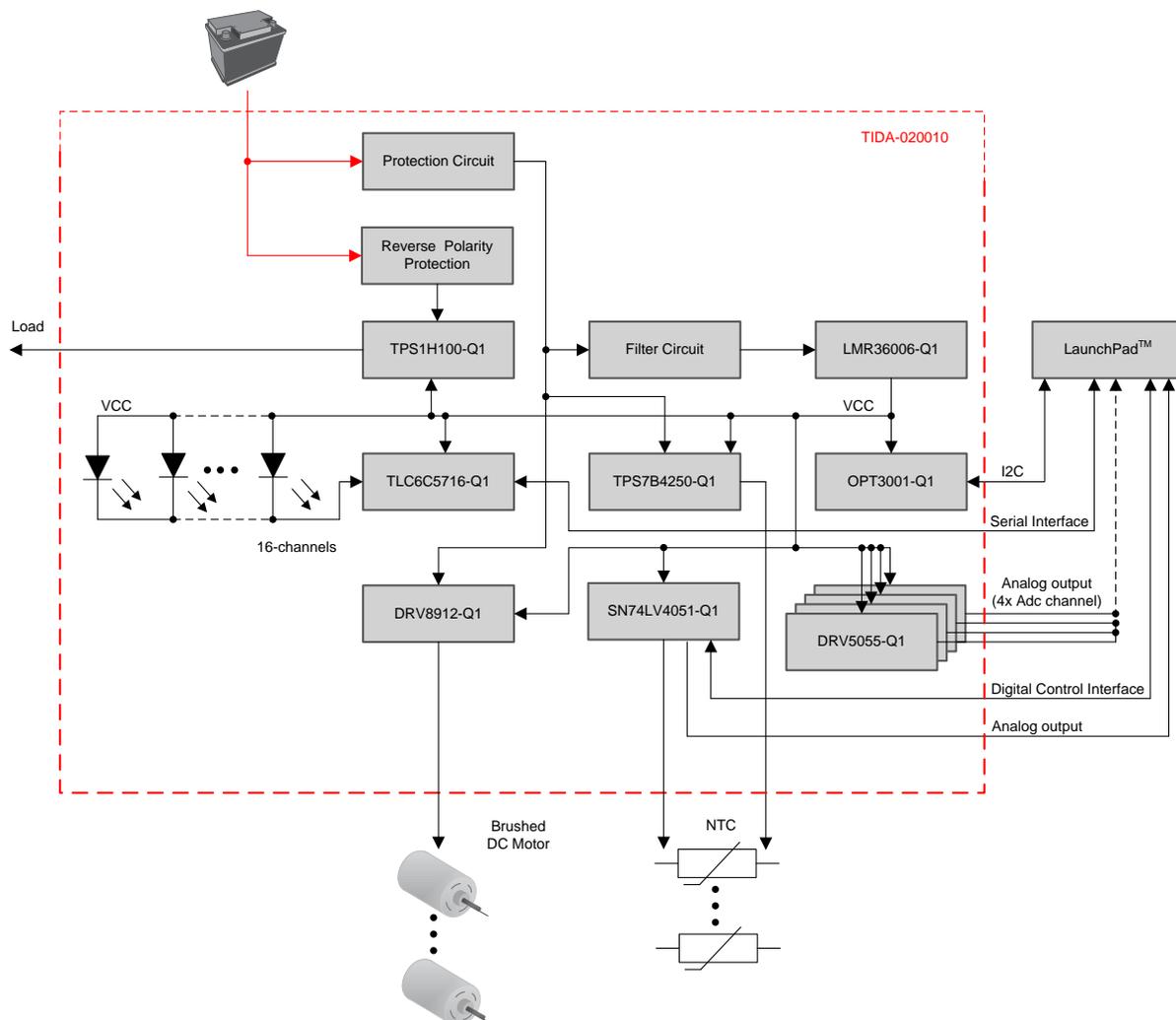
2 System Overview

2.1 Block Diagram

Figure 1 shows the TIDA-020010 block diagram, which comprises ten main modules:

- Protection circuit
- Reverse polarity protection (high-side switch only)
- High-side switch (TPS1H100-Q1)
- Filter circuit (input filter for the power supply)
- Synchronous step-down converter (LMR36006-Q1)
- Ambient light sensor (OPT3001-Q1)
- Brushed DC motor driver (DRV8912-Q1)
- Voltage-tracking LDO (TPS7B4250-Q1)
- Analog multiplexer, demultiplexer (SN74LV4051-Q1)
- Ratiometric linear Hall-effect sensor (DRV5055-Q1)
- Constant-current LED driver (TPS6C5716-Q1)

Figure 1. TIDA-020010 Block Diagram



2.2 Highlighted Products

2.2.1 TPS1H100-Q1

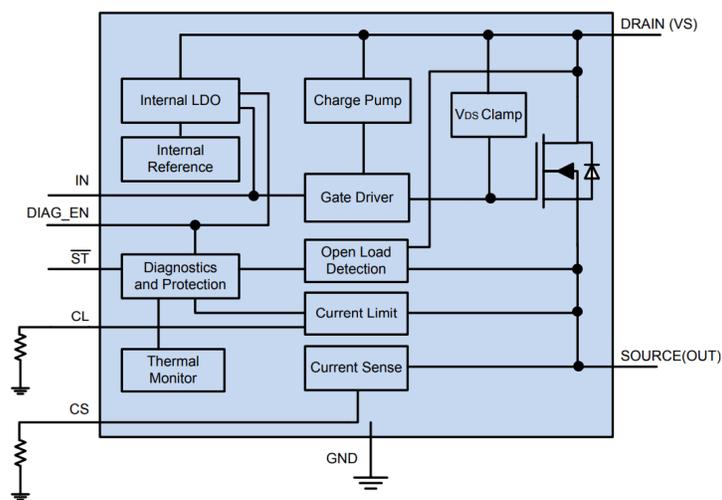
The TPS1H100-Q1 device is a single-channel, fully-protected, high-side power switch with an integrated NMOS power FET and charge pump. Figure 2 shows the device block diagram. Full diagnostics and high-accuracy current-sense features enable intelligent control of the load. A programmable current-limit function greatly improves the reliability of the whole system. The device diagnostic reporting has two versions to support both digital status and analog current-sense output, both of which can be set to the high-impedance state when diagnostics are disabled, for multiplexing the MCU analog or digital interface among devices

An active drain and source voltage clamp is built in to address switching off the energy of the inductive loads, such as relays, solenoids, pumps, motors, and so forth. During the inductive switching-off cycle, both the energy of the power supply (E_{BAT}) and the load (E_{LOAD}) are dissipated on the high-side power switch itself. The TPS1H100-Q1 device can achieve excellent power dissipation capacity, which can help save the external free-wheeling circuitry in most cases

The main features of this device follow:

- Wide operating voltage
- Very-low standby current
- Input control, 3.3-V and 5-V logic compatible
- High accuracy current sense
- Programmable current limit
- Diagnostic function
 - Overload and short-circuit protection
 - Inductive load negative voltage clamp
 - Undervoltage lockout (UVLO) protection
 - Thermal shutdown or thermal swing with self recovery
 - Loss of GND, loss of supply protection

Figure 2. TPS1H100-Q1 Block Diagram



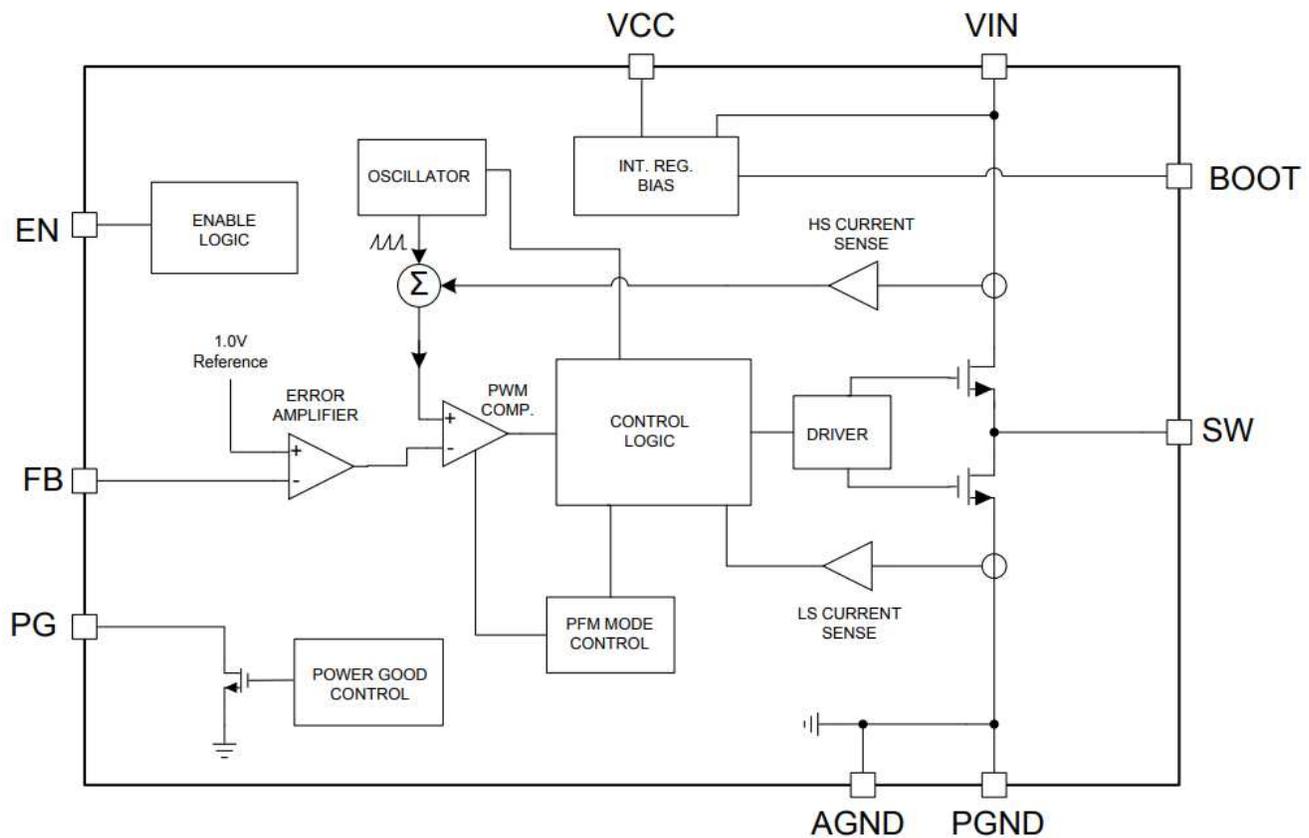
2.2.2 LMR36006-Q1

The LMR36006-Q1 device in [Section 2.2.3](#) is a synchronous peak-current-mode buck regulator designed for a wide variety of industrial applications. The device features internal loop compensation which reduces design time and requires fewer external components than externally compensated regulators. The LMR36006-Q1 device is designed with a flip-chip or HotRod™ technology, greatly reducing the parasitic inductance of pins. In addition, the layout of the device allows for reduction in the radiated noise generated by the switching action through partial cancellation of the current generated magnetic field. As a result the switch-node waveform exhibits less overshoot and ringing.

The main features of this device follow:

- Small package size
- Low power dissipation across load spectrum
- Wide input voltage range

Figure 3. LMR36006-Q1 Block Diagram



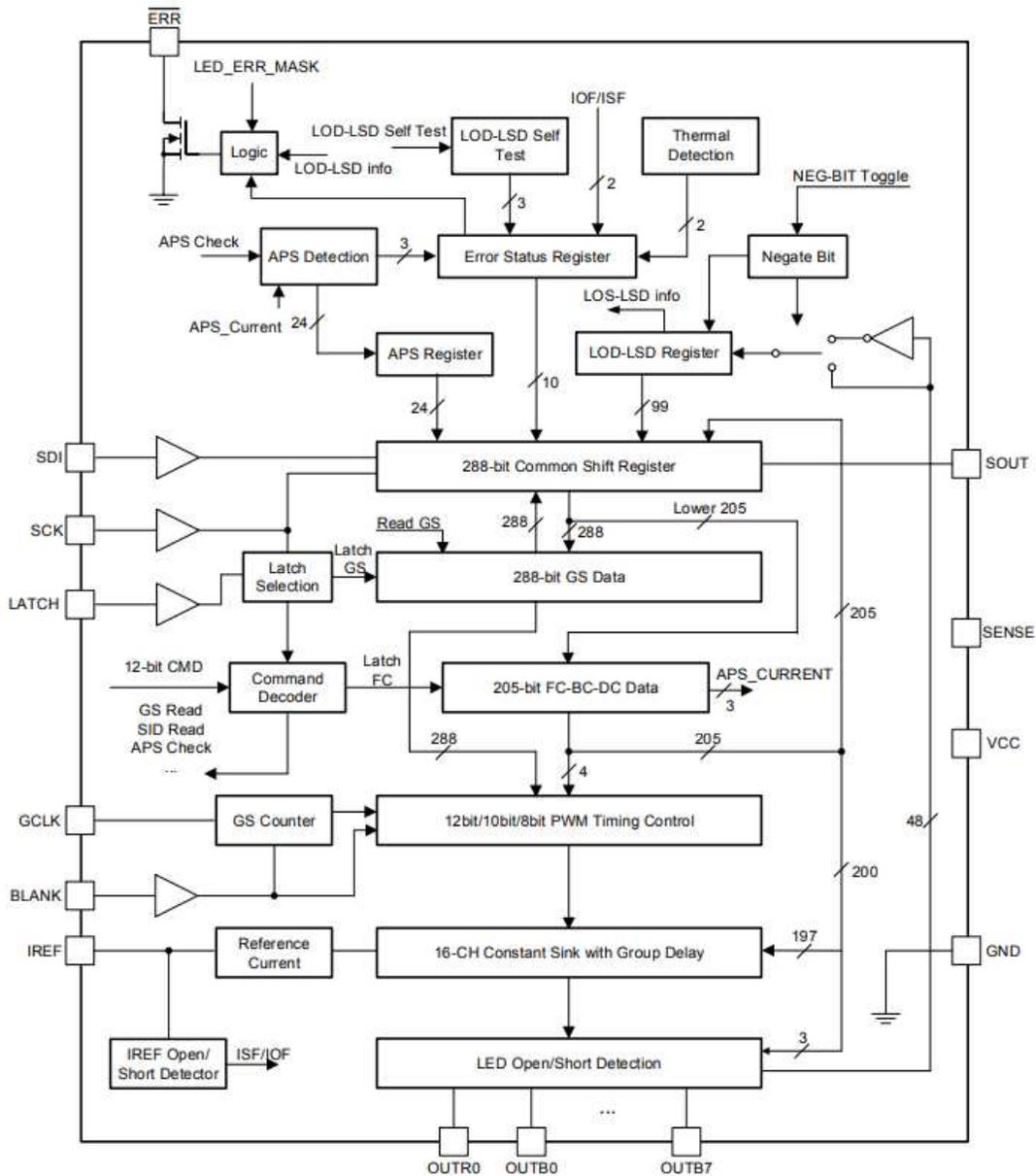
2.2.3 TLC6C5716-Q1

The TLC6C5716-Q1 is an automotive 16-channel constant-current LED driver with LED diagnostics. [Figure 4](#) shows the block diagram of the device. The TLC6C5716-Q1 provides up to 50 mA of output current set by an external resistor. The current is adjusted with 7-bit dot correction with two subranges for individual outputs, and an 8-bit brightness control for all the outputs of each color group. The brightness can be adjusted individually for each channel through a 12-, 10-, or 8-bit grayscale control. Fault-detection circuits are available to detect system faults including LED faults, adjacent-pin short faults, reference-resistor faults, and more. Negate bit toggle and LOD-LSD self-test provide a device self-check function to improve system reliability. Configurable slew-rate control optimizes the noise generation of the system and improves the system EMC performance. Output-channel group delay helps to reduce inrush current to optimize the system design. The SDI and SDO pins allow more than one device to be connected in a daisy chain for control through one serial interface.

The main features of this device follow:

- 16 constant-current-sink output channels
- Output current adjustment
- Integrated PWM grayscale generator
- Protection and diagnostics
- Output channel group dimming
- Serial data interface

Figure 4. TLC6C5716-Q1 Block Diagram



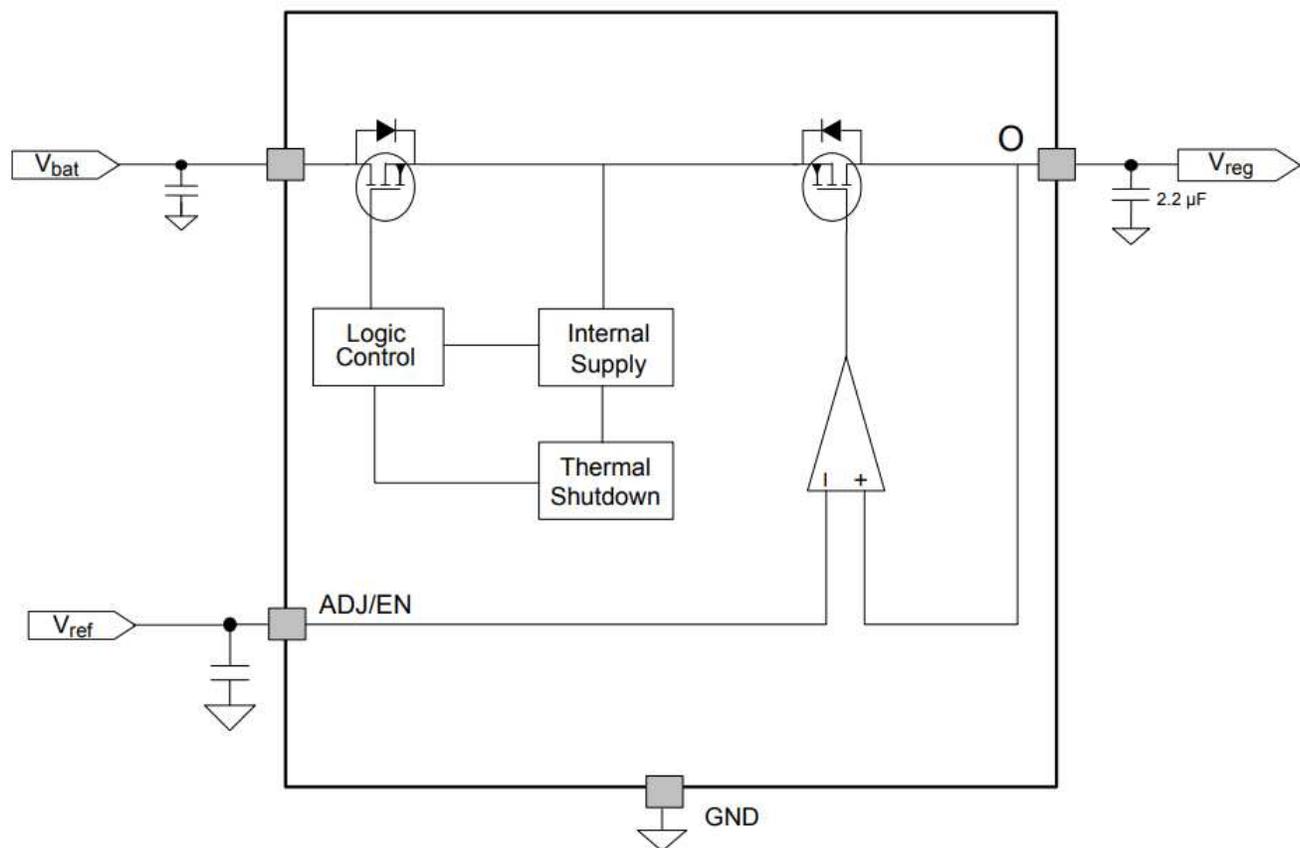
2.2.4 TPS7B4250-Q1

The TPS7B4250-Q1 device is a monolithic integrated low-dropout voltage tracker with ultra-low tracking tolerance. Several types of protection circuits are also integrated in the device such as output current limitation, reverse polarity protection, and thermal shutdown in case of overtemperature. Figure 5 shows the block diagram of the device.

The main features of this device follow:

- Output current 50 mA
- Very-low output tracking tolerance
- Reverse polarity protection
- Overtemperature protection
- Output short-circuit proof to ground and supply

Figure 5. TPS7B4250-Q1 Block Diagram



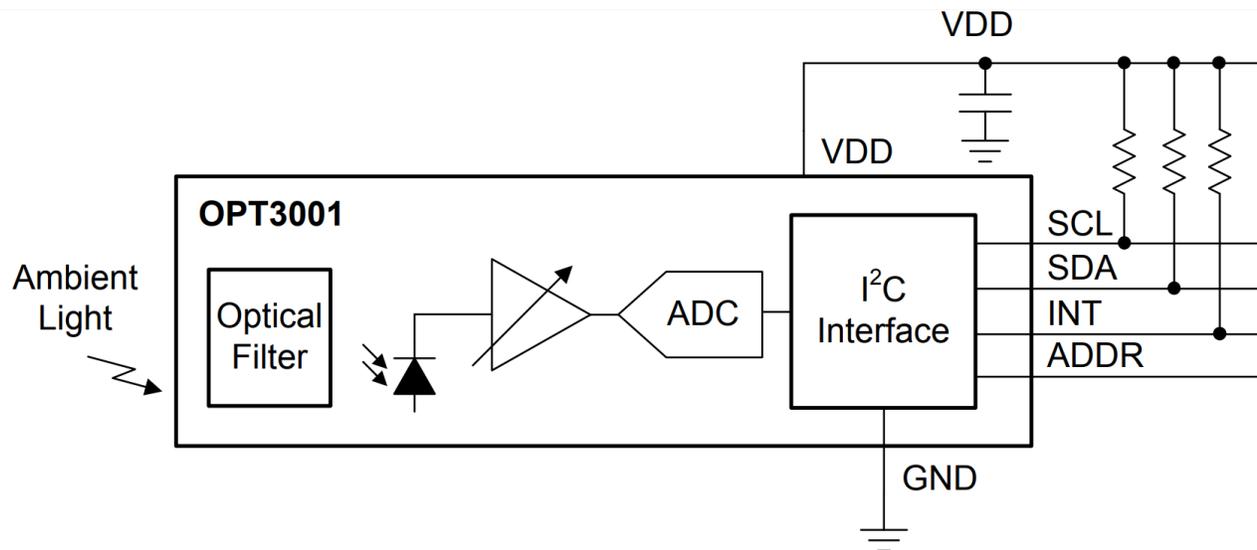
2.2.5 OPT3001-Q1

The OPT3001-Q1 is a single-chip lux meter which measures the intensity of light as visible with the human eye. The spectral response of the sensor tightly matches the photo picture response of the human eye and includes significant infrared (IR) rejection. The precision spectral response and strong IR rejection of the device enables the OPT3001-Q1 device to accurately meter the intensity of light as seen by the human eye, regardless of the light source. The OPT3001-Q1 is an ideal, preferred replacement for photodiodes, photoresistors, or other ambient light sensors with less human eye matching and IR rejection. Users can make measurements from 0.01 lux up to 83 klux without manually selecting full-scale ranges by using the built-in, full-scale setting feature. Measurements can be either continuous or single shot. The digital output is reported over an I²C- and SMBus-compatible, two-wire serial interface. The low-power consumption and low-power supply voltage capability of the OPT3001-Q1 device enhance the battery life of battery-powered systems. Figure 6 shows the block diagram of the sensor with digital interface and INT output pin, which can use the result to alert the system and interrupt the processor.

The main features of this device follow:

- Precision optical filtering to match the human eye:
 - Rejects > 99% (typical) of IR
- Measurements: 0.01 lux to 83 klux
- 23-bit effective dynamic range with automatic gain ranging
- Low operating current: 1.8 μ A (typical)
- Wide power-supply range: 1.6 V to 3.6 V
- Flexible interrupt system
- Small-form factor: 2 mm \times 2 mm \times 0.65 mm

Figure 6. OPT3001-Q1 Block Diagram



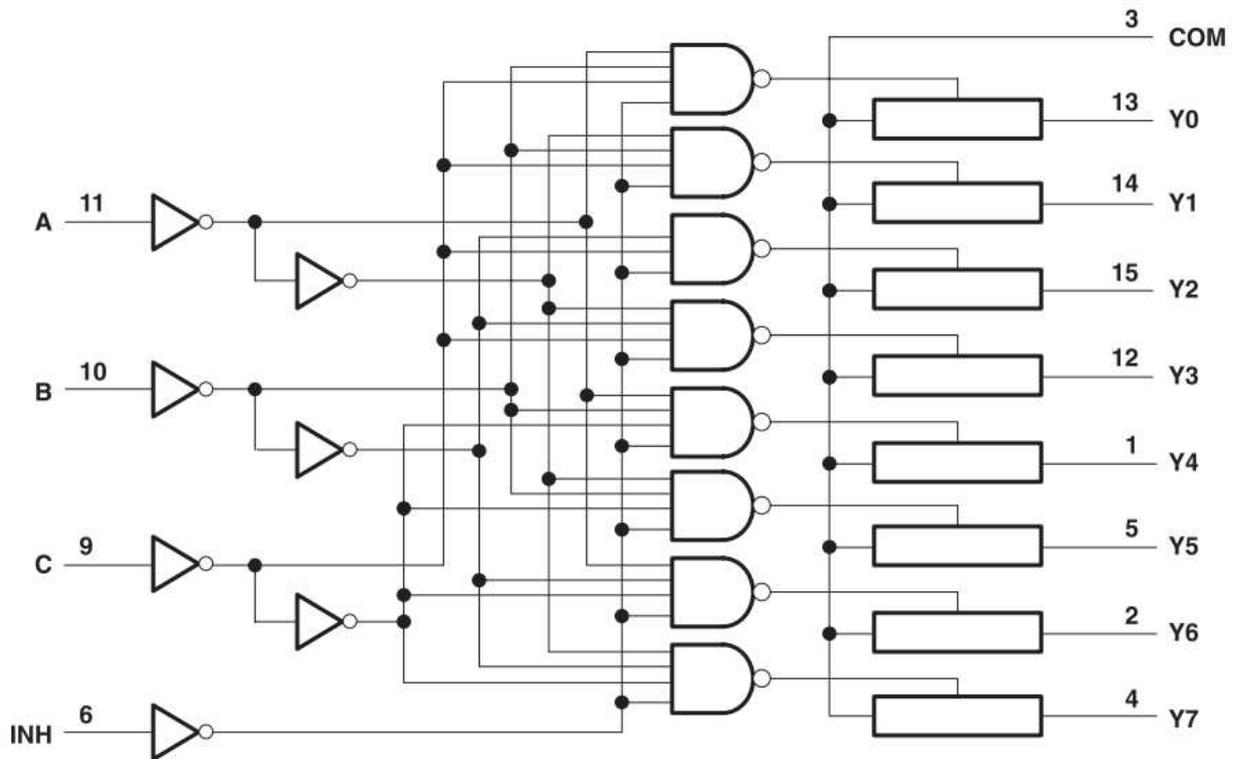
2.2.6 SN74LV4051A-Q1

The SN74LV4051A-Q1 device handles analog and digital signals. Each channel permits signals with amplitudes up to 5.5 V (peak) to be transmitted in either direction. Figure 7 shows the block diagram of the device.

The main features of this device follow:

- Operating voltage 2 V to 5.5 V
- Supports mixed-mode operation on all ports
- Low crosstalk between switches
- Extremely low input current

Figure 7. SN74LV4051A-Q1 Block Diagram



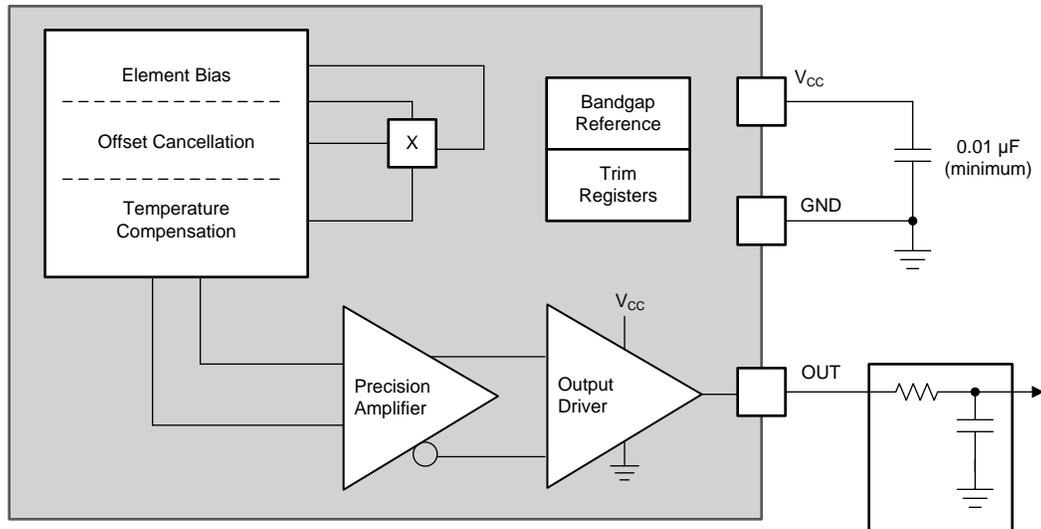
2.2.7 DRV5055-Q1

Figure 8 shows the block diagram of the DRV5055-Q1, which is a 3-pin linear Hall-effect sensor with fully integrated signal conditioning, temperature compensation circuits, mechanical stress cancellation, and amplifiers. The device operates from 3.3-V and 5-V ($\pm 10\%$) power supplies, measures magnetic flux density, and outputs a proportional analog voltage that is referenced to VCC.

The main features of this device follow:

- Fast 20-kHz sensing bandwidth
- Low-noise output with ± 1 mA drive

Figure 8. DRV5055-Q1 Block Diagram



2.2.8 DRV8912-Q1

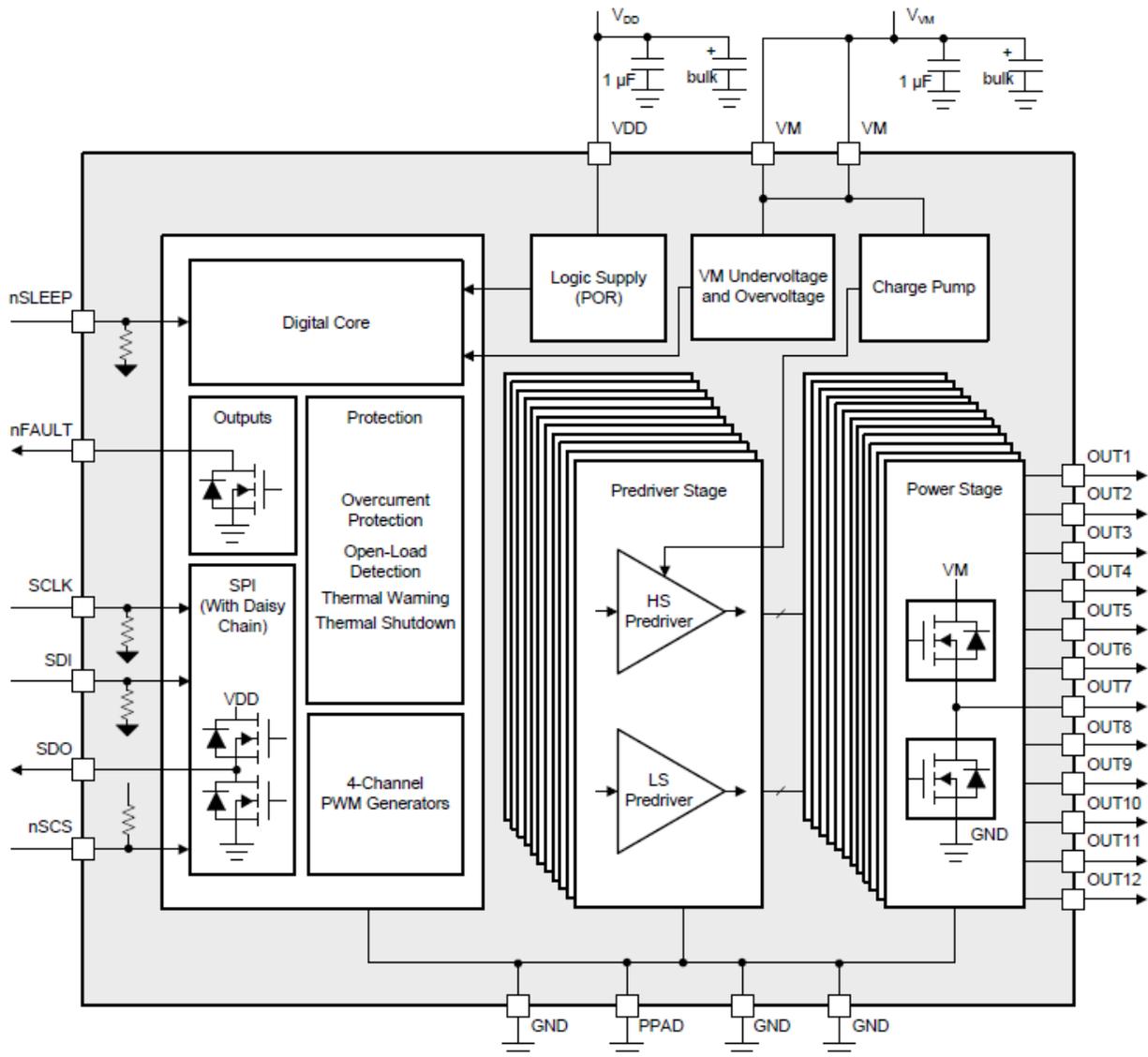
The DRV89xx-Q1 device is an integrated multichannel half-bridge driver for automotive applications such as control of heating, ventilation, and airconditioning (HVAC) flap DC motor.

Each of the high-side and low-side drivers can drive rms currents up to 1 A. The device can drive the brushed-DC (BDC) motors in independent, sequential, or parallel mode. The BDC and stepper motor is fully controllable with forward, reverse, coasting and braking mode support. With its wide voltage range, the device can support high fluctuation in battery voltage. The configuration, operation and diagnostics of the device is controlled by a 16-bit SPI with daisy chain compatibility. Internal PWM generators are also supported on this device, which allows current limiting during motor operation. The device has four PWM generators which are programmable for four different PWM frequency and individual 8-bit duty control. Any half-bridge can be mapped to any internal PWM generator for realizing a parallel operation. The device has an open load detection feature, which allows an easy monitoring of the load connected to the half-bridge. The device is fully-protected from short-circuit conditions (short to OUTx, short to supply and short to ground) with OCP protection. Figure 9 shows the block diagram of DRV8912-Q1.

The main features of this device follow:

- 12 half-bridge outputs
- Wide operating voltage range (4.5-V to 20-V)
- 1.0-A RMS current per half-bridge
- Low-power sleep mode (3- μ A)
- Supports 3.3-V and 5-V logic Inputs
- SPI interface for communication and diagnostics
- Integrated protection features

Figure 9. DRV8912-Q1 Block Diagram



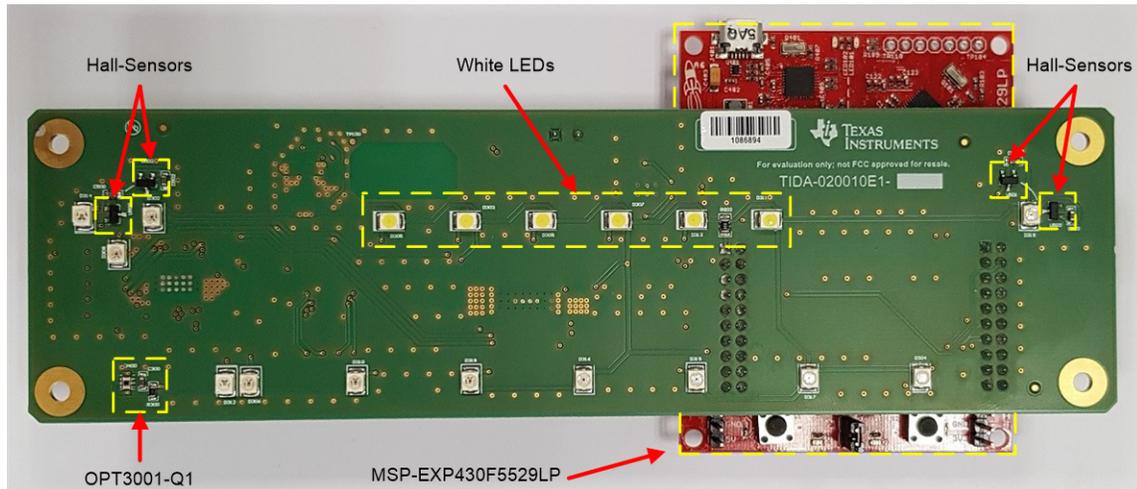
2.3 System Design Theory

This TI design represents the HVAC control unit with HMI, that incorporates multiple devices controlled with the main microcontroller (in this case, LaunchPad). The displays and buttons in HVAC HMIs are illuminated with a number of LEDs. The drive circuit for these LEDs is typically realized in a discrete way using a current-limiting resistor and low-side BJT for each LED (or a couple of them in series) where MCU controls the basis pin of the transistor. Therefore in such topologies controlling of 18 LEDs independently would require same amount of independently driven low side BJTs and PWM-output pins of the MCU in order to create a dimming effect.

The primary goal of this reference design, with regards to the printed-circuit board (PCB), is to make a compact solution and still offer the possibility to drive from the board various of loads whether resistive, inductive or capacitive, which is possible by using the TPS1H100-Q1. One another requirement is, to drive total of 18 LEDs simultaneously (of which 16 can be driven independently) to provide the LED dimming depending on the ambient light intensity. These features are possible by using one TLC6C5716-Q1 device and one OPT3001-Q1 device. It is also important to have capability to drive the off board sensors, such as negative temperature coefficient (NTC) temperature sensors, which is realized by using the TPS7B4250-

Q1 (tracking LDO) and SN74LV4051-Q1 (multiplexer, demultiplexer). This TI-design uses the DRV8912-Q1 device to drive 6 BDC HVAC flap motors in independent, sequential, or parallel mode. The devices on this TI design are controlled with a TI LaunchPad Development Kit (MSP-EXP430F5529LP), as [Figure 10](#) shows. Some of the devices are controlled with the MCU through digital communication interfaces, such as I2C and serial data interface and the others are controlled through parallel digital interface. The TIDA-020010 incorporates also four hall effect sensors, that are used to detect the rotation of the magnetic rotary knobs.

Figure 10. LaunchPad™ Development Kit With TIDA-020010 – Top Side



[Figure 10](#) and [Figure 11](#) show the TIDA-020010 board from the top and bottom side. The top side of the PCB is populated with LEDs, the ambient light sensor and hall effect sensors. The TLC6C5716-Q1, LMR36006-Q1 (buck converter), TPS1H100-Q1 (high-side switch), DRV8912-Q1 (motor driver), SN74LV4051-Q1 (multiplexer, demultiplexer), TPS7B4250-Q1 (voltage tracker) and the discreet protection circuit are on the bottom side of the PCB. The reason for such a population is the HMI housing (see [Figure 12](#)) where the TIDA-020010 is fixed. The yellow dashed box in [Figure 12](#) shows the opening through which the light enters and falls on the sensing surface of the ambient light sensor (ALS) OPT3001-Q1.

Figure 11. TIDA-020010-Q1 – Bottom Side

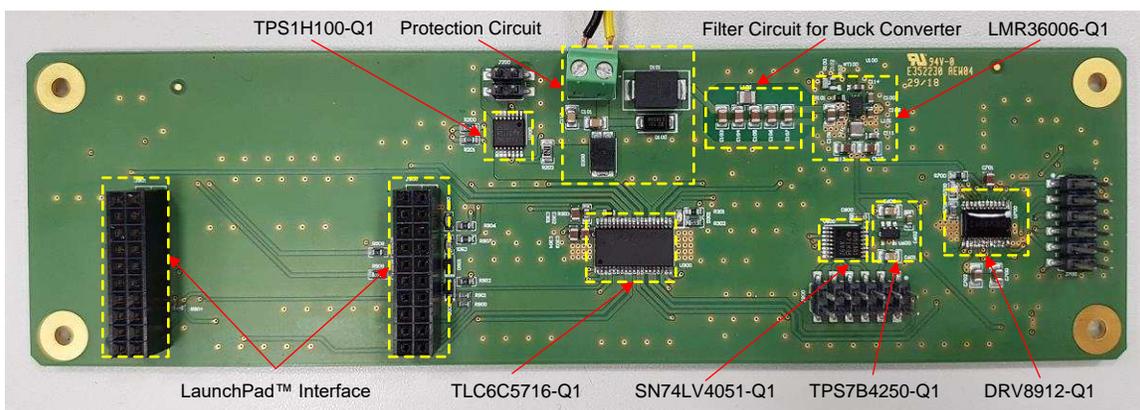


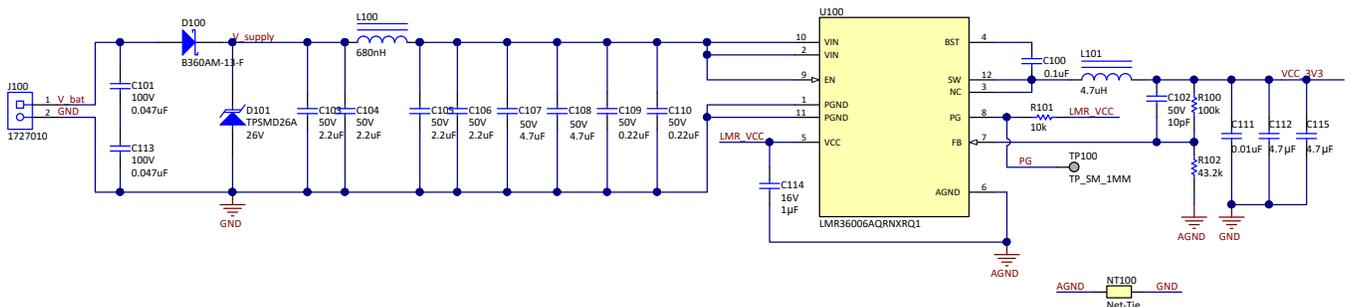
Figure 12. HVAC HMI Housing



2.3.1 Protection Circuit and Power Supply

The protection circuit of the TIDA-020010 design that [Figure 13](#) shows consists of an electrostatic-discharge (ESD) protective part, reverse battery protection diode and the transient voltage suppressor (TVS) diode. The protection circuit is followed by the filter circuit for the buck-converter, that improves the EMI performance for this TI design.

Figure 13. Protection Circuit and Buck-Converter (LMR36006-Q1) With the Input Filter



This design incorporates two in-series capacitors with high-voltage rating values (100 V) for ESD protection. These capacitors are populated on the PCB in an L-shape (90° rotated from each other), which is a common technique in automotive applications. This way of arranging the ESD capacitors can prevent short circuit. When PCB bending occurs due to vibrations, the ceramic capacitor is subject to mechanical damage and the inner layers of the capacitor are at the risk of being shorted.

A TVS diode protects the circuit against load dump transient, which occurs in the event of disconnecting a discharged battery while the alternator is generating charging current to the other loads that remain on the alternator circuit. Another important requirement for a TVS diode is the 24-V jump-start (for 12-V systems). In this design, the TVS has been chosen in such a way that the standoff voltage value of the diode is above the voltage level, which can occur at the start of a jump-start event. In other words, below this voltage level, which is called the reverse standoff voltage, the TVS diode is transparent for the rest of the circuit.

As [Figure 13](#) shows, LMR36006-Q1 is used as a only power supply on the printed circuit board (PCB). This device is a synchronous step-down converter, that has wide input voltage range (4.2 V–60 V) and delivers up to 0.6 A at 3.3 V on the output. The switching frequency of the device is 2.1 MHz. LMR36006-Q1 has a pinout designed for simple PCB layout and requires few external components, the R100 and R102 in the schematic in [Figure 13](#) are optional and are not populated on the PCB.

2.3.2 LED Driver TLC6C5716-Q1

This reference design uses a 16-channel constant-current sink LED driver (TLC6V5716-Q1) that has a digital serial data interface. For this design, the maximum current for each output channel is set using an external resistor, R303 [Figure 14](#). This LED full-scale current can be set by using an external resistor between the IREF pin and GND pin and the value of this resistor (R_{IREF}) is calculated with the following formula:

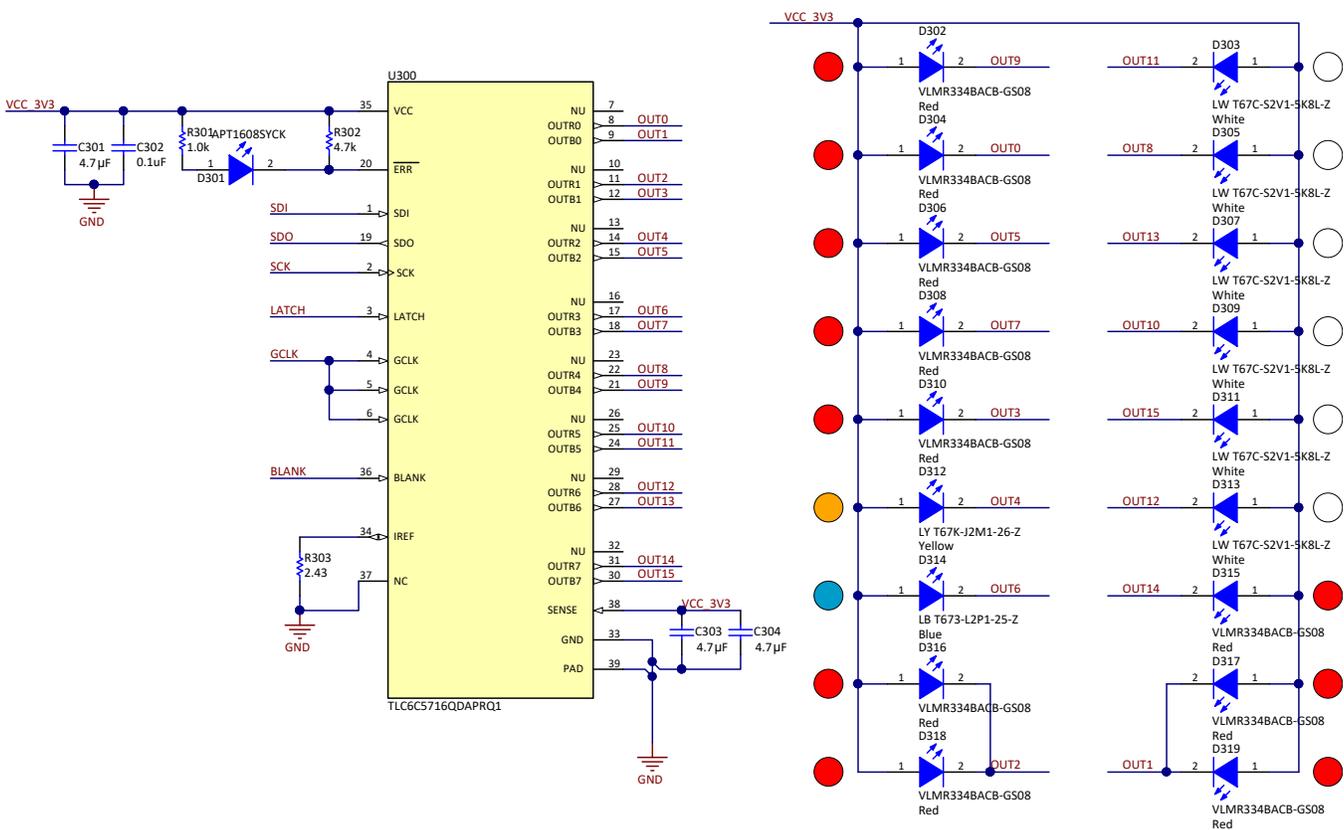
$$R_{IREF} = K \times \frac{V_{IREF}}{I_{(OUT)max}}$$

- V_{IREF} is the reference voltage
- K is the IREF current to output current ratio
- $I_{(OUT)max}$ is full-scale current for each output

(1)

For this design the calculated value of the R_{IREF} is 2.43 k Ω , which corresponds to the maximum current of 25-mA for each output channel.

Figure 14. TLC6C5716-Q1 16-Channel Constant Current Sink LED Driver With Serial Data Interface



The TLC6C5716-Q1 device implements an 8-bit group brightness control (BC) and 7-bit individual dot correction (DC) to calibrate the output current. The 16 output channels are divided into two groups: OUTRn and OUTBn. Each group contains 8 output channels. There are two configurable ranges for the DC value of each group. One is the low DC range with output current from 0 to 66.7% $I_{(OUT)max}$, the other is the high DC range with output current from 33.3% $I_{(OUT)max}$ to 100% $I_{(OUT)max}$.

Equation 2 shows the output current calculation formula for low DC range and Equation 3 shows the calculation formula for high DC range.

$$I_{OUT} = \frac{2}{3} \times I_{(OUT)max} \times \frac{DC}{127} \times \frac{BC}{255} \quad (2)$$

$$I_{OUT} = \left(\frac{1}{3} \times I_{(OUT)max} + \frac{2}{3} \times I_{(OUT)max} \times \frac{DC}{127} \right) \times \frac{BC}{255}$$

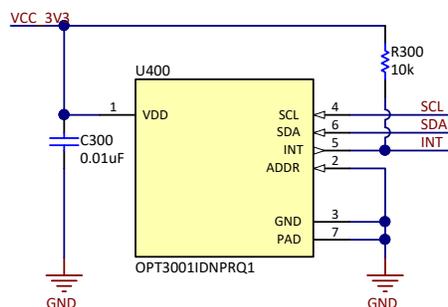
- DC is 7-bit individual dot correction
 - BC is 8-bit group brightness control
 - $I_{(OUT)max}$ is LED full-scale current set by an external R_{IREF}
- (3)

The TLC6C5716-Q1 device implements a grayscale configuration function to realize an individual PWM dimming function for the output channels. The grayscale has three global configuration modes, 12-bit, 10-bit and 8-bit. The GCLK input provides the clock source for the internal PWM generator. In this TI-design the LaunchPad delivers the same clock signal (PWM) for all three GCLK inputs. The GS counter counts the GCLK number and compares the number with channel grayscale register value, and the output channel turns off when the GS counter value reaches the grayscale register value.

2.3.3 Ambient Light Sensor OPT3001-Q1

This reference design uses an ambient light sensor (OPT3001-Q1) that continuously measures the ambient light intensity and delivers the data through the I2C bus to the MCU (LaunchPad), after which the MCU sets the duty cycle of each LED to adapt the light intensity of the LEDs to the environmental light intensity. Figure 15 shows the circuit diagram of the OPT3001 sensor. The INT pin of the device represents an open-drain output, which requires the placement of a pullup resistor on it. The measurement result of the sensor can be used to alert a system and interrupt the MCU with the INT pin. The power supply is bypassed with a 10-nF ceramic capacitance placed close to the VDD-pin of the OPT3001. The ADDR pin allows the designer to set the I2C address of the device, which is 1000 100 in this case

Figure 15. OPT3001-Q1 Ambient Light Sensor



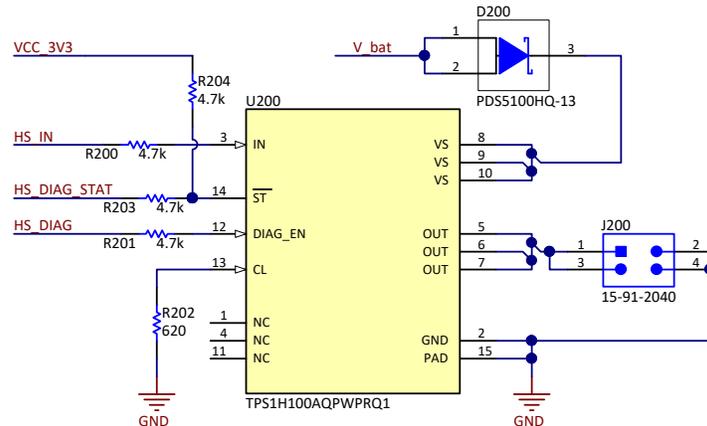
2.3.4 TPS1H100-Q1 Single-Channel Smart High-Side Switch

In this TI-design is used TPS1H100-Q1, which is single-channel fully protected high side power switch. This device is targeted to drive resistive, capacitive and inductive loads, it has excellent power dissipation capacity, which can help save external free-wheeling circuitry in most cases. The setting of maximum current is done by using an external resistor R202 between the CL pin and GND pin in Figure 16. The value of an external current sense resistor ($R_{CL} = 620 \Omega$) is calculated with the following formula Equation 4 and corresponds to the maximum current of 4 A.

$$I_{CL} = \frac{V_{CL,th}}{R_{CL}} = \frac{I_{OUT}}{K_{CL}} \rightarrow R_{CL} = \frac{V_{CL,th} \times K_{CL}}{I_{OUT}}$$

- K_{CL} is current limit current ratio
 - $V_{CL,th}$ is the current limit internal threshold voltage
 - R_{CL} is an external resistor, that is used to set the current limit
 - I_{CL} is current limit
 - I_{OUT} is an output current
- (4)

Figure 16. TPS1H100-Q1 Single-Channel Smart High-Side Switch

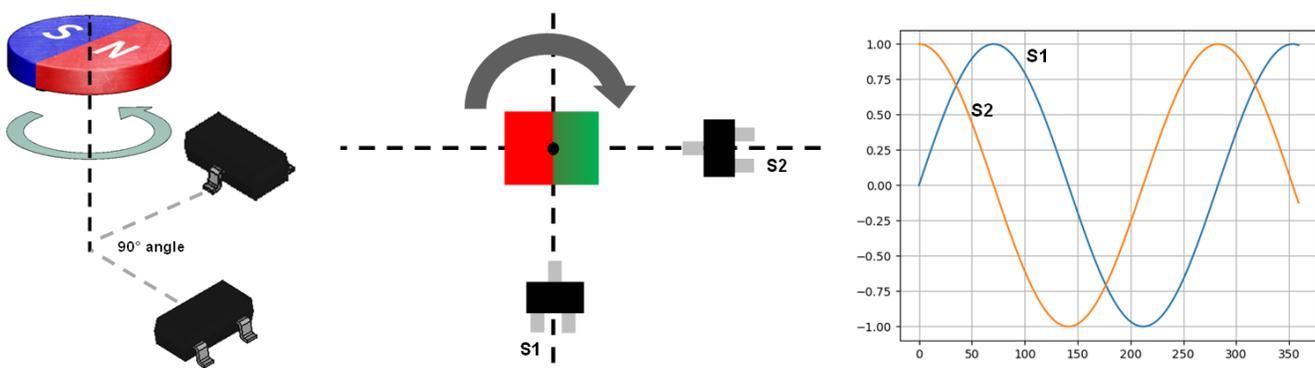


In many conditions, such as the negative ISO pulse, or the loss of battery with an inductive load, a negative potential on the device GND pin may damage the MCU I/O pins. Therefore, the serial resistors R200, R201, and R203 in Figure 16 are required between the MCU and control pins of the high side switch. It is recommended to use 4.7 kΩ when the MCU is supplied with 3.3 V. In this design is used a block diode connected to the supply pin of the TPS1H100 (V_S), in that way both the device and load are protected when in reverse polarity. The forward current rating of the block diode is up to 5.0 A and the repetitive peak reverse voltage goes up to 100 V.

2.3.5 DRV5055-Q1 Ratiometric Linear Hall-Effect Sensor

In this TI-design are used four DRV5055-Q1 devices for the contactless rotation detection of the two rotary knobs. For each rotary knob are used two hall effect sensors, that are located on the top side of the PCB and are mounted at 90° angle to each other. To the rotary knobs are attached the diametral magnetized magnets, that are facing the sensitive surface of the DRV5055-Q1 devices. This method of sensor alignment allows measurement of the rotation of a magnetic field, so that the output voltage of the Hall sensors is two continuous signals, that are shifted in phase by 90 degrees. These signals could be described as sine and cosine accordingly. Figure 17 shows the measurement principle.

Figure 17. Measurement Principle of Rotating Magnetic Field



S1 and S2 represent Hall-effect sensor 1 and 2, accordingly.

The outputs of the DRV5055-Q1 devices are connected through low pass filters to the analog to digital converter (ADC) of the LaunchPad. The MCU on the LaunchPad does sampling of the signals and afterwards calculates the magnetic angle. Since the magnet is attached to the mechanical knob magnetic angle corresponds to the mechanical angle of rotary knob position.

Equation 5 shows the inverse of the tangent function, which is used for the angle calculation.

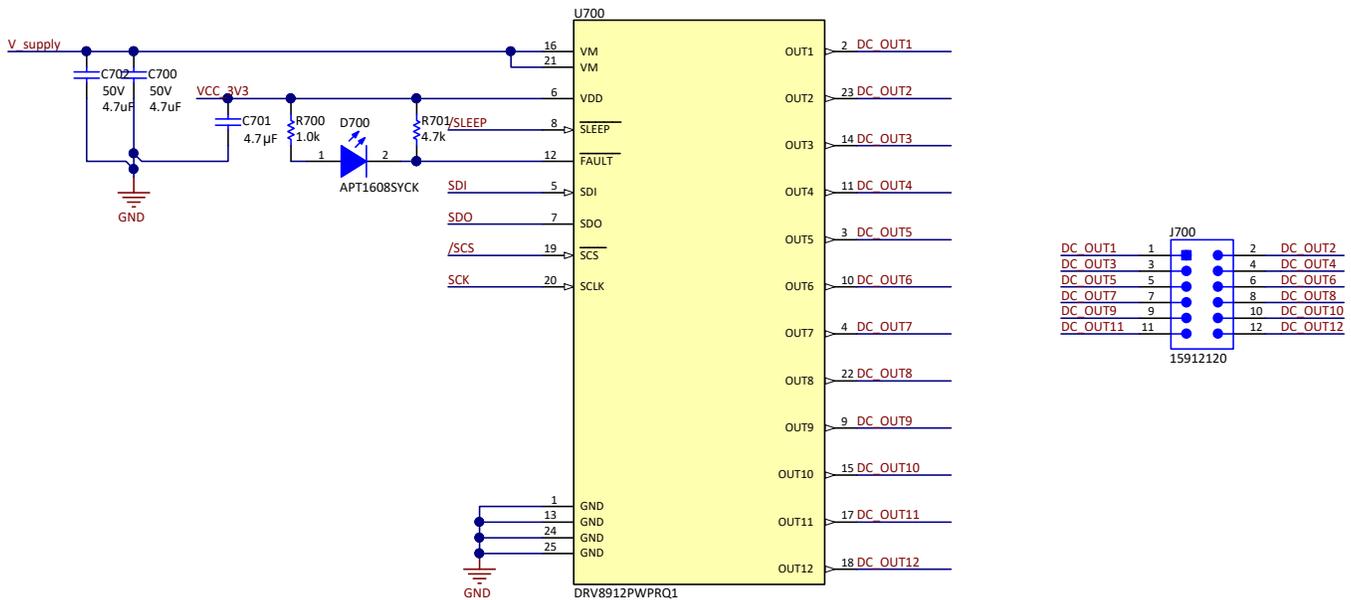
$$\text{Angle} = \arctan\left(\frac{S1_{\sin}}{S2_{\cos}}\right)$$

- Angle-magnetic/mechanical angle
 - $S1_{\sin}$ is the output voltage of first sensor, which is sine voltage
 - $S1_{\cos}$ is the output voltage of second sensor, which is cosine voltage
- (5)

2.3.6 DRV8912-Q1 Brushed DC Motor Driver

The DRV8912-Q1 is controlled by the MCU over the 4-wire SPI interface. Figure 18 shows the circuit of the DRV8912-Q1 device, the VM pin is for the motor supply voltage and is connected right after protection circuit in order to protect the device from reverse polarity. The VDD pin is connected to the 3.3-V rail and supplies the logic part of the device. The Fault pin is connected to the resistor in series with the LED, in that way the debugging process of the device during programming is easier, because any kind of fault state is directly illuminated. All 12 half-bridge outputs are connected to the connector and form 6 full-bridges, therefore the DRV8912-Q1 device is able to drive 6 BDC motors simultaneously.

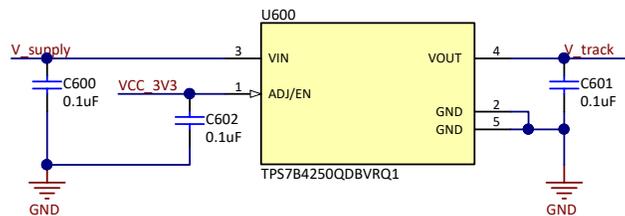
Figure 18. DRV8912-Q1 Circuit



2.3.7 TPS7B4250-Q1 Voltage-Tracking LDO

The tracking LDO in this TI design is connected with the VIN pin right after the protection circuit and the ADJ/EN pin is connected to the 3.3-V rail of the buck converter in Figure 19. In that way the off-board sensors (NTC in this case) are always supplied with adjusted 3.3-V coming from VOUT of the tracking LDO. In Figure 19, V_{track} represents the supply voltage for off-board sensors.

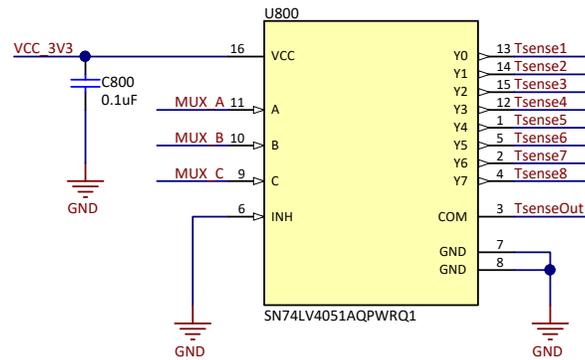
Figure 19. TPS7B4250-Q1 Circuit



2.3.8 SN74LV4051A-Q1 Analog Multiplexer, Demultiplexer

One 8-channel analog multiplexer, demultiplexer is used in this TI design for multiplexing the output signals from the off-board sensors (NTC temperature sensors). The SN74LV4051A-Q1 is controlled by GPIO pins on the LaunchPad. Since the SN74LV4051A is an 8 to 1 device (8-inputs, 1-output in [Figure 20](#)) the MCU permanently switches between channels and does ADC measurement of the eight off-board sensor signals. In [Figure 20](#), MUX_x represent the control signals.

Figure 20. SN74LV4052-Q1 8-Channel Analog Multiplexer, Demultiplexer



3 Hardware, Software, Testing Requirements, and Test Results

3.1 Required Hardware and Software

Figure 21 shows the TIDA-020010 board mounted on the MSP-EXP430F5529LP LaunchPad. The following LEDs are mounted on the TIDA-020010 board: six white LEDs, ten red LEDs, one amber LED, and one blue LED. The TIDA-020010 board is supplied with 12 V. The software in the MSP430F5529 device controls the ambient light sensor and LED driver autonomously through the I2C and serial data bus. Cover the opening on the left corner of the HMI housing to see the dimming effect on the HMI surface (see Figure 22).

Figure 21. TIDA-020010 With MSP-EXP430F5529LP

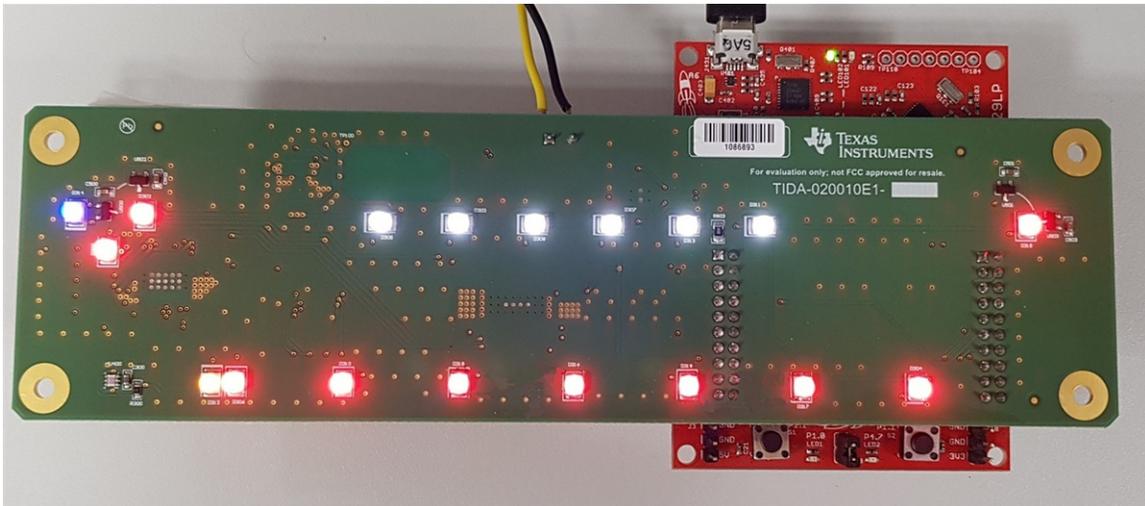


Figure 22. TIDA-020010 HMI Housing

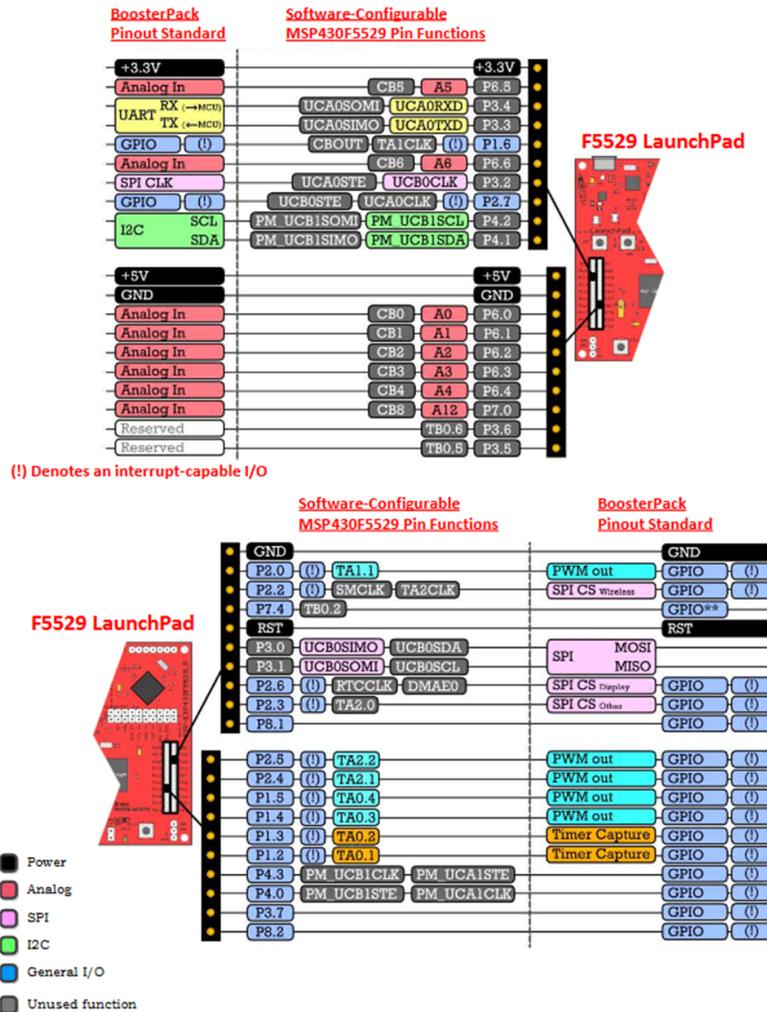


3.1.1 LaunchPad™

LaunchPads are MCU development kits from TI. These kits are available in a variety of types to address various applications. The MSP-EXP430F5529LP (or the F5529 LaunchPad) is an inexpensive and simple development kit for the MSP430F5529 USB MCU. This LaunchPad offers an easy way to begin developing on the TI MSP430™ MCU, with onboard emulation for programming and debugging.

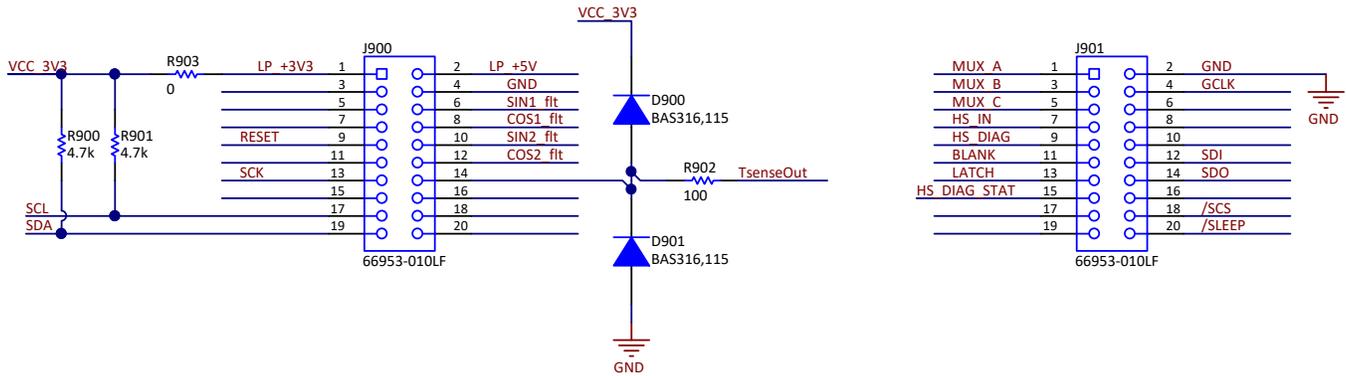
Figure 23 shows the pinout of the F5529 LaunchPad, which allows easy access to all the peripherals on the F5529 device

Figure 23. MSP430F5529 LaunchPad™ Connector Pinout



The schematic in Figure 24 shows the connections on the J900 and J901 pins, both of which are 20-pin connectors. The pin assignments are in accordance with the BoosterPack™ standard, which allows connection to various LaunchPad boards. All the logic signals from an MCU are referenced to the 3.3 V. R900 and R901 (4.7 kΩ) are the pullup resistors for the I2C communication bus. The resistor R902 together with D900 and D901, that are high-speed switching diodes, represent the input protection for the ADC pin. R902 acts as a current limiter and D900 and D901 are clamping diodes.

Figure 24. TIDA-020010 Board Connection to LaunchPad™



3.1.2 Software

Special testing software is created for this design which measures Hall-sensor signals with ADC, and controls the high-side switch and multiplexer, demultiplexer with GPIOs. The LED driver as well as the ambient light sensor are controlled through the I2C and the serial data bus. The software is structured in such a way that the MCU systematically requests the ambient light values from the OPT3001-Q1 driver, starts exponential smoothing of the raw data stream, and then takes the duty cycle value (%) from the predefined look-up table and sets in the TLC6C5716 the register accordingly with 288-bit long data frame so that all the LEDs on the output have an equivalent lighting intensity. The flow chart in [Figure 25](#) shows the simplified structure (without high-side switch and multiplexer, demultiplexer control) of the software.

Figure 25. Software Flow Chart

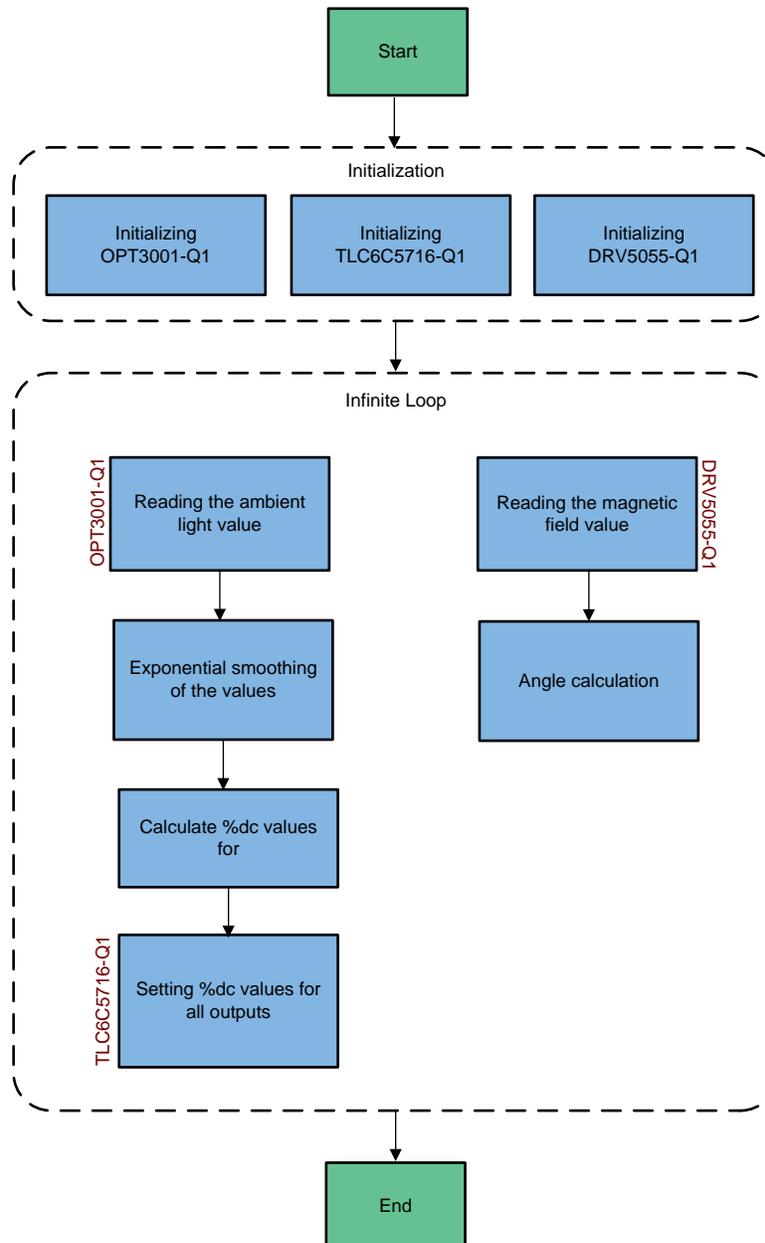


Figure 26 shows how the MCU sets the control register in TLC6C5716 device. Since the TLC6C5716 device has a 288-bit long common register, used for function control (FC), brightness control (BC), dot correction (DC) and grayscale control (GS), there are three different criteria how to write data into common register:

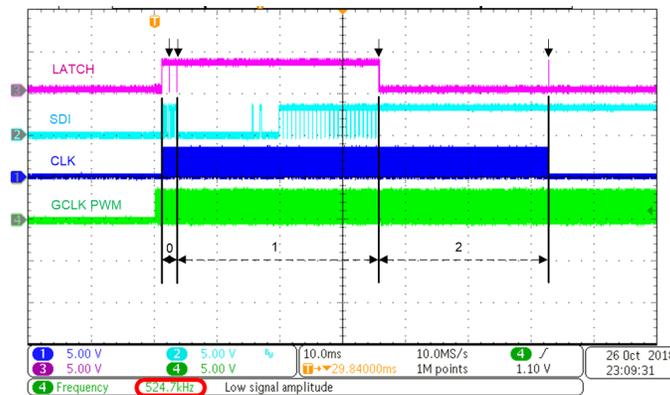
- When LATCH is high at the 288th SCK rising edge, and the 12 MSBs of the 288-bit data are 0, the 205 LSBs of the 288-bit data shift to the function control (FC), brightness control (BC) and dot correction (DC) registers on the LATCH rising edge, as section 1 in Figure 26 shows.
- When LATCH is low at the 288th SCK rising edge, all 288-bit data shifts into the grayscale (GS) configuration registers on the LATCH rising edge, as section 2 in Figure 26 shows.
- When LATCH is high at the 288th SCK rising edge, and the 12 MSBs of the 288-bit data match any of the eight 12-bit command codes (described in the datasheet of the TLC6C5716-Q1), the device executes the corresponding command after the LATCH rising edge.

Section 0 in Figure 26 represents the writing sequence of the **Global Reset** and the **Error Clear** commands.

The TLC6C5716-Q1 device implements grayscale configuration function to realize an individual PWM dimming function for the output channels.

The frequency of the PWM signal, which is used for grayscale PWM counter (GCLK) is 524 kHz (Figure 26 GCLK PWM) and is being generated from the MSP430F5519.

Figure 26. Communication Between MCU and TLC6C5719-Q1



The control signals (LATCH, SDI, CLK, GCLK) represent the setting of the parameters (such as current for each channel) and dimming values.

3.2 Testing and Results

The goal of this reference design, is to make a compact solution and offer the possibility to drive from the board various types of loads (resistive, inductive, capacitive), which is done by TPS1H100-Q1. The waveform in Figure 27 shows the switching behavior of the TPS1H100 (driven by 32.6 Hz PWM signal). The waveform in Figure 28 shows TPS1H100 turn-on delay time. The measurement is done with the 7- Ω resistive load, a load current of 1.42 A, and the turn-on delay time is 48 μ s.

Figure 27. TPS1H100-Q1 is Driven by PWM Signal With 32.6 Hz of Frequency

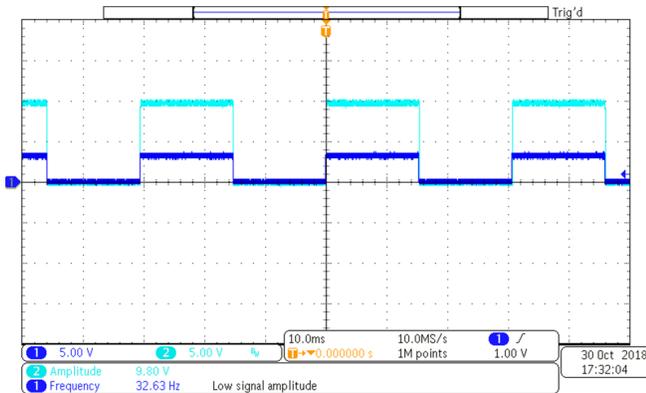
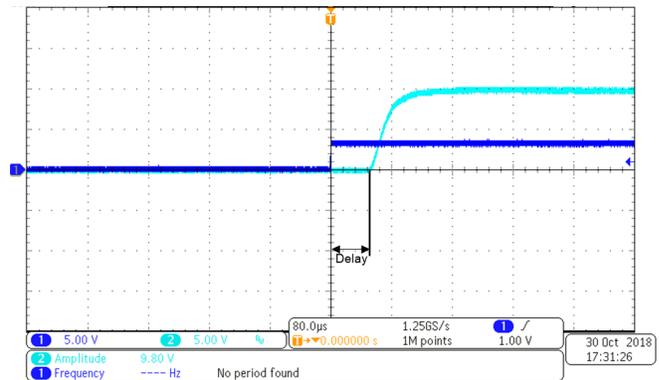


Figure 28. TPS1H100-Q1 Switch-On Delay



One another requirement is, to drive total of 18 LEDs simultaneously (of which 16 can be driven independently) to provide the LED dimming depending on the ambient light intensity. This feature is realized by using of one TLC6C5716-Q1 and one OPT3001-Q1. The best way to see the effect of LED dimming for the HVAC HMI application is to put the TIDA-020010 device into the HMI housing and monitor the LED lighting intensity based on the ambient light level. The following Figure 29 through Figure 32 show the difference in LED lighting intensity between a 5%, 45%, 75%, and 100% duty cycle.

Figure 29. LED Dimming With 5% Duty Cycle



Figure 30. LED Dimming With 45% Duty Cycle



Figure 31. LED Dimming With 75% Duty Cycle



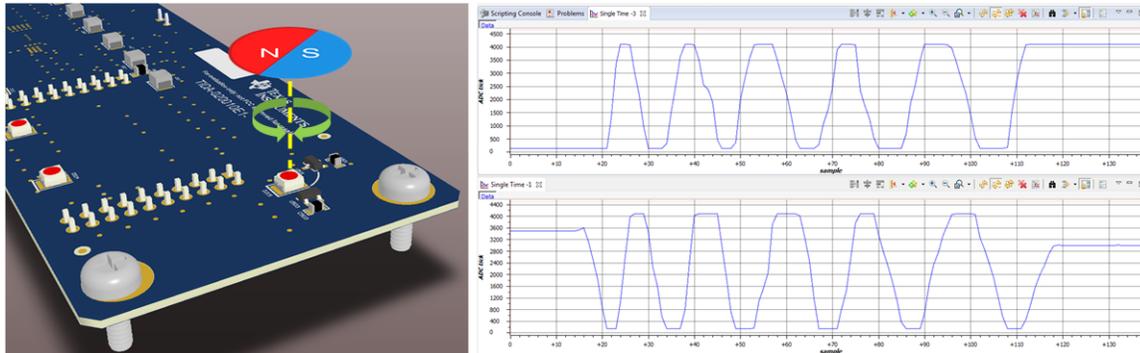
Figure 32. LED Dimming With 100% Duty Cycle



This TI design uses TPS7B4250-Q1 (tracking LDO) and SN74LV4051-Q1 (multiplexer, demultiplexer) to drive and multiplex the eight off board temperature (NTC) sensors.

TIDA-020010 incorporates also hall effect sensors, for the contactless rotation detection of the magnetic rotary knobs. Figure 33 shows the rotation of the diagonal magnetized magnet, which is attached to the rotary knob. Figure 17 shows the alignment of the hall effect sensors relative to each other and to the magnet on the PCB. The signals in Figure 33 are the raw values delivered from the ADC (12-bit) of MSP430 and they represent the output signals of the two hall sensors, this waveforms correspond to the rotation of the diametral magnetized magnet (rotary knob). As the both hall sensors are located on the PCB at 90° degrees relative to each other the output signals of this hall sensors are also shifted in phase by 90 degrees. The shape of the waveform is dependent on the rotation speed and smoothness. Nevertheless, it has no influence on the angle calculation.

Figure 33. TIDA-020010 description of the application with a magnetic rotary knob and the output signals of the hall effect sensors, that correspond to the rotation of the rotary knob



This design uses TI's DRV8912-Q1 multiple half-bridge driver to drive 6 BDC motors (six Flap actuators) simultaneously and is controlled by the MCU through the 4-wire SPI bus. Figure 34 and Figure 35 show the motor supply voltage of flap actuators (delivered through half-bridges to the BDC motors) and the SPI communication between MCU and DRV8912-Q1. Both figures show at two different supply voltages (6 V and 20 V) how the output channels of DRV8912 are switched on and off. DRV8912-Q1 drives at both supply voltage levels (6 V and 20 V) all 6 flap actuators simultaneously. To enable or disable all output channels, the MCU sends on the SDI line 3 times appropriate 16-bit command.

Figure 34. DRV8912-Q1 Switching all Channels on and off at 6-V

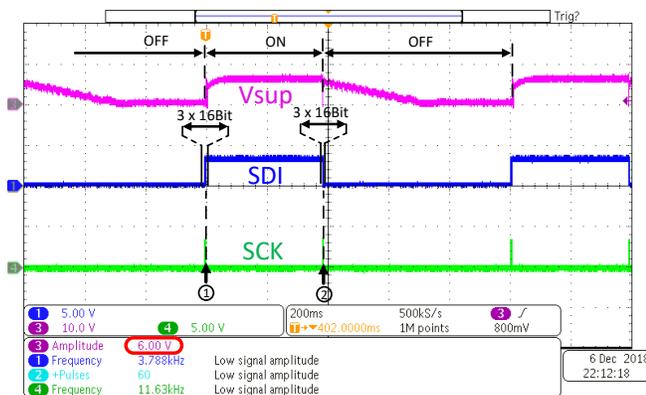


Figure 35. DRV8912-Q1 Switching all Channels on and off at 20-V

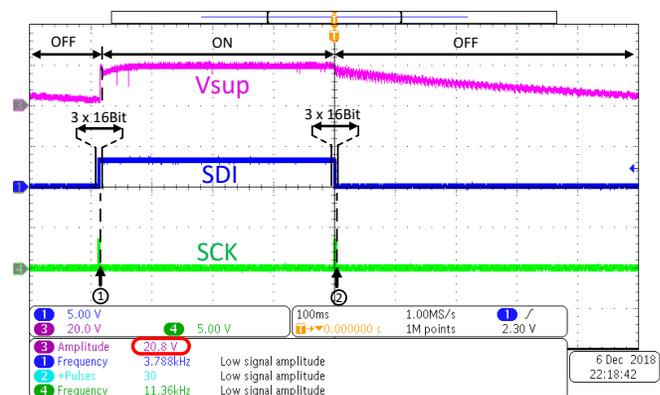


Figure 36 shows the startup moment of one BDC motor, which is driven by 2 output channels in H-bridge configuration. As soon as the DRV8912 receives the 16-bit command through the SDI line, which is for enabling of one high-side and one low-side switch in two different half-bridges (both connected to the motor), current to the load will be delivered immediately (marking 1: dashed line in Figure 36). Figure 37 shows the disabling of the same output channels.

Figure 36. DRV8912-Q1 Enabling all Channels

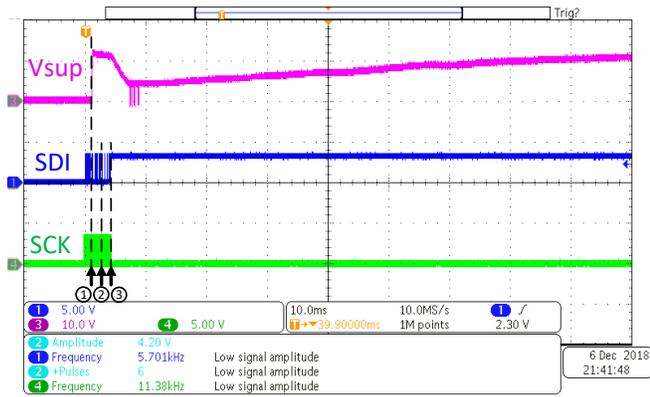
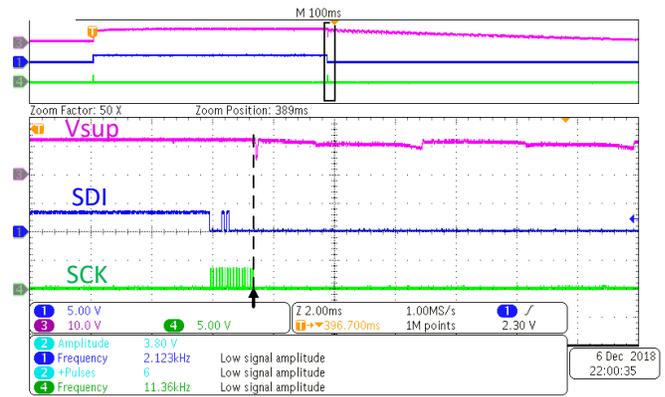


Figure 37. DRV8912-Q1 Disabling all Channels



4 Design Files

4.1 Schematics

To download the schematics, see the design files at [TIDA-020010](#).

4.2 Bill of Materials

To download the bill of materials (BOM), see the design files at [TIDA-020010](#).

4.3 PCB Layout Recommendations

4.3.1 Layout Prints

To download the layer plots, see the design files at [TIDA-020010](#).

4.4 Altium Project

To download the Altium Designer® project files, see the design files at [TIDA-020010](#).

4.5 Gerber Files

To download the Gerber files, see the design files at [TIDA-020010](#).

4.6 Assembly Drawings

To download the assembly drawings, see the design files at [TIDA-020010](#).

5 Software Files

To download the software files, see the design files at [TIDA-020010](#).

6 Related Documentation

1. Texas Instruments, [TPS1H100-Q1 40-V, 100-mΩ Single-Channel Smart High-Side Power Switch Data Sheet](#)
2. Texas Instruments, [LMR36006-Q1 4.2-V to 60-V, 0.6-A Ultra-Small Synchronous Step-Down Converter Data Sheet](#)
3. Texas Instruments, [TLC6C5716-Q1 Automotive 16-Channel, Full Diagnostics, Constant-Current LED Driver Data Sheet](#)

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7 About the Author

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