

TI Designs: TIDA-020010

带 HMI 的汽车 HVAC 控制参考设计



说明

该参考设计为暖通空调 (HVAC) 人机界面 (HMI) 应用提供了一种具有成本效益的解决方案。该参考设计包含同步降压转换器、用于刷式直流电机 (BDC) 的多通道半桥电机驱动器、多通道发光二极管 (LED) 驱动器、用于驱动各种负载的高侧开关、用于测量可见光强度的环境光传感器、用于以非接触方式测量旋钮旋转的多个霍尔传感器、用于为非板载传感器供电的跟踪电压稳压器、用于对连接至微控制器模数转换器 (ADC) 的多个模拟传感器输出进行多路复用的多路复用器。此设计使用 TI LaunchPad™ 开发套件实现控制，该开发套件可根据环境光强度来调节 LED 的调光 PWM，控制高侧开关，检测磁旋钮的旋转运动，驱动多个 BDC 电机，测量来自非板载温度传感器的多个模拟信号。

资源

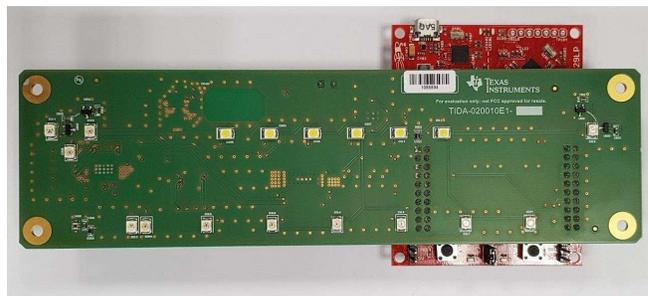
TIDA-020010	设计文件夹
LMR36006-Q1	产品文件夹
OPT3001-Q1	产品文件夹
DRV5055-Q1	产品文件夹
TLC6C5716-Q1	产品文件夹
TPS7B4250-Q1	产品文件夹
SN74LV4051A-Q1	产品文件夹
TPS1H100-Q1	产品文件夹
DRV8912-Q1	产品文件夹

特性

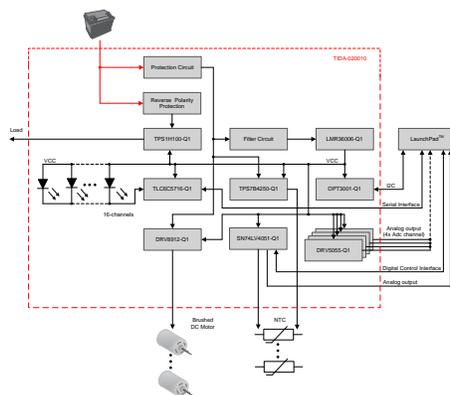
- 可承受反向电池保护
- 可驱动多达 6 个 BDC 电机
- 单芯片解决方案，使用 LED 驱动器中的 16 个独立 PWM 控制器驱动多达 18 个 LED
- LED 不需要电流限制电阻器即可轻松实现电阻器匹配
- 根据环境光强度自动进行 LED 调光
- 可针对旋钮以非接触方式进行旋转检测
- 高效电源
- 具有精确电流检测功能且受到全面保护的高侧电源开关

应用

- 汽车 HVAC HMI



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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

表 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					

表 1. Key System Specifications (continued)

PARAMETER	SPECIFICATIONS	MIN	TYP	MAX	UNIT
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
$V_{S,UVF}$	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	μ A
I_{VDDQ}	VDD sleep mode current	-	-	1	μ A
$R_{HS,DS(on)}$	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	μ A
C_{OUT}	Output capacitor requirements	1	-	50	μ F
ANALOG MULTIPLEXER, DEMULTIPLEXER					
V_{CC}	Supply voltage	2	-	5.5	V
I_{CC}	Supply current ($V_{CC} = 5V$)	-	-	40	μ A
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

表 1. Key System Specifications (continued)

PARAMETER	SPECIFICATIONS	MIN	TYP	MAX	UNIT
B _L	Linear magnetic sensing range (T _A = 25°C)	±22			mT

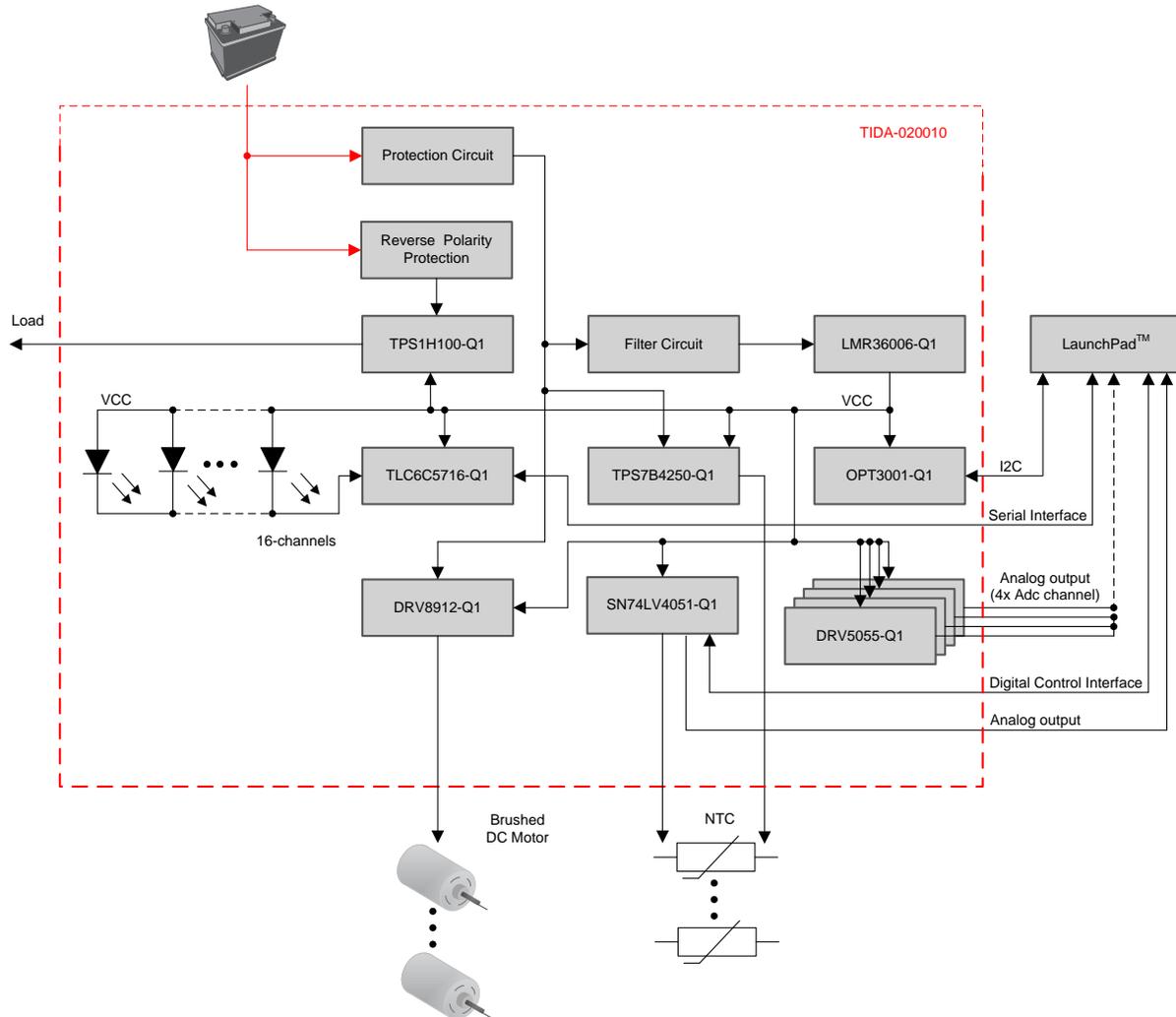
2 System Overview

2.1 Block Diagram

 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)

图 1. TIDA-020010 Block Diagram



2.2 Highlighted Products

2.2.1 TPS1H100-Q1

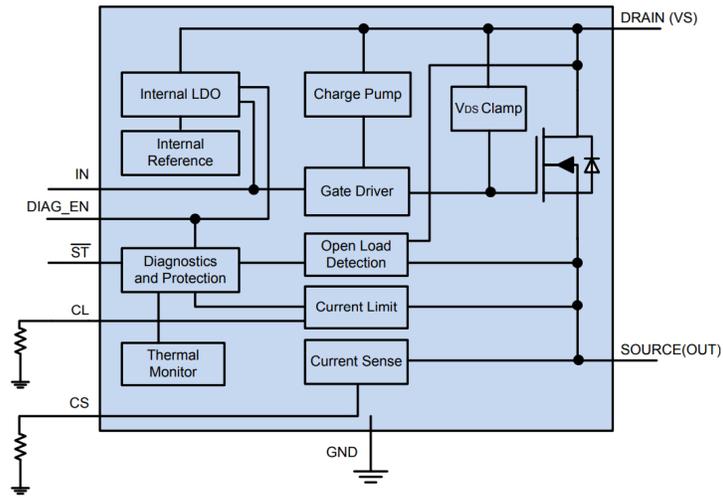
The TPS1H100-Q1 device is a single-channel, fully-protected, high-side power switch with an integrated NMOS power FET and charge pump. 图 2 shows the device block diagram. Full diagnostics and high-accuracy current-sense features enable intelligent control of the load. A programmable current-limit function 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
- Protection
 - 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

图 2. TPS1H100-Q1 Block Diagram



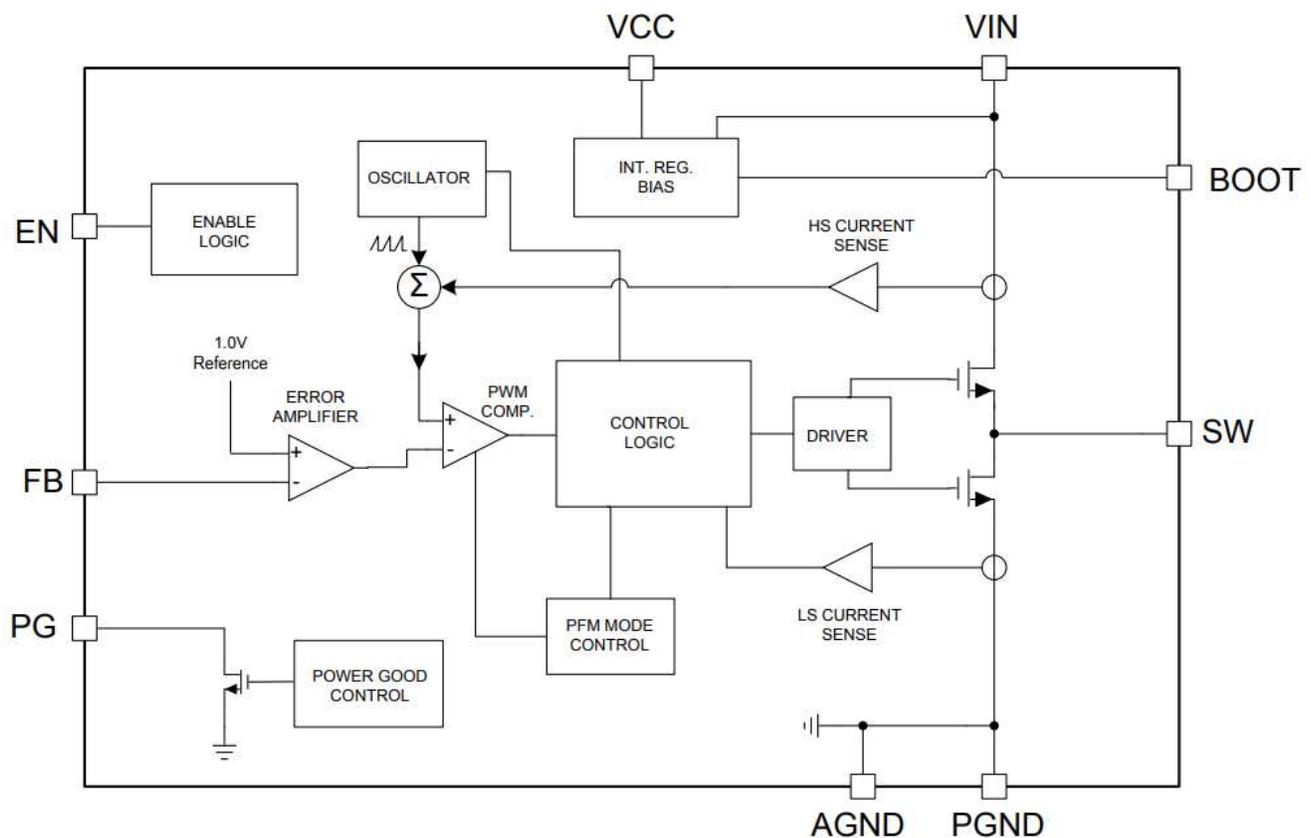
2.2.2 LMR36006-Q1

The LMR36006-Q1 device in 节 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

图 3. LMR36006-Q1 Block Diagram



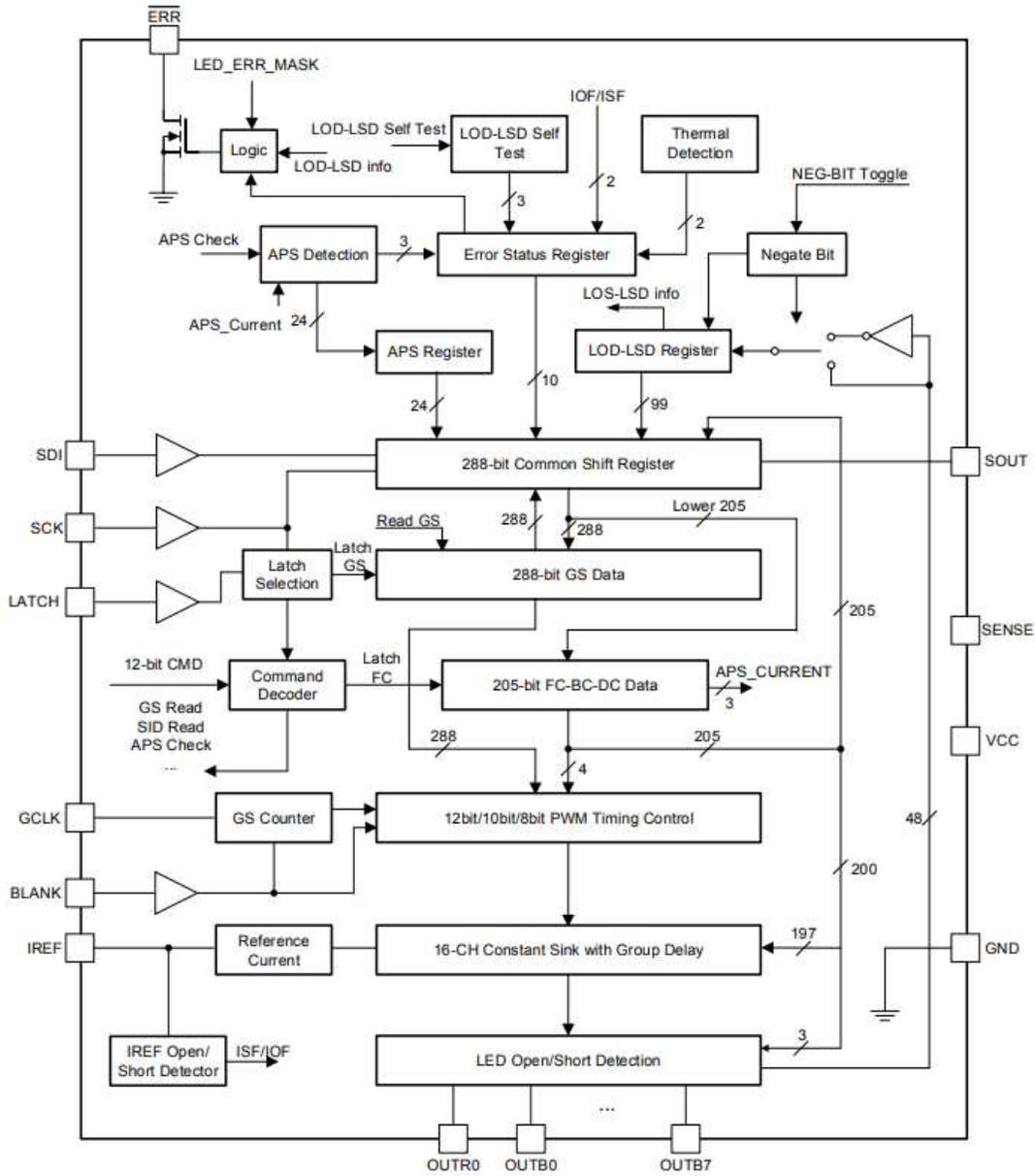
2.2.3 TLC6C5716-Q1

The TLC6C5716-Q1 is an automotive 16-channel constant-current LED driver with LED diagnostics  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

图 4. TLC6C5716-Q1 Block Diagram



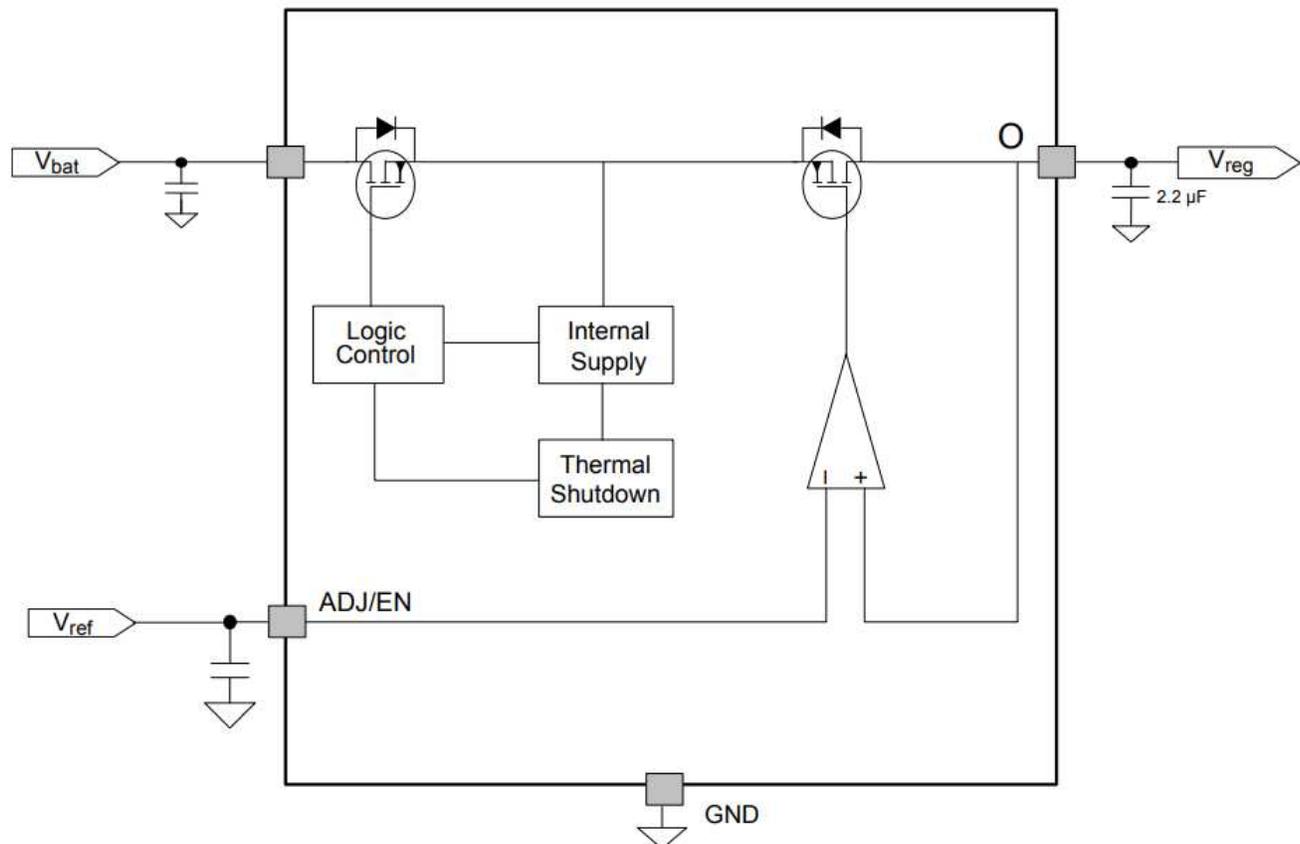
2.2.4 TPS7B4250-Q1

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. 图 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

图 5. TPS7B4250-Q1 Block Diagram



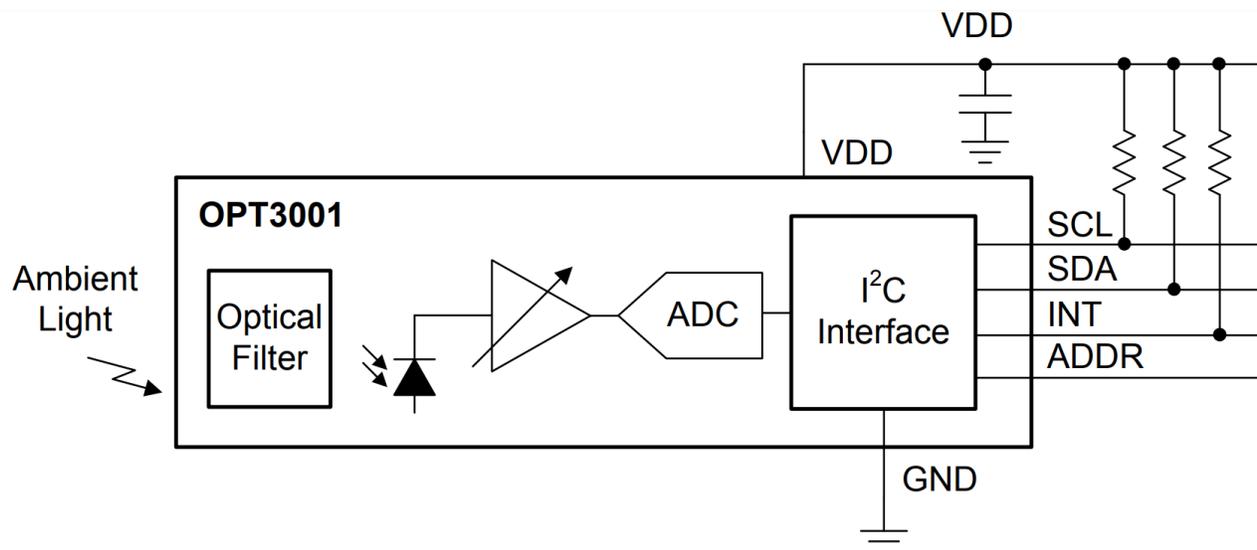
2.2.5 OPT3001-Q1

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. 图 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

图 6. OPT3001-Q1 Block Diagram



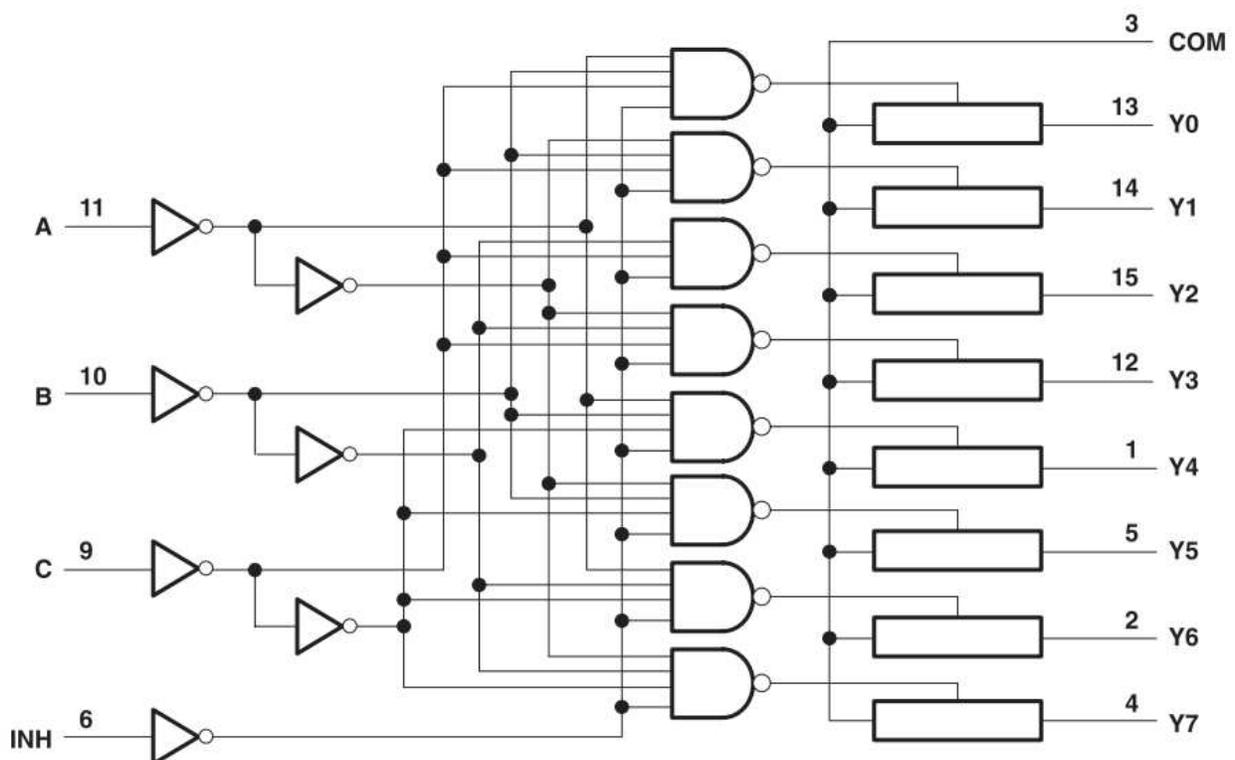
2.2.6 SN74LV4051A-Q1

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. 图 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

图 7. SN74LV4051A-Q1 Block Diagram



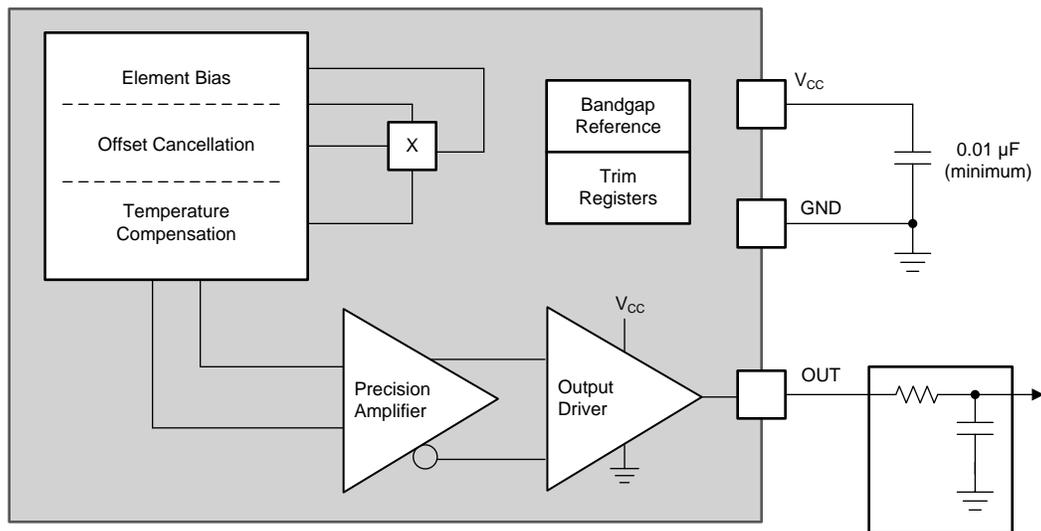
2.2.7 DRV5055-Q1

图 8 显示了 DRV5055-Q1 的块图，它是一个 3 引脚线性霍尔效应传感器，具有完全集成的信号调理、温度补偿电路、机械应力抵消和放大器。该设备可从 3.3-V 和 5-V ($\pm 10\%$) 电源供电，测量磁通密度，并输出与 VCC 参考成比例的模拟电压。

该设备的主要特性如下：

- 快速 20-kHz 传感带宽
- 低噪声输出，带 ± 1 mA 驱动

图 8. DRV5055-Q1 块图



2.2.8 DRV8912-Q1

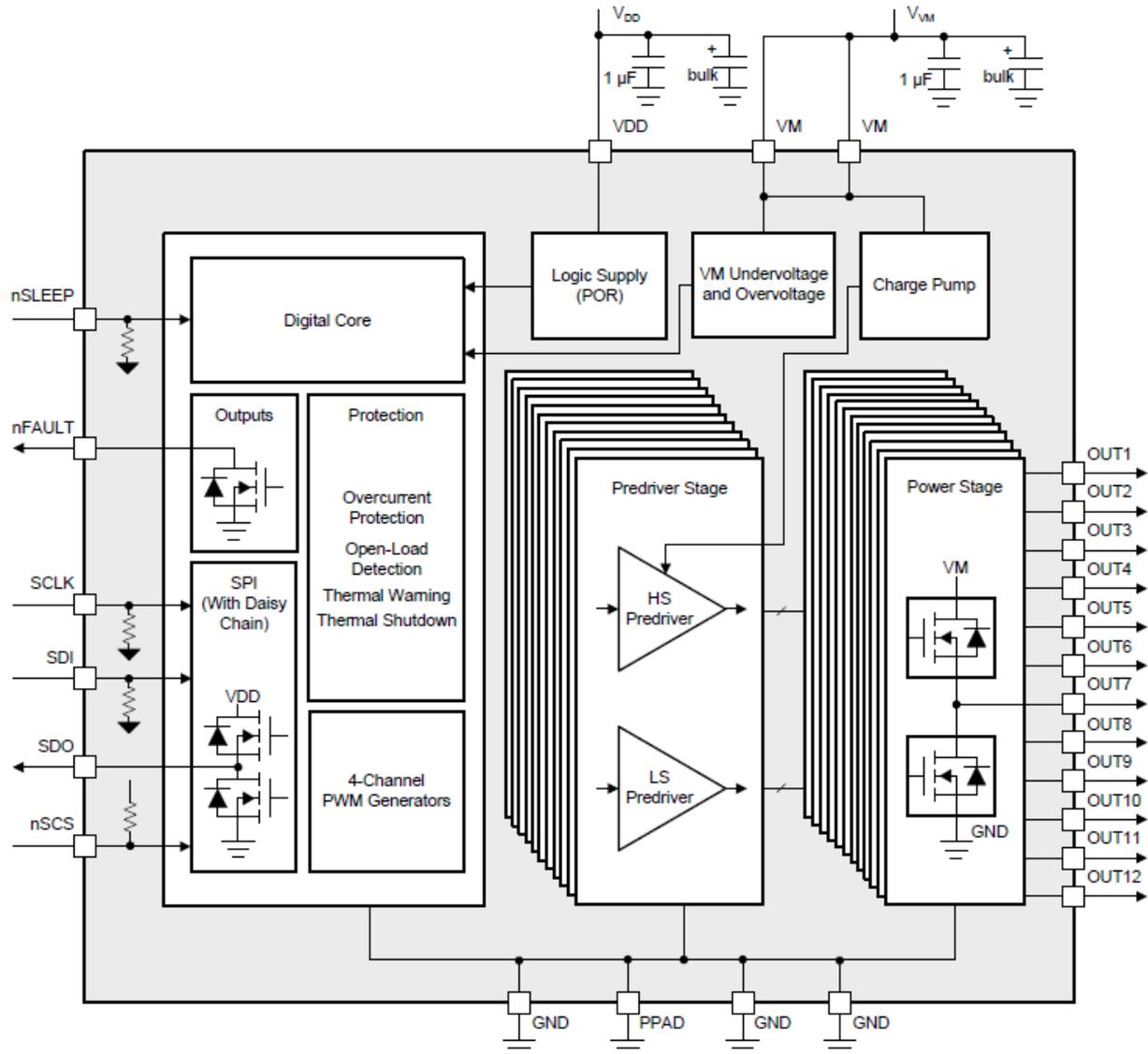
DRV89xx-Q1 器件是用于汽车应用（如加热、通风和空调（HVAC）风门直流电机控制）的集成多通道半桥驱动器。

每个高边和低边驱动器均可驱动高达 1 A 的 rms 电流。该器件可驱动直流无刷电机（BDC）和步进电机，支持独立、顺序或并联模式。BDC 和步进电机完全可控，支持前进、反向、滑行和制动模式。凭借其宽电压范围，该器件可支持电池电压的高波动。该器件的配置、操作和诊断由 16 位 SPI 控制，支持菊花链兼容性。该器件还支持内部 PWM 发生器，可实现电流限制。该器件具有四个 PWM 发生器，可针对四个不同的 PWM 频率和单个 8 位占空比进行编程。任何半桥均可映射到任何内部 PWM 发生器，以实现并联操作。该器件具有开路检测功能，便于轻松监测连接到半桥的负载。该器件完全受短路保护（对 OUTx 短路，对电源短路和对地短路），并具有 OCP 保护。图 9 显示了 DRV8912-Q1 的块图。

该设备的主要特性如下：

- 12 个半桥输出
- 宽工作电压范围（4.5-V 至 20-V）
- 1.0-A RMS 电流每半桥

- 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

图 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 discreet 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 图 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.

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

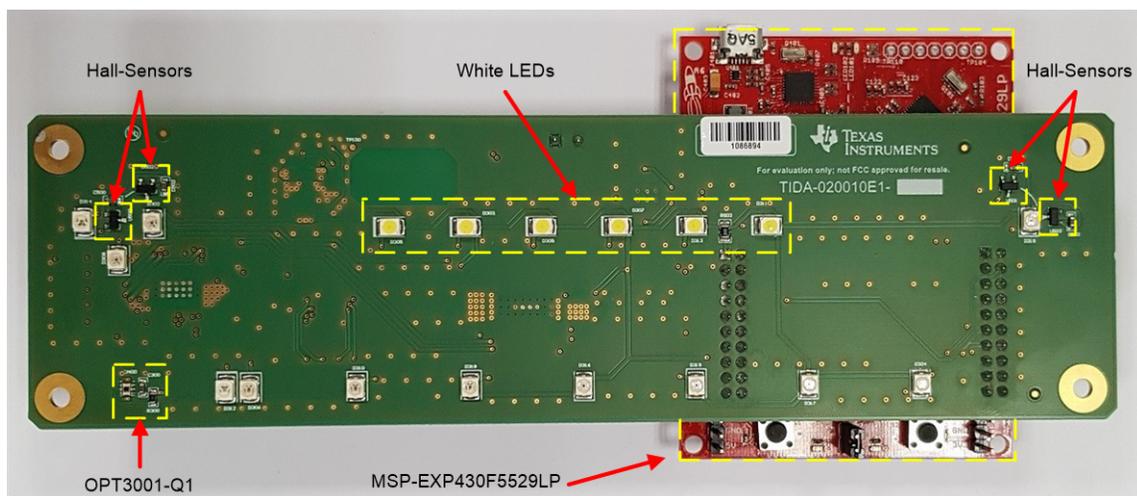


图 10 和 图 11 显示 TIDA-020010 板子的顶部和底部。PCB 的顶部 populated 有 LEDs、环境光传感器和霍尔效应传感器。TLC6C5716-Q1、LMR36006-Q1 (buck converter)、TPS1H100-Q1 (high-side switch)、DRV8912-Q1 (motor driver)、SN74LV4051-Q1 (multiplexer, demultiplexer)、TPS7B4250-Q1 (voltage tracker) 和离散的过压保护电路在 PCB 的底部。这样布局的原因是因为 HMI 外壳 (见 图 12) 其中 TIDA-020010 是固定的。图 12 中的黄色虚线框显示了光线进入并落在环境光传感器 (ALS) OPT3001-Q1 的 sensing 表面上的开口。

图 11. TIDA-020010-Q1 – Bottom Side

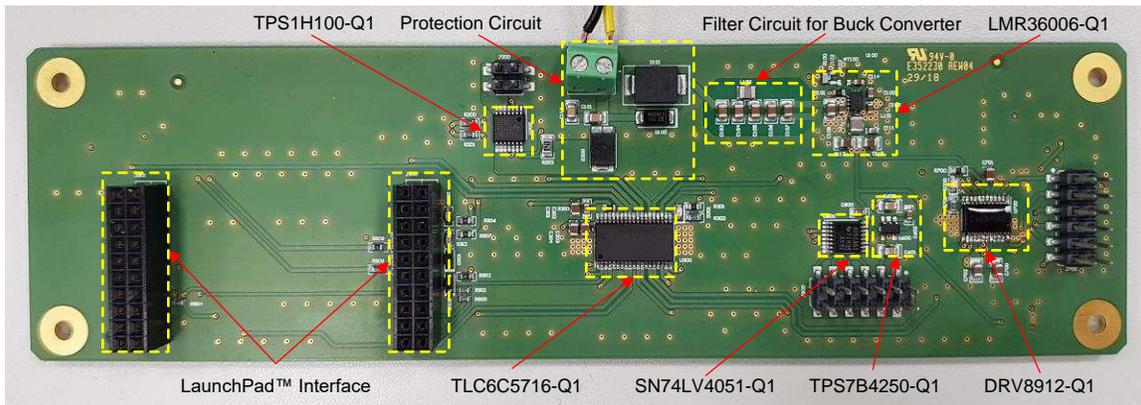


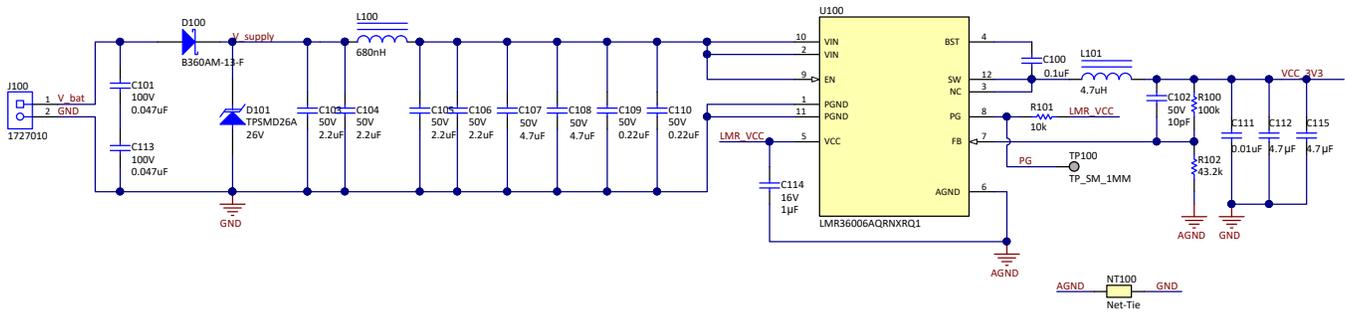
图 12. HVAC HMI Housing



2.3.1 Protection Circuit and Power Supply

The protection circuit of the TIDA-020010 design that 图 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.

图 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 [图 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 [图 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 [图 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:

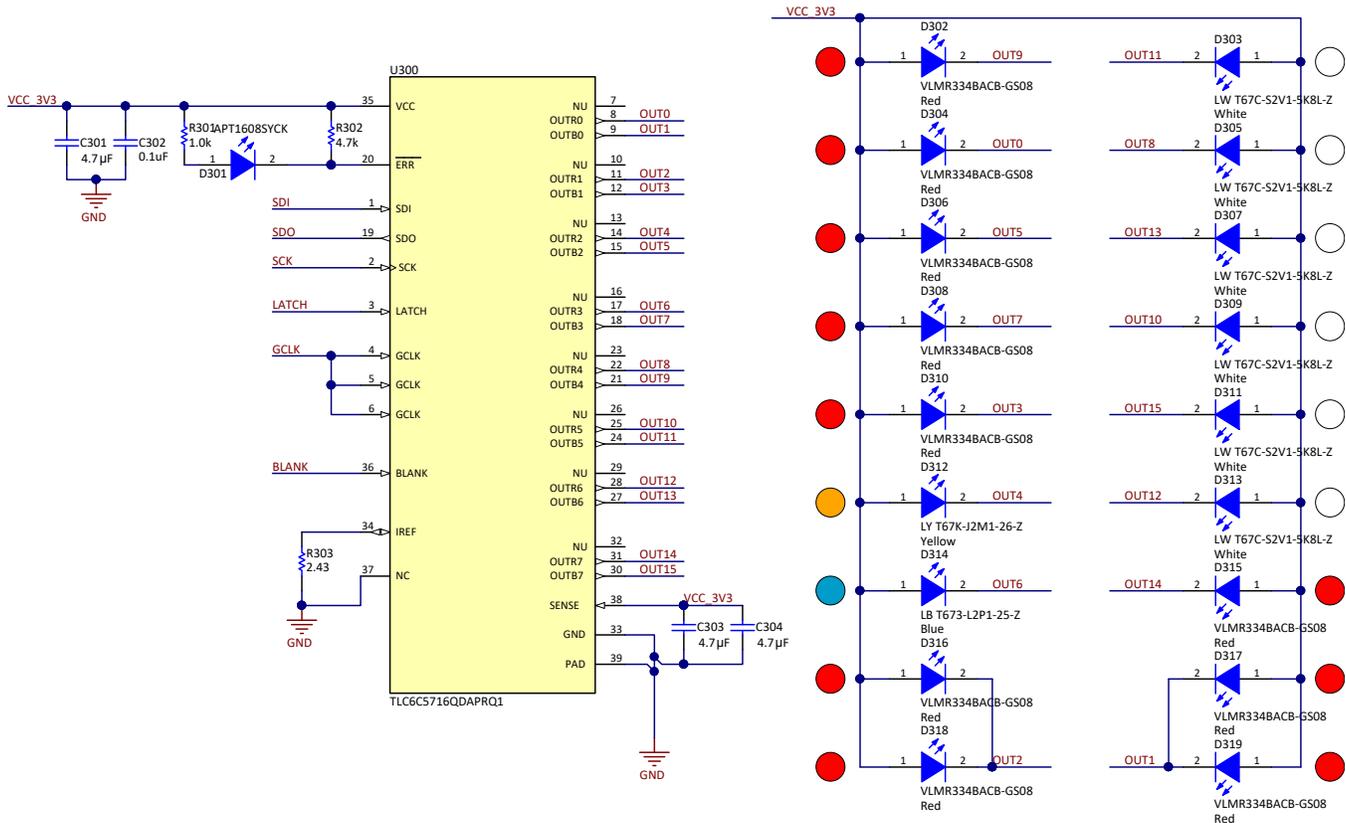
$$R_{IREF} = K \times \frac{V_{IREF}}{I_{(OUT)max}}$$

- 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 kΩ, which corresponds to the maximum current of 25-mA for each output channel.

图 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% $I_{(OUT)max}$.

公式 2 shows the output current calculation formula for low DC range and 公式 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}

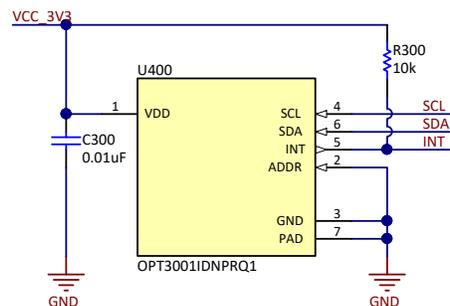
(3)

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. 图 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

图 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 图 16. The value of an external current sense resistor ($R_{CL} = 620 \Omega$) is calculated with the following formula 公式 4 and corresponds to the maximum current of 4 A.

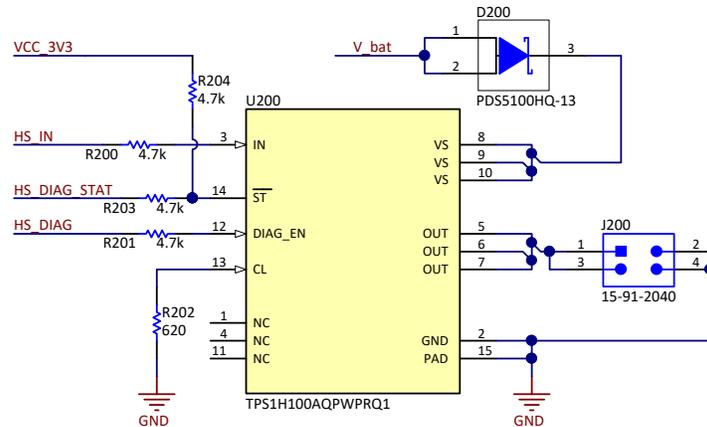
$$I_{CL} = \frac{V_{CL,th}}{R_{CL}} = \frac{I_{OUT}}{K_{CL}} \rightarrow R_{CL} = \frac{V_{CL,th} \times K_{CL}}{I_{OUT}}$$

- 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)

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

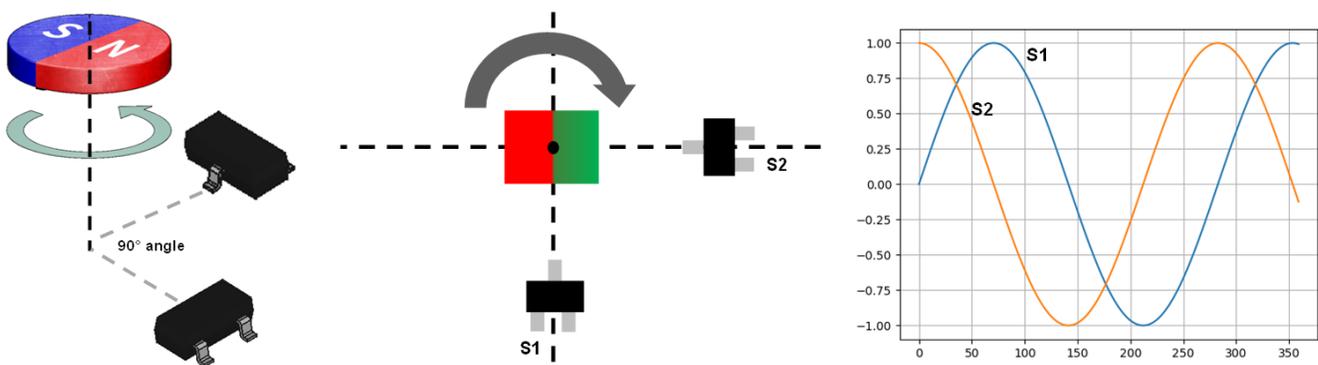


In many conditions, such as the negative ISO pulse, or the loss of battery with an inductive load, a negative potential on the device GND pin may damage the MCU I/O pins. Therefore, the serial resistors R200, R201, and R203 in 图 16 are required between the MCU and control pins of the high side switch. 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. 图 17 shows the measurement principle.

图 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.

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

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

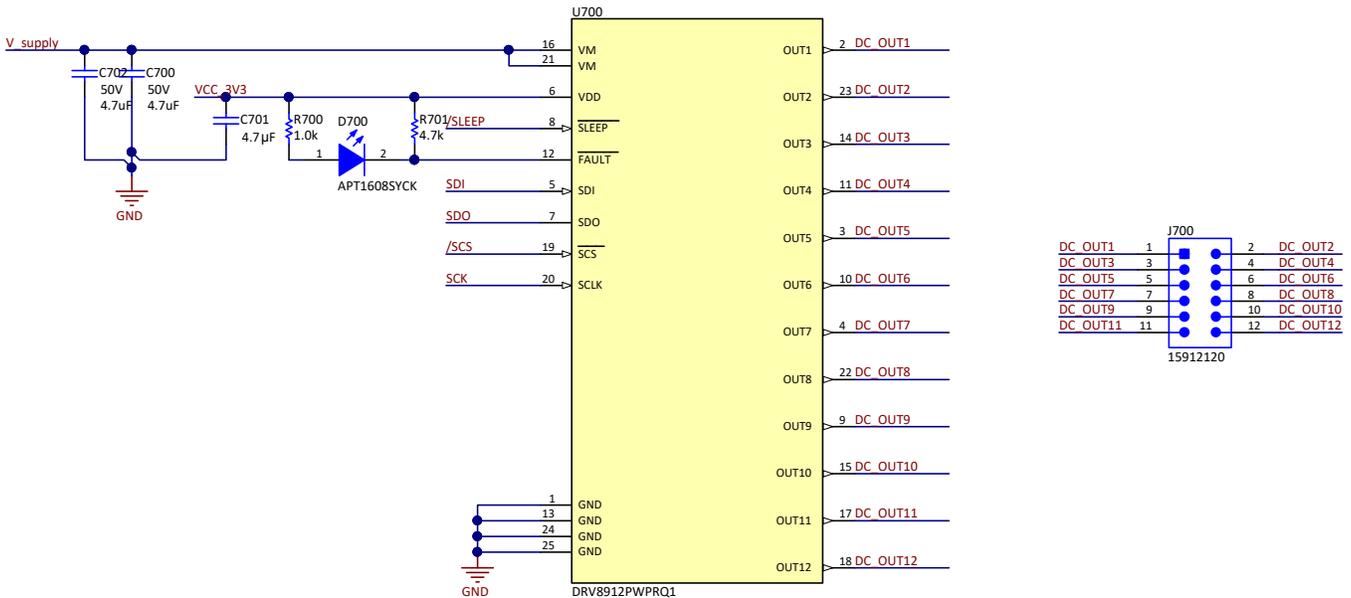
- Angle-magnetic/mechanical angle
- $S1_{\sin}$ is the output voltage of first sensor, which is sine voltage
- $S1_{\cos}$ is the output voltage of second sensor, which is cosine voltage

(5)

2.3.6 DRV8912-Q1 Brushed DC Motor Driver

The DRV8912-Q1 is controlled by the MCU over the 4-wire SPI interface. 图 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.

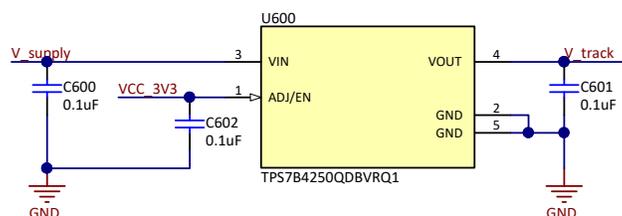
图 18. DRV8912-Q1 Circuit



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 图 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 图 19, V_track represents the supply voltage for off-board sensors.

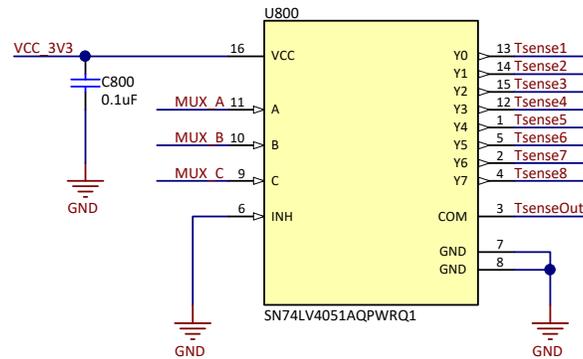
图 19. TPS7B4250-Q1 Circuit



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 图 20) the MCU permanently switches between channels and does ADC measurement of the eight off-board sensor signals. In 图 20, MUX_x represent the control signals.

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



3 Hardware, Software, Testing Requirements, and Test Results

3.1 Required Hardware and Software

图 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 图 22).

图 21. TIDA-020010 With MSP-EXP430F5529LP

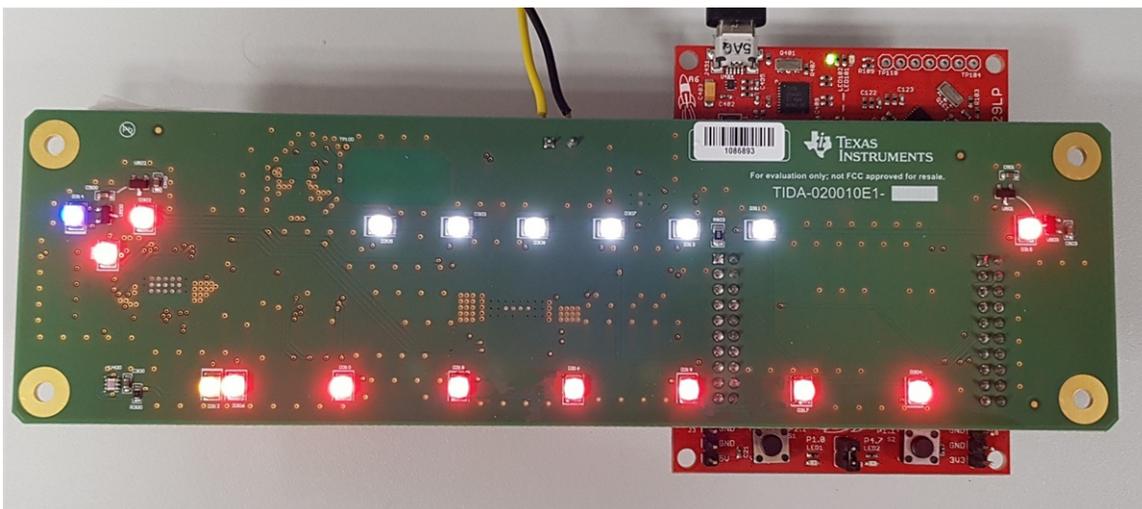
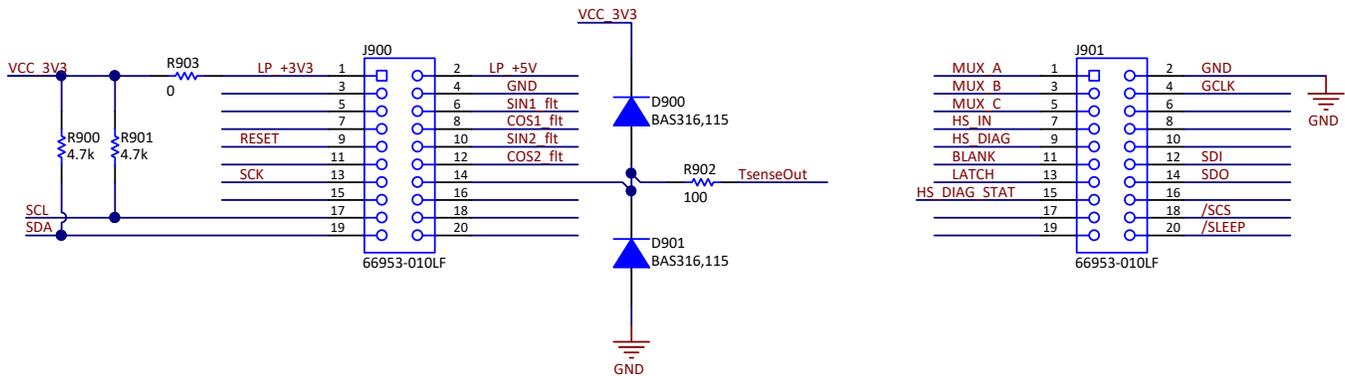


图 22. TIDA-020010 HMI Housing



The schematic in 图 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.

图 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 图 25 shows the simplified structure (without high-side switch and multiplexer, demultiplexer control) of the software.

图 25. Software Flow Chart

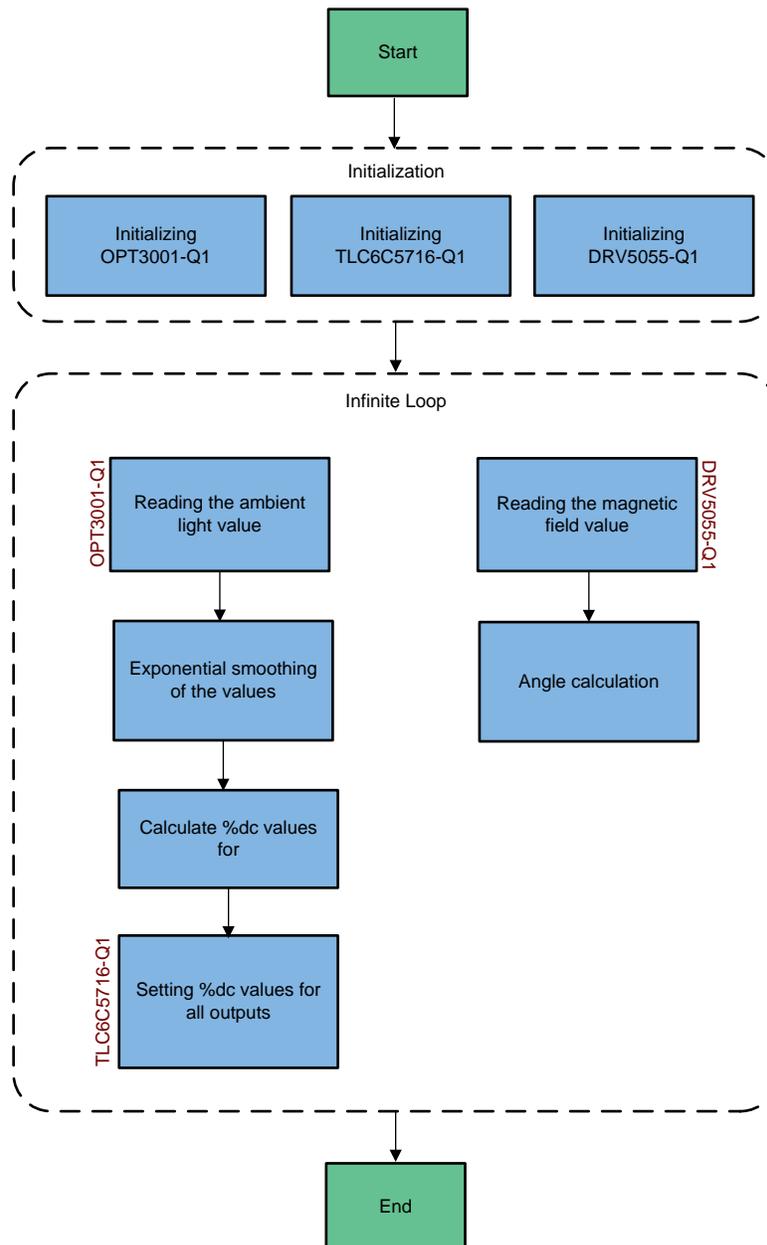


图 26 shows how the MCU sets the control register in TLC6C5716 device. Since the TLC6C5716 device has a 288-bit long common register, used for function control (FC), brightness control (BC), dot correction (DC) and grayscale control (GS), there are three different criteria how to write data into common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

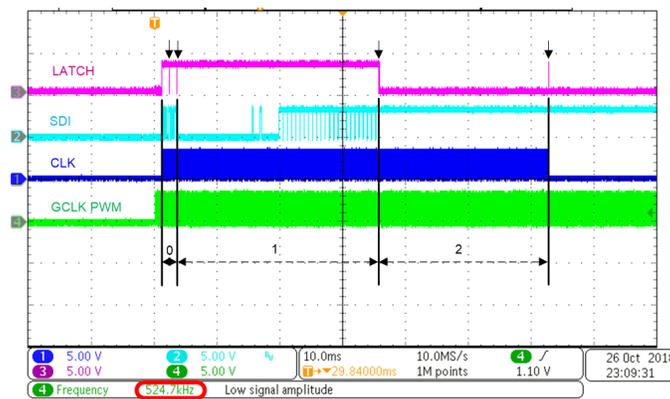
- When LATCH is high at the 288th SCK rising edge, and the 12 MSBs of the 288-bit data are 0, the 205 LSBs of the 288-bit data shift to the function control (FC), brightness control (BC) and dot correction (DC) registers on the LATCH rising edge, as section 1 in 图 26 shows.
- When LATCH is low at the 288th SCK rising edge, all 288-bit data shifts into the grayscale (GS) configuration registers on the LATCH rising edge, as section 2 in 图 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 图 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 (图 26 GCLK PWM) and is being generated from the MSP430F5519.

图 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 图 27 shows the switching behavior of the TPS1H100 (driven by 32.6 Hz PWM signal). The waveform in 图 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 μs.

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

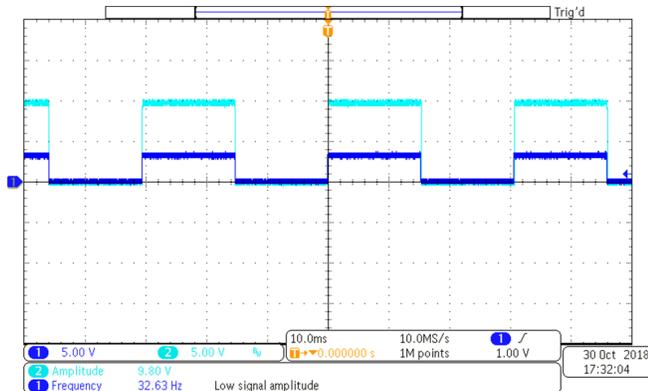
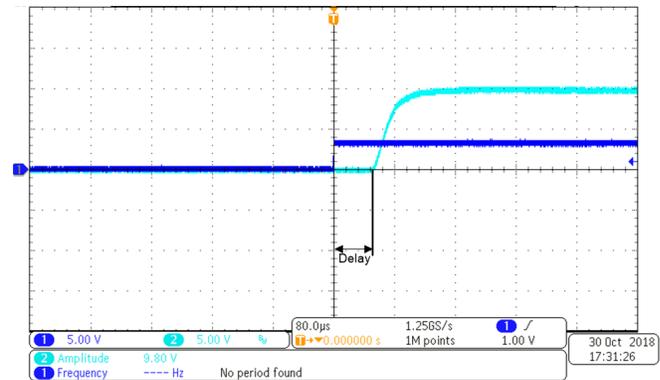


图 28. TPS1H100-Q1 Switch-On Delay



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 图 29 through 图 32 show the difference in LED lighting intensity between a 5%, 45%, 75%, and 100% duty cycle.

图 29. LED Dimming With 5% Duty Cycle



图 30. LED Dimming With 45% Duty Cycle



图 31. LED Dimming With 75% Duty Cycle



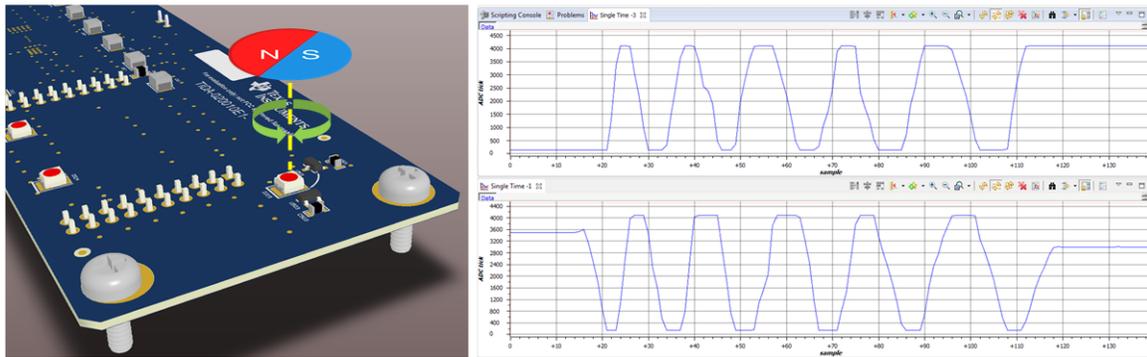
图 32. LED Dimming With 100% Duty Cycle



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. 图 33 shows the rotation of the diagonal magnetized magnet, which is attached to the rotary knob. 图 17 shows the alignment of the hall effect sensors relative to each other and to the magnet on the PCB. The signals in 图 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.

图 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. 图 34 and 图 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.

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

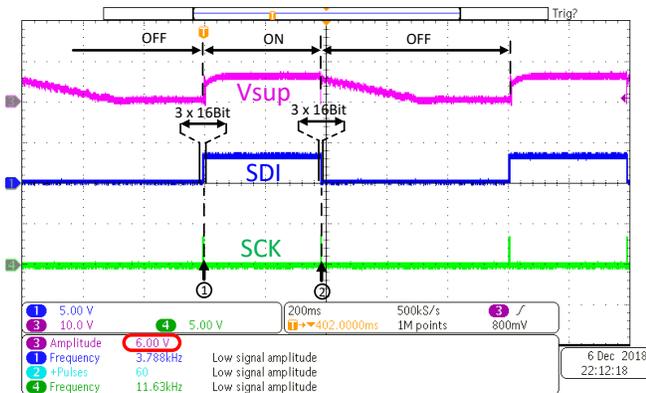


图 35. DRV8912-Q1 Switching all Channels on and off at 20-V

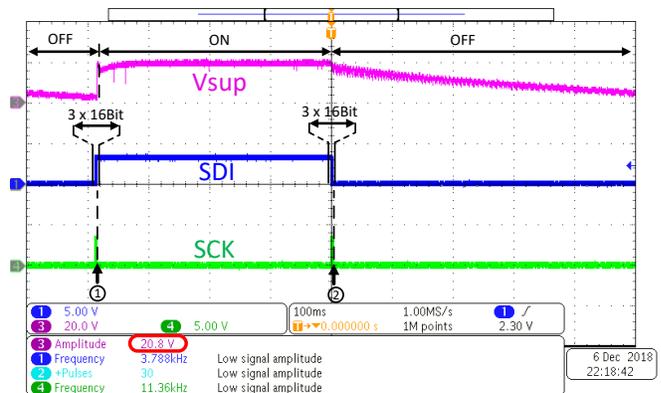


图 36 shows the startup moment of one BDC motor, which is driven by 2 output channels in H-bridge configuration. As soon as the DRV8912 receives the 16-bit command through the SDI line, which is for enabling of one high-side and one low-side switch in two different half-bridges (both connected to the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

图 36. DRV8912-Q1 Enabling all Channels

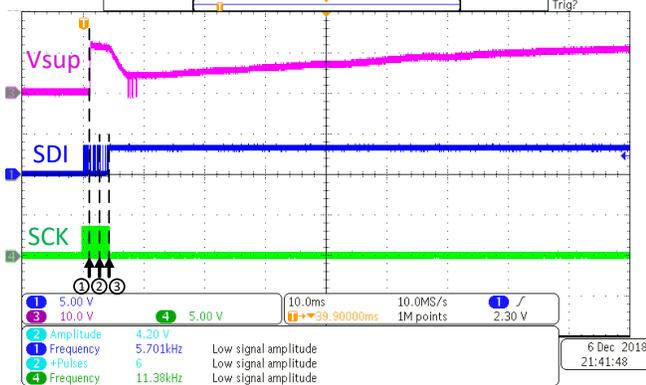
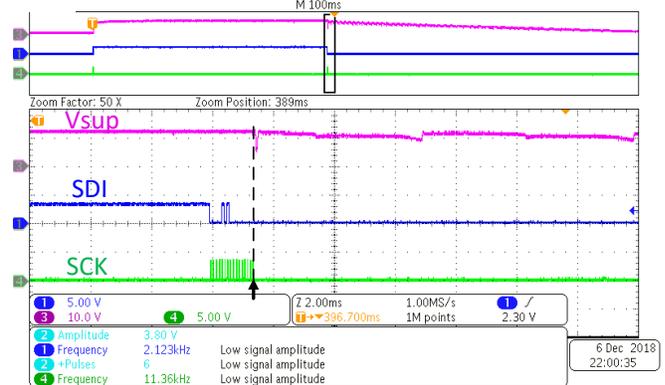


图 37. DRV8912-Q1 Disabling all Channels



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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