Design Guide: TIDA-020027

Automotive Full-Featured Side Mirror Module Reference Design

Description

The modern luxury side mirror includes many convenient features that allow for a better and safer experience for the driver beyond simple X-Y directional control of the mirror. This includes automatically-dimming mirrors for glare reduction; mirror assembly folding to prevent damage in tight parking spaces; LED indicators for blind spot object detection, puddle lights and turn indicators; and heaters for defogging and de-icing the mirror in cold conditions. The addition of each of these features necessitates more electronics, so there is a desire from automotive electronics designers for multi-function integrated solutions that are also scalable as the load requirements change. This reference design provides a starting point for these types of electronics design considerations in a small form factor solution.

Resources

TIDA-020027	Design Folder
DRV8906-Q1	Product Folder
DRV8873-Q1	Product Folder
TPS1HB16-Q1	Product Folder
LM2904B-Q1	Product Folder
TLIN1028-Q1	Product Folder

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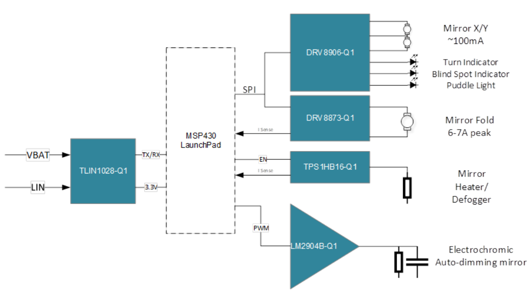
Features

- 300-mA motor drivers for X-Y mirror tilt control
- 8-A motor driver for mirror assembly fold
- 16-mΩ power switch for mirror heater
- Electrochromic mirror driver
- Three 300-mA LED drivers
- LIN interface for communication

Applications

- Side mirror module
- Door module



1 System Description

This reference design uses multi-channel motor drivers (DRV8906-Q1 and DRV8873-Q1), a power switch (TPS1HB16-Q1), and an op amp-based (LM2904B-Q1) buffer circuit to drive 3 motors, 3 LEDs, an electrochromic load, and resistive heating element. Each of these devices was chosen to offer a combination of high integration for multiple loads and extreme flexibility to scale this design for the specific needs of the mirror assembly at hand. Pin-to-pin replacements are available for both DRV8906-Q1 and TPS1HB16-Q1, allowing the design to easily adjust for different current requirements or additional loads.

Additionally, the devices on this design feature extensive diagnostic and fault-protection features, including a combination of the following:

- Integrated current sense
- Overvoltage and overcurrent protection
- Current limiting
- Shoot-through protection

Each of these features are configurable based on the load protection requirements of the side mirror.

1.1 Key System Specifications

Table 1-1. Key System Specifications

PARAMETER	SPECIFICATIONS
Input voltage range (survivable)	-20 V to 40 V
Input supply voltage (operating)	6 V to 18 V
X/Y adjustment motor max current, each motor	150 mA
Fold motor maximum current	7 A
Heater max current	8 A
Electrochromic mirror current	150 mA
Board layers	Two
Board form factor	60.75 mm × 60.05 mm

2 System Overview

2.1 Block Diagram

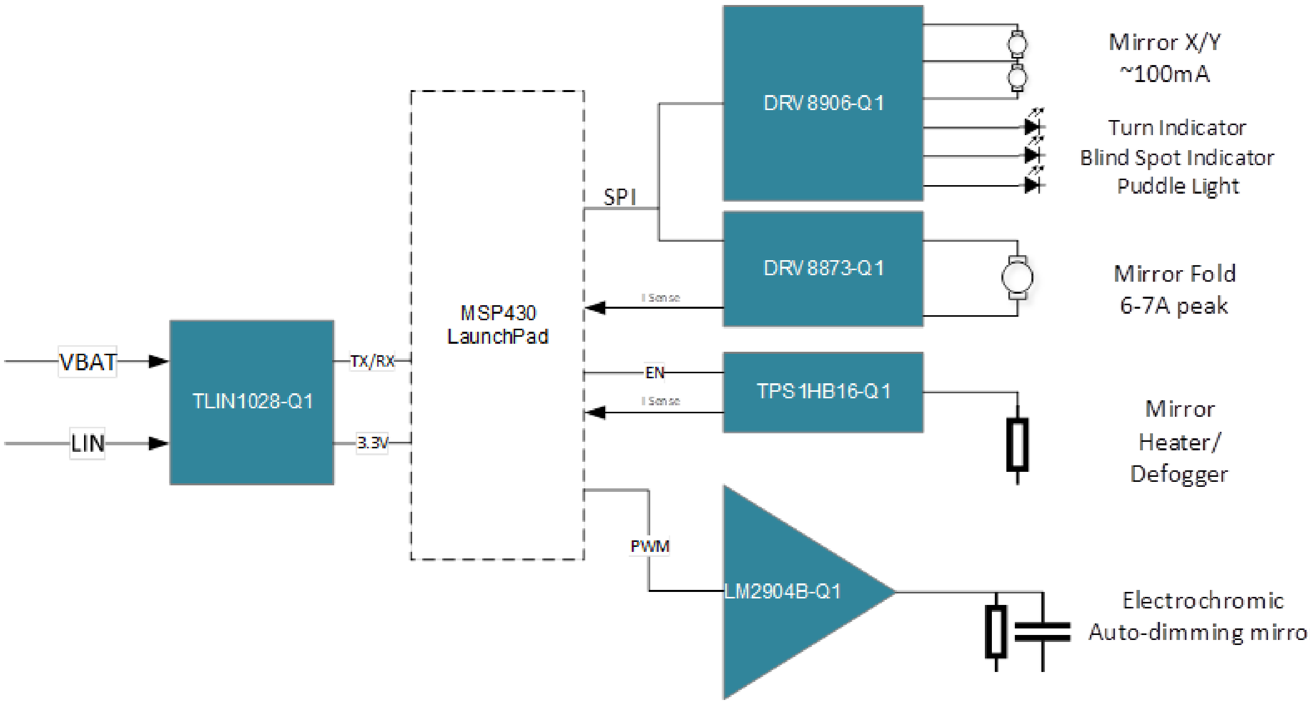


Figure 2-1. TIDA-020027 Block Diagram

2.2 Design Considerations

One of the main design considerations for a mirror module is form factor. A major goal was to keep this design flexible for different load configurations, but that had to keep total footprint and size considered throughout. This design has a total solution size of 3.2 square inches, which should be within typical total design form factor for a mirror module.

Additionally, flexibility was important. Depending on the vehicle, there will be different size mirrors, different features, control from different locations in the vehicle, and so forth. Having flexibility in adjusting the load driving capabilities of the design based on the mirror at hand was important in allowing designers to create a mirror module design that was functional across multiple mirror sizes and types.

Form factor and flexibility can sometimes conflict with each other, but the selection of parts in this design offer a good middle ground that tries to solves both design considerations.

2.3 Highlighted Products

2.3.1 DRV8906-Q1

The DRV89xx-Q1 is a pin-to-pin compatible family of integrated multi-channel half-bridge drivers with 4 to 12 half-bridges, primarily targeted for automotive applications such as control of air-conditioning (HVAC) flap DC motor. Alternatively, this device also finds relevance in automotive-body applications such as side-mirrors and LEDs. The DRV8906-Q1 in specific contains 6 half-bridge outputs.

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 or stepper motors in independent, sequential, or parallel mode. The half-bridges are fully controllable to achieve a forward, reverse, coasting and braking operation of motor. With its wide voltage range, the device can support high fluctuation in battery voltage because of crank-start and load dump conditions.

A standard 16-bit, 5-MHz serial peripheral interface (SPI) with daisy chain capability provides a simple method for configuring the various device settings and reading fault diagnostic information through an external controller.

Internal PWM generators are also supported, which allows current limiting during motor operation and can be used for the dimming control of LEDs. The device has four PWM generators which are programmable for four different PWM frequencies and individual 8-bit duty control. Any half-bridge can be mapped to any internal PWM generator for realizing a parallel operation.

The device supports numerous protection and diagnostic features. Open load detection (OLD) feature 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. Moreover, OTW and OTSD ensures the device thermal protection in scenario of over-heating.

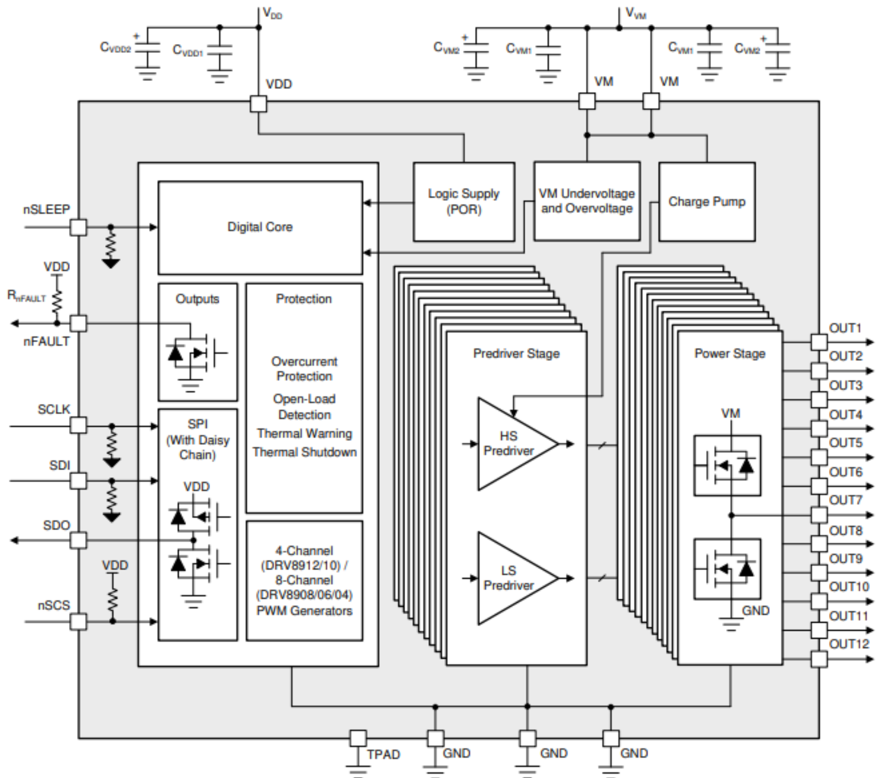


Figure 2-2. DRV8906-Q1 Block Diagram

2.3.2 DRV8873-Q1

The DRV8873-Q1 device is an integrated driver IC for driving a brushed DC motor in automotive applications. Two logic inputs control the H-bridge driver, which consists of four N-channel MOSFETs that drive motors bi-directionally with up to 10-A peak current. The device operates from a single power supply and supports a wide input supply range from 4.5 V to 38 V.

A PH/EN or PWM interface allows simple interfacing to controller circuits. Alternatively, independent half-bridge control is available to drive two solenoid loads.

A current mirror allows the controller to monitor the load current. This mirror approximates the current through the high-side FETs, and does not require a high-power resistor for sensing the current.

A low-power sleep mode is provided to achieve very-low quiescent current draw by shutting down much of the internal circuitry. Internal protection functions are provided for undervoltage lockout, charge pump faults, overcurrent protection, short-circuit protection, open-load detection, and overtemperature. Fault conditions are indicated on an nFAULT pin and through the SPI registers.

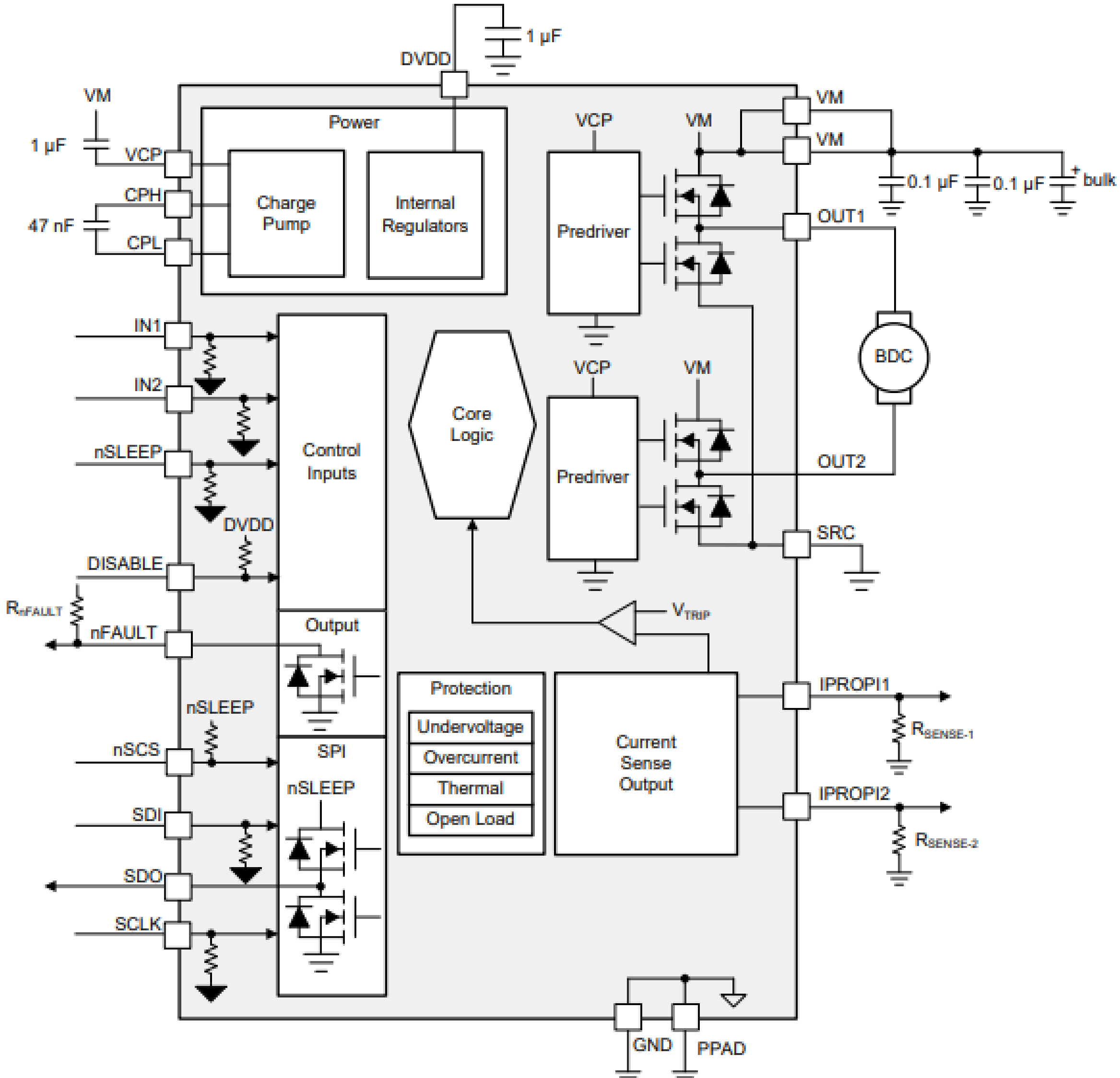


Figure 2-3. DRV8873-Q1 Block Diagram

2.3.3 TPS1HB16-Q1

The TPS1HB16-Q1 device is a smart high-side switch intended for use in 12-V automotive systems. The device integrates robust protection and diagnostic features to ensure output port protection even during harmful events like short circuits in automotive systems. The device protects against faults through a reliable current limit, which, depending on device variant, is adjustable from 4.4 A to 49 A. The high current limit range allows for usage in loads that require large transient currents, while the low current limit range provides improved protection for loads that do not require high peak current. The device is capable of reliably driving a wide range of load profiles.

The TPS1HB16-Q1 also provides a high accuracy analog current sense that allows for improved load diagnostics. By reporting load current and device temperature to a system MCU, the device enables predictive maintenance and load diagnostics that improves the system lifetime.

The TPS1HB16-Q1 is available in a HTSSOP package which allows for reduced PCB footprint.

Figure 2-4 shows the block diagram of the TPS1HB16-Q1.

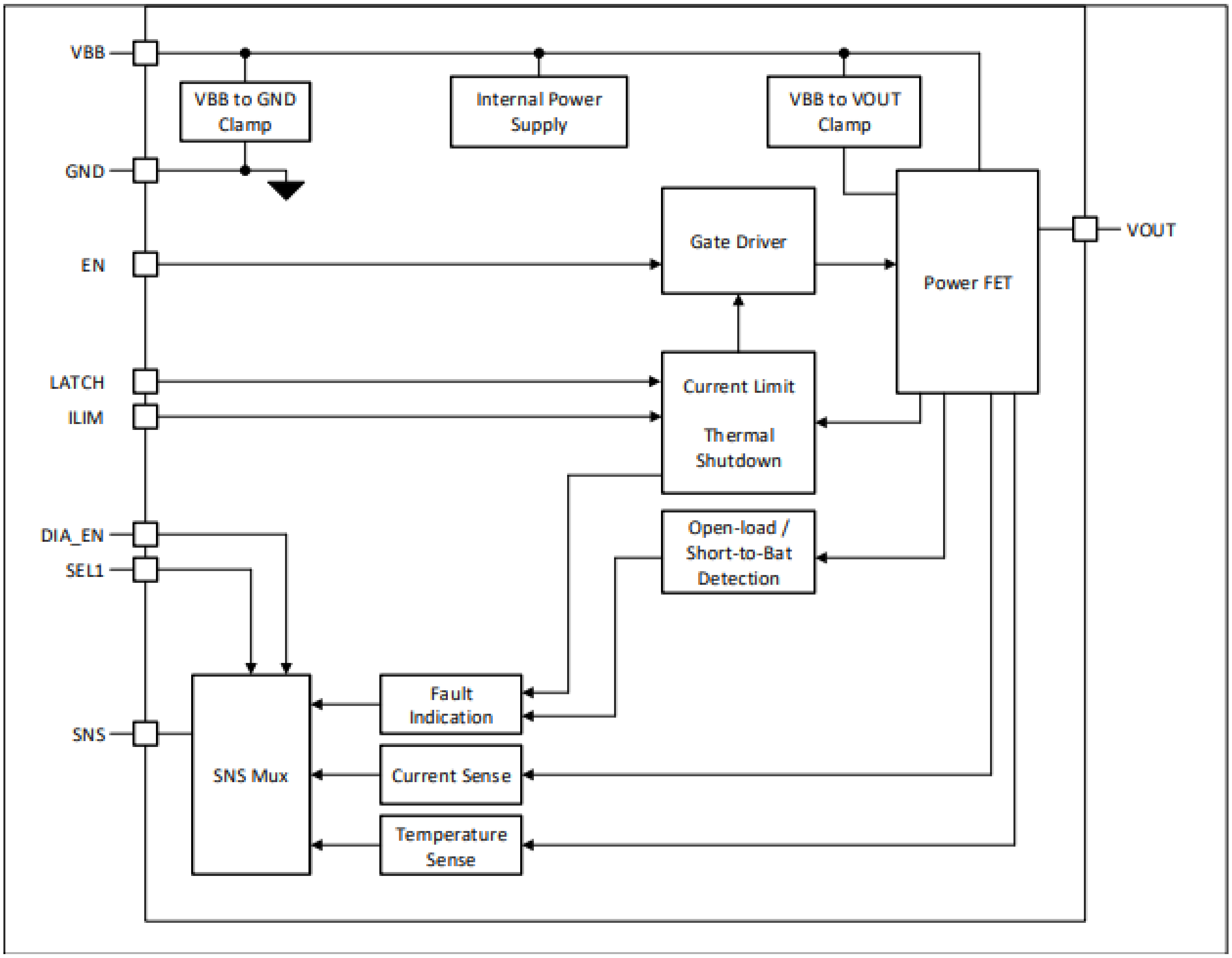


Figure 2-4. TPS1HB16-Q1 Block Diagram

2.3.4 LM2904B-Q1

The LM2904-Q1 and LM2904B-Q1 are industry-standard operational amplifiers that have been qualified for automotive use in accordance to the AEC-Q100 specifications. The LM2904B-Q1 is the next-generation version of the LM2904-Q1, which include two high-voltage (36 V) operational amplifiers (op amps). The LM2904B-Q1 provides outstanding value for cost-sensitive applications,with features including low offset (1 mV, typical), common-mode input range to ground, and high differential input voltage capability.

The LM2904B-Q1 simplifies circuit design with enhanced features such as unity-gain stability, lower offset voltage of 1 mV (typical), and lower quiescent current of 300 µA (typical). High ESD (2 kV, HBM) and integrated EMI and RF filters enable the LM2904B-Q1 devices to be used in the most rugged, environmentally challenging applications for the automotive marketplace.

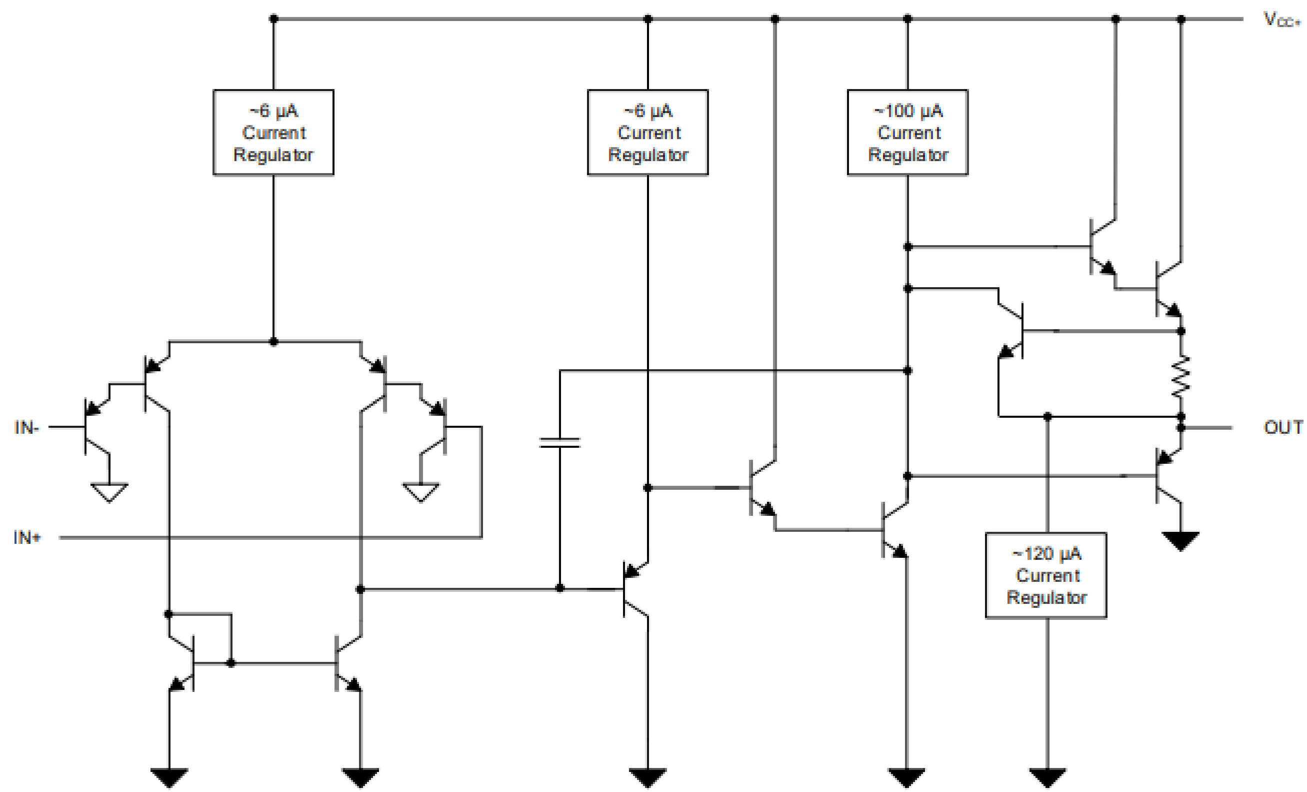


Figure 2-5. LM2904B-Q1 Block Diagram

2.3.5 TLIN1028-Q1

The TLIN1028-Q1 is a local interconnect network (LIN) physical layer transceiver, compliant to LIN 2.2A ISO/DIS 17987–4.2 standards, with an integrated low dropout (LDO) voltage regulator.

LIN is a single-wire bidirectional bus typically used for low speed in-vehicle networks using data rates up to 20 kbps. The LIN receiver supports data rates up to 100 kbps for end-of-line programming. The TLIN1028-Q1 converts the LIN protocol data stream on the TXD input into a LIN bus signal. The receiver converts the data stream to logic level signals that are sent to the microprocessor through the open-drain RXD pin. The TLIN1028-Q1 reduces system complexity by providing a 3.3-V or 5-V rail with up to 70 mA (D) and 100 mA (DRB) of current to power microprocessors, sensors or other devices. The TLIN1028-Q1 has an optimized current-limited waveshaping driver which reduces electromagnetic emissions (EME).

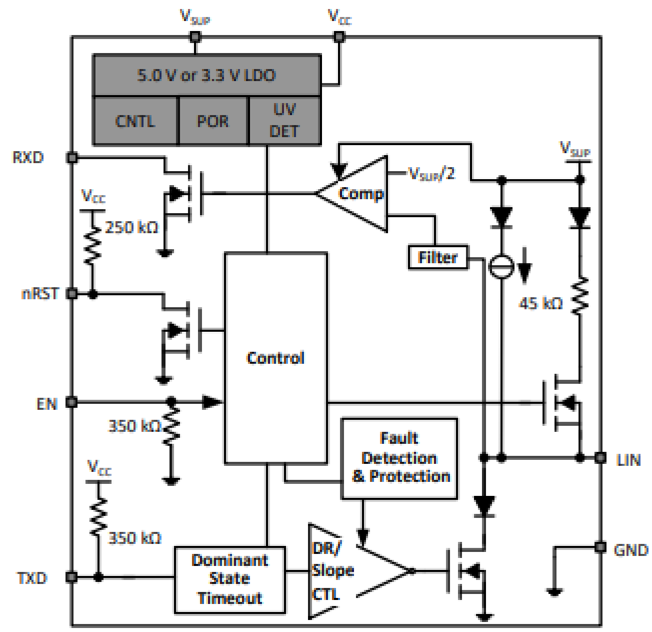


Figure 2-6. TLIN10283-Q1 Block Diagram

2.4 System Design Theory

2.4.1 Mirror XY and LED Driver

The mirror X&Y angle adjust motors and the LEDs are driven by the DRV8906-Q1. The DRV8906-Q1 has a total of 6 half-bridges. Three of the 6 half-bridges drive the three LEDs and the rest of the half-bridges drive the two brushed DC motors used for X&Y angle adjust.

Figure 2-7 shows the DRV8906-Q1 configuration schematic. To save one half-bridge, the two brushed DC motors are connected in a sequential configuration. In this configuration, the two motors share one half-bridge since the two motors will never be driven simultaneously.

The decoupling capacitors (C1, C2, C3, C4) values are selected based on the recommended values on the data sheet. The nFAULT pin is open drain so a 10-kΩ pullup resistor pulls nFAULT to VDD. Each of the three LEDs have a 200-Ω resistor in series to limit the current.

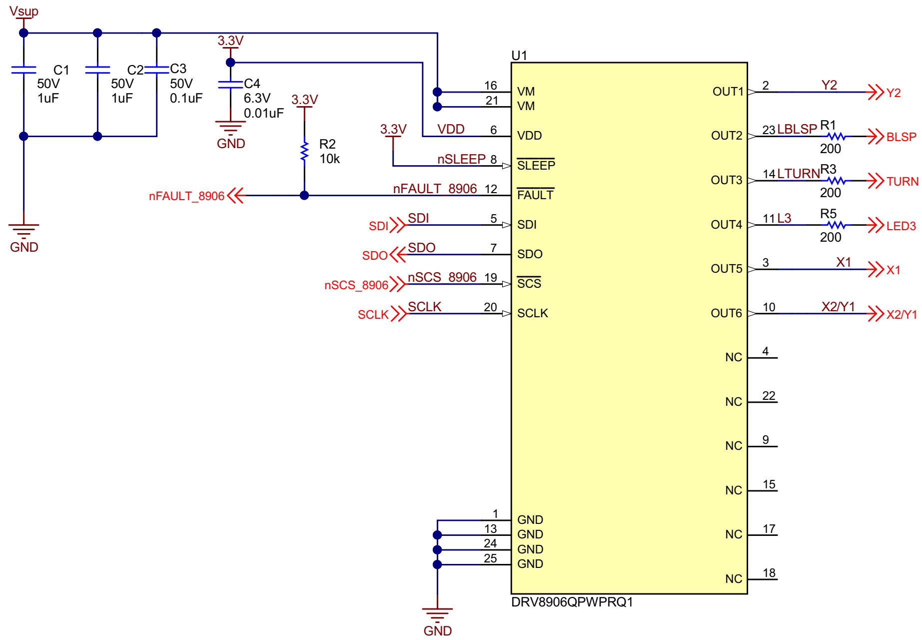


Figure 2-7. DRV8906-Q1 Configuration Schematic

2.4.2 Mirror Fold Driver

The mirror fold driver is handled by the DRV8873-Q1, a 10-A integrated motor driver. This driver can provide the 8-A maximum peak current needed to drive the mirror fold motor.

Figure 2-8 shows the configuration schematic. The capacitors (C6, C7, C8, and C9) are selected based on the recommendations on the DRV8873-Q1 data sheet. Likewise, the data sheet recommends a pullup resistor greater than 10 kΩ on the nFAULT pin. The two IPROPI resistors are chosen such that the maximum drive current is set to 8 A which is the maximum current rating of the motor. The SRC pins are shorted to GND to create a low impedance path between the power FET source and GND.

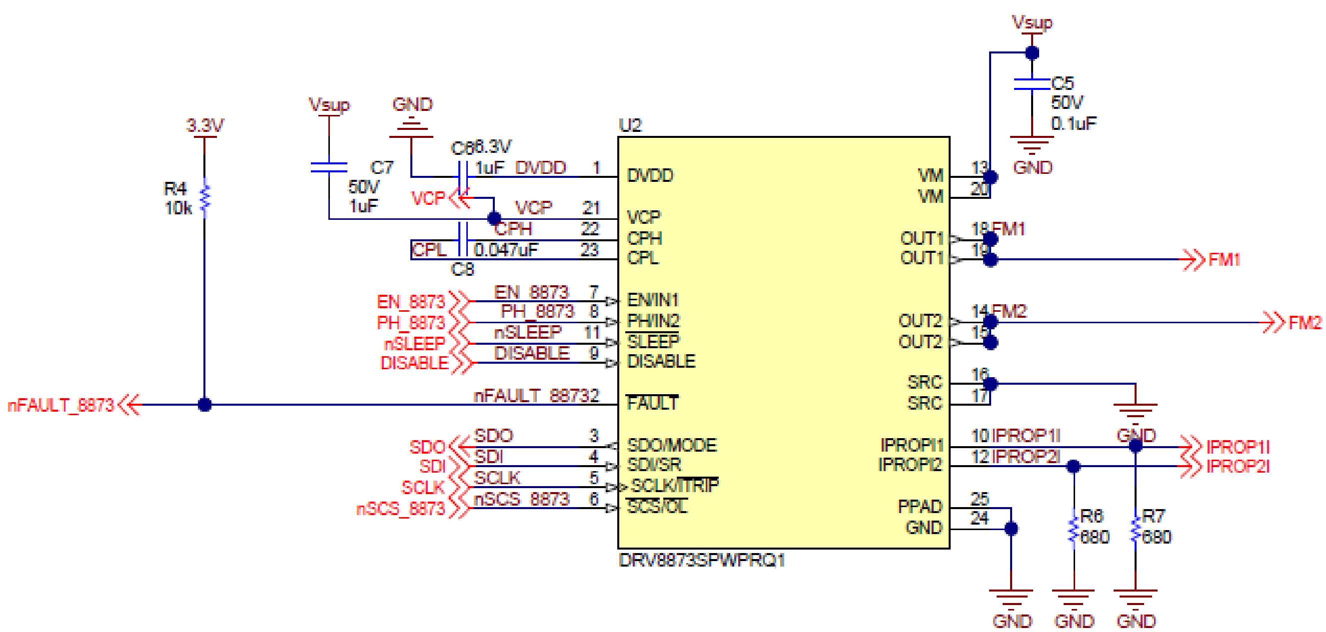


Figure 2-8. DRV8873-Q1 Configuration Schematic

2.4.3 Mirror Heater Driver for Defogging and De-icing

The mirror heater load is driven by the TPS1HB16-Q1, a smart high-side power switch. The high-side switch has two variants. Variant B is used for this design which has a current limit range from 9.8 A to 49 A.

Figure 2-9 shows the configuration schematic for the mirror heater driver. The resistors (R10-R13, R15, and R23) and capacitors (C14, C15, and C21) values are chosen based on the recommendations by the data sheet. The capacitor C16 is used to filter voltage transients at the output. The resistor R14 is chosen to set the output current limit to 12.3 A.

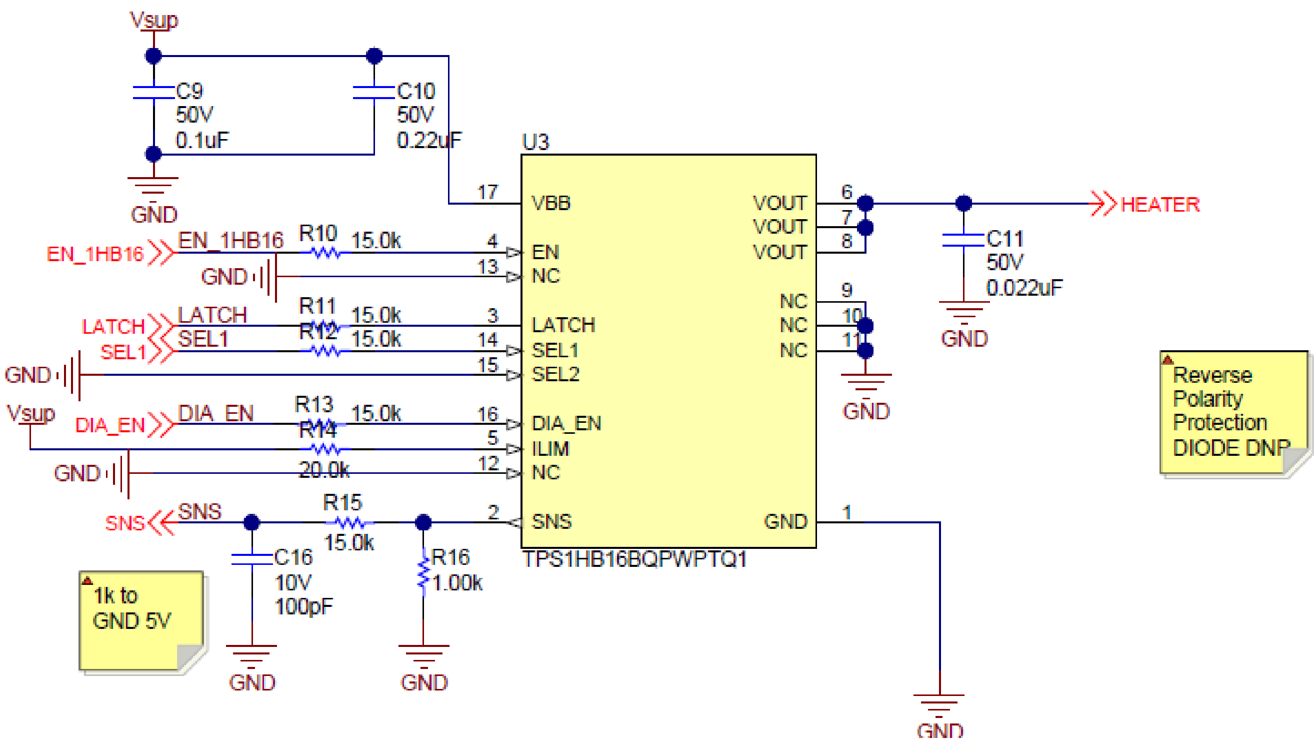


Figure 2-9. TPS1HB16-Q1 Configuration Schematic

2.4.4 Electrochromic Mirror Driver

The electrochromic (EC) mirror utilizes a proprietary electrochromic chemical placed between two conductive layers and glass panels. When a voltage is applied to these conductive elements, the current flow through the chemical causes it to change in color and darken. Electrically, the electrochromic mirror behaves like a very large capacitor, typically greater than 1 F, as well as a small shunt resistance. The total capacitance measured largely depends on the total area of the mirror.

Figure 2-10 shows the EC mirror driver schematic.

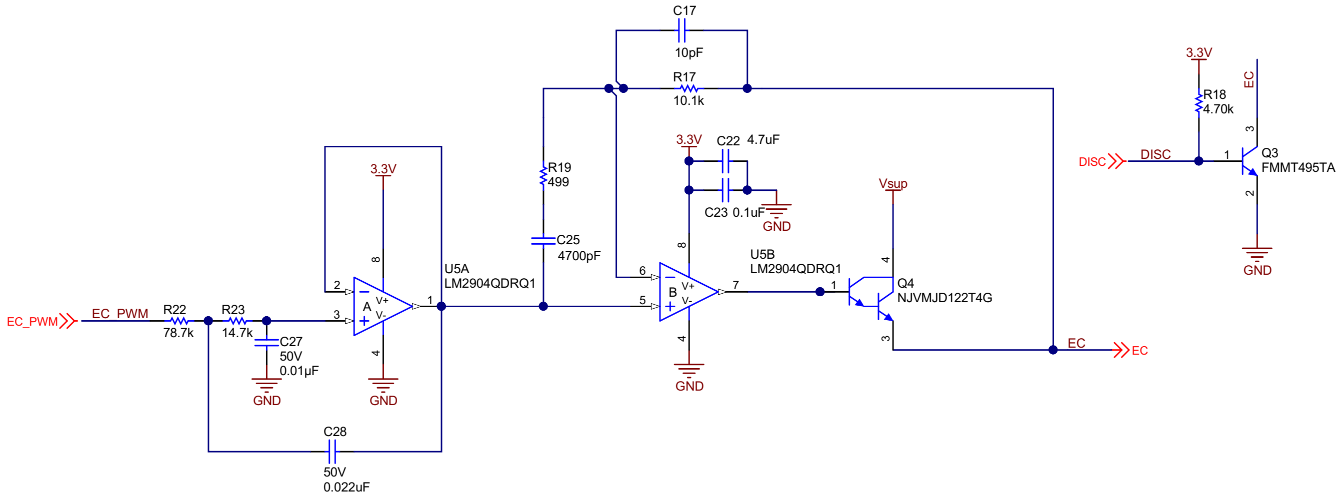


Figure 2-10. Electrochromic Mirror Driver Circuit

2.4.4.1 Sallen-Key Low-Pass Filter

A unity gain second order Sallen-Key low-pass filter is used to filter a PWM signal from the MSP430™ LaunchPad™ to a stable analog voltage value. The voltage value can range from 0 V to 3.3 V depending on the duty cycle of the PWM signal. This low-pass filter output voltage goes to a high-current buffer amplifier circuit which drives the electrochromic mirror.

The resistors and capacitors were chosen such that the cut-off frequency is set to roughly around 315 Hz and the Q factor to around 1/2. The low cut-off frequency allows only the DC component of the PWM signal to pass through the filter. The Q factor being close to 1/2 sets the system in a critically damped state which limits oscillations at the output and results in a faster response with minimum overshoot.

2.4.4.2 High-Current Buffer Amplifier

To drive this mirror, the voltage output necessary is less than 2 V for the maximum amount of dimming. Due to the size of this capacitive load, the current necessary to charge it can reach as much as 400 mA. A steady state of approximately 150 mA is also required to maintain proper dimming. To meet these specifications, use an op amp and a Darlington bipolar junction transistor (BJT) to buffer from the output of the Sallen-Key filter and drive the electrochromic load. The BJT sources the current for the load and the use of an op amp feedback provides stability and linearity regardless of the temperature or process variation of the BJT.

The MJD122 Darlington-pair BJT is chosen for its large 100-V collector-emitter voltage to allow use across both the typical and non-typical automotive battery operating voltage range, as well as the very-large, 8-A continuous current operation. The DPAK package is great for dissipating heat generated by the typical 2 W of power flowing through the device.

2.4.4.3 Buffer Amplifier Stability for Very-Large Capacitive Loads

Due to the size of the capacitive load, stability of the buffer amplifier is a concern. Designers can improve capacitive load stability through the use of both noise gain and capacitive feedback compensation. Using rate of closure analysis provides a guideline on the expected phase margin on an amplifier based on the angle of the slopes between the modified open loop gain and 1/β bode plots. A key rule is to ensure the rate of closure is not greater than 20 dB/decade, which ensures the phase margin of the design is greater than 45°. For more information on op amps and stability, see the training resource TI Precision Labs - Ops Amps: Stability 2.

The noise gain compensation consists of implementing high-frequency gain to allow the 1/β of the amplifier to be larger than the modified open-loop gain at the pole introduced by the capacitive load, which allows the rate of the closure to be 20 dB/decade rather than 40 dB/decade. This method retains the desired 0-dB gain at DC that allows the amplifier to continue to operate as a buffer. The noise gain provides the necessary bump in the phase margin to maintain stability across the entire bandwidth of the amplifier and prevent ringing.

This high-frequency gain is implemented with R1, R3, and C6, which creates a zero and provides a 20-dB/decade slope on the 1/β plot above approximately 1 kHz. The rate of closure at the intersection is then |–40 dB/decade + 20 dB/decade| = 20 dB/decade.

To add to the stability improvements found with noise gain, an additional capacitor C1 is used to implement a capacitive feedback, or Cf, compensation. This additional high-frequency pole boosts the phase even more in the area of concern.

Figure 2-11 shows a TINA simulation of the bode plot without the noise gain implemented and Figure 2-12 shows the result of the noise gain.

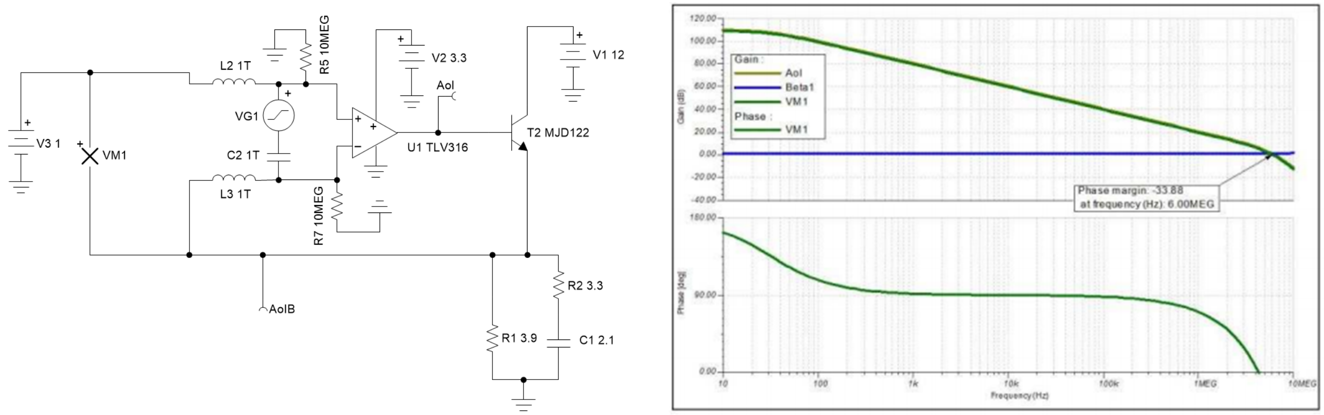


Figure 2-11. TINA-TI™ Stability Analysis of EC Mirror Driver Without Compensation

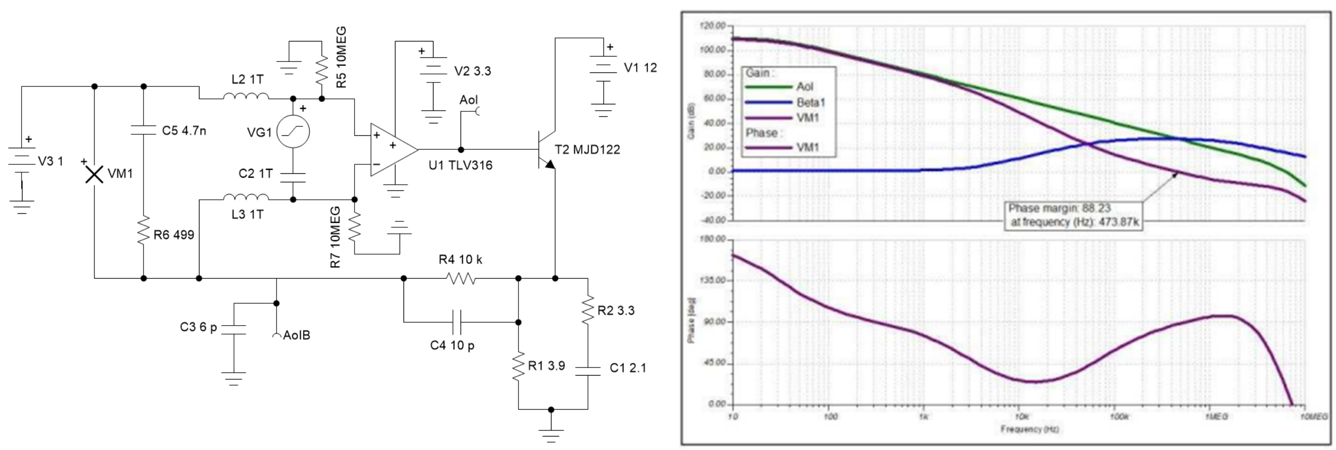


Figure 2-12. TINA-TI™ Stability Analysis of EC Mirror Driver With Compensation

2.4.4.4 Fast Discharge of Large Capacitive Load

If the voltage applied to the mirror is set to 0 V, the capacitance on the mirror slowly discharges and the electrochromic element returns to a transparent, non-colored state. To accelerate the discharge of the capacitive load and reduce the amount of time to reach the transparent state, use a low-side transistor.

This simple open-drain transistor can be turned on by pulling the base high, which provides a direct path to ground for the capacitance on the mirror. Take care to ensure this transistor is only enabled when the output of the DAC has already been set to 0 V to prevent unnecessary current flow through the voltage buffer output and this transistor.

The base of this transistor is tied to a GPIO on the MCU which controls this design. Use a local pullup resistor of 4.7 kΩ with the open-drain output of the MCU GPIO.

2.4.5 SBC - LIN Communication Interface and System Supply

The TLIN1028-Q1 is used for the LIN communication interface due to its wide operating ranges and protection features that it provides; such as ESD protection, undervoltage protection, DTO protection, and thermal protection. All these protection features ensure that the LIN transceiver operates normally without damaging itself or other components.

The local decoupling capacitors (C20 and C21) and the LDO output capacitors (C18 and C19) are chosen based on the recommendations given on the data sheet. The data sheet recommends a 200-pF capacitor between the LIN pin and ground for slave applications. C4 is chosen to be 220 pF for filtering noise from the LIN signal. The 10-kΩ resistor (R20) is used as a pullup resistor from the RXD pin to 3.3 V. R21 is used to limit the input current to the device and C26 is used to filter noise.

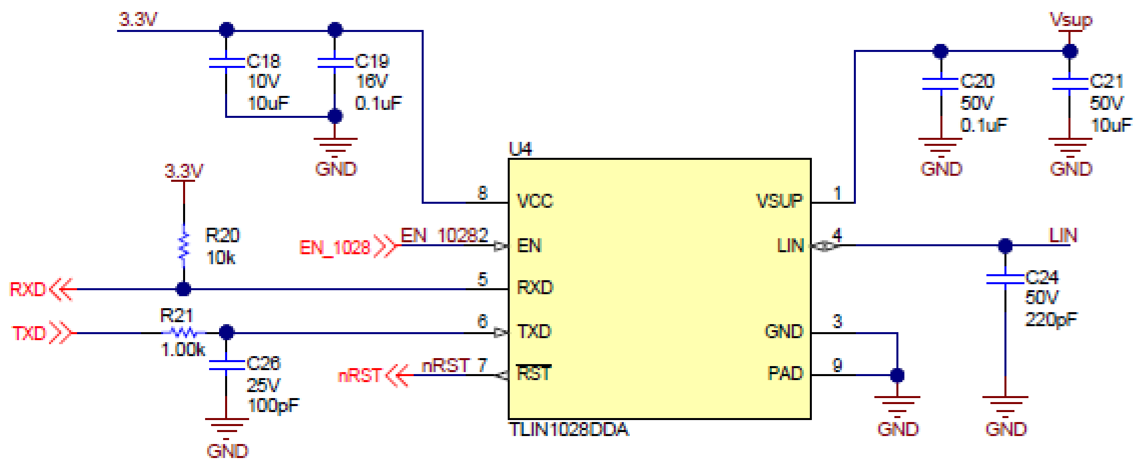


Figure 2-13. TLIN1028-Q1

3 Hardware, Software, Testing Requirements, and Test Results

3.1 Required Hardware and Software

3.1.1 Hardware

The TIDA-020027 reference design requires the use of the EXP-MSP430F5529LP LaunchPad for full functionality. The design has been outfitted with 2 10 × 2 connectors to connect to the LaunchPad.

The input connector for a typical automotive battery voltage of 12 V and for the LIN bus is provided by jumper J4.

The reference design board provides jumper J2 for the motors, LEDs, heater, and the auto-dimming control signals. Pin 1 is the 3.3-V output of the TLIN1028-Q1 internal LDO output which powers the MSP430 LaunchPad. Pin 15 and 16 are for the hall sensor outputs from the side mirror unit. These hall sensor outputs can be used to implement precise motor positioning and stall detection algorithms.

Jumper J3 contains additional control signals and the SPI communication. Jumper J1 is the output connector where the side mirror unit is connected.

A simple software was developed for the MSP430 MCU to test and validate the board. The firmware monitors and controls the GPIOs which control the different components of the board. The firmware also configures the DRV8873-Q1 and DRV8906-Q1 motor drivers via SPI and monitors the current sense and diagnostic failures.

Figure 3-1, Figure 3-2, and Figure 3-3 show the schematic of the jumper connectors on the board and Figure 3-4 shows an image of the reference design connected to the MSP430 LaunchPad.

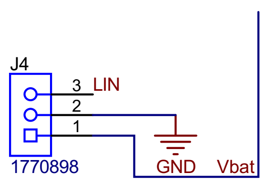


Figure 3-1. J4 Connector

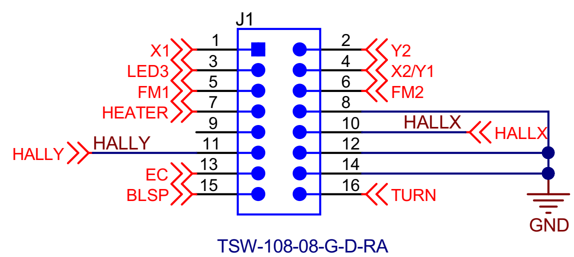


Figure 3-2. J1 Connector

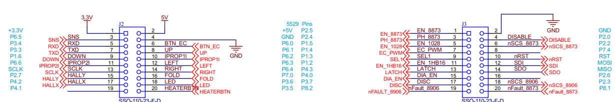


Figure 3-3. J2 and J3 Connector

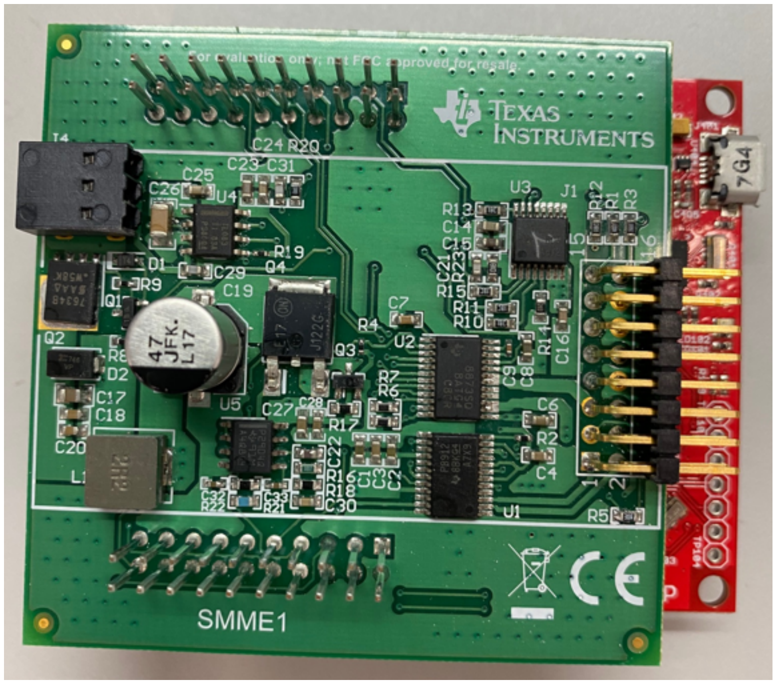


Figure 3-4. Image of TIDA-020027 Connected to MSP-EXP430F5529LP LaunchPad™

3.2 Testing and Results

3.2.1 Test Setup

The testing was done using the TIDA-020027 PCB and the EXP-MSP430F5529 LaunchPad. The 12-V power supply was connected to pin 1 and 2 of connector J4. A side mirror assembly equipped with X&Y direction motor, fold motor, electrochromic mirror, and defogger is connected to the TIDA board on connector J1. Figure 3-5 shows the test set up.

Figure 3-5. TIDA-020027 Test Set-up

3.2.2 Test Results

3.2.2.1 Reverse Battery Protection

The board is equipped with reverse battery protection. When the power supply is connected properly, current will flow through the reverse battery protection FET (Q2) and onto the rest of the board. The charge pump voltage pin of the DRV8873-Q1 (VCP) provides the high voltage needed to allow current to flow through the FET while the power supply is connected properly. Conversely, when the power supply is connected in reverse, the FET will be off and no current will go to the board. The reverse battery protection circuit is shown in Figure 3-6.

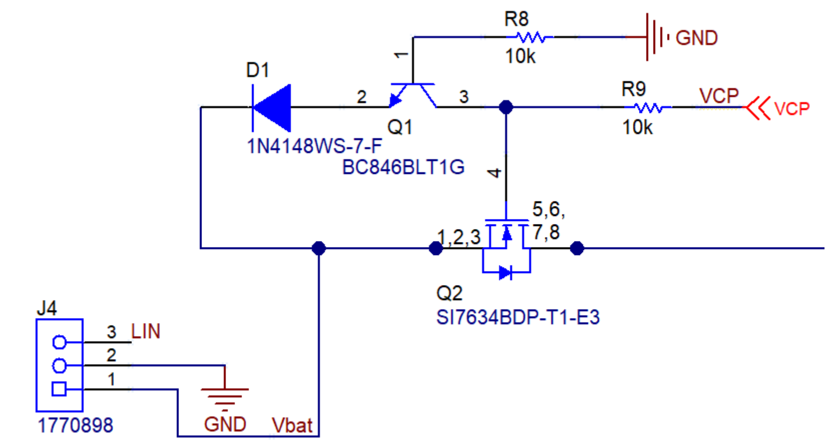


Figure 3-6. Reverse Battery Protection Circuit

To test the performance of the reverse battery protection circuit, the input voltage was varied from –20 V to 40 V and the input current was measured with a current meter while no loads were being driven. Figure 3-7 shows the input current as a function of the input voltage. At –20 V, the leakage current is close to 5 mA and at 40 V, the input current is around 11 mA.

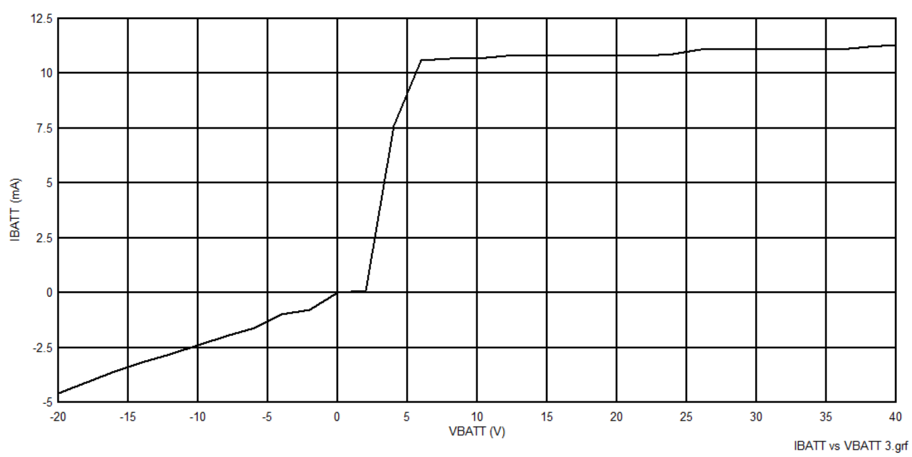


Figure 3-7. Input Voltage vs Input Current Graph

3.2.2.2 X&Y Motors and LED Driver

The DRV8906-Q1, which drives the two X&Y motors and the LEDs, is tested by measuring the operating current of each of the loads while varying the input voltage from 6 V to 18 V. Additionally, the stall current of the X&Y motors and the amount of time it takes the motors to move the mirror from one end to another is measured.

Table 3-1 shows the current through the turn signal LED for input voltage of 6 V, 12 V, and 18 V. The current through the LED is much smaller at 6 V which is expected. Despite the low current, the LED turns on.

Table 3-1. Current Through Turn Signal LED

INPUT VOLTAGE (V)	CURRENT (mA)
6	1.30
12	17.0
18	33.3

Table 3-2 and Table 3-3 shows the running current and stalling current of the Y-direction and X-direction motor for 6-V, 12-V, and 18-V input voltage respectively. The table also shows the time it takes for the mirror to travel from one end to another. In both motors, the running current and stall current increases as the supply voltage increases.

Table 3-2. Y-direction Motor Results

INPUT VOLTAGE (V)	RUNNING CURRENT (mA)	STALL CURRENT (mA)	TIME TO REACH END (sec)
6	28.5	37.7	15.8
12	33.7	44.5	6.45
18	37.6	47.0	4.10

Table 3-3. X-direction Motor Results

INPUT VOLTAGE (V)	RUNNING CURRENT (mA)	STALL CURRENT (mA)	TIME TO REACH END (sec)
6	10.5	10.6	12.64
12	27.5	37.5	5.60
18	33.2	44.0	4.01

3.2.2.3 Thermal Performance

Thermal images of the TIDA-020027 board were taken under various operations to test the thermal performance of the board. The operations tested include operating the mirror folding motor, mirror heater, and the electrochromic mirror. The thermal images display the average and maximum temperature of the board.

Figure 3-8 shows the reference thermal image of the board connected to a power supply of 12.5 V with no loads being driven. The average temperature of the PCB is 25.5°C and the max temperature is 31.2°C.

Figure 3-9 is the thermal image while driving the mirror heater. The heater was driven to about a minute before taking the thermal image to allow the heater to reach its peak temperature. The average temperature of the PCB is 26.8°C and the maximum is 32.2°C.

Figure 3-10 shows the thermal image while driving the fold motor. The thermal image was taken while the fold motor was driven from one end to the other continuously. The max temperature of the board was measured at 31.7°C and the average temperature at 26.1°C.

Figure 3-11 is the thermal image of the PCB while driving the EC. The thermal image was taken once the mirror reached the programmed dimness level. The maximum temperature of the PCB was measured at 41.7°C which is concentrated around the Darlington BJT. The overall average temperature of the board is 28.4°C.

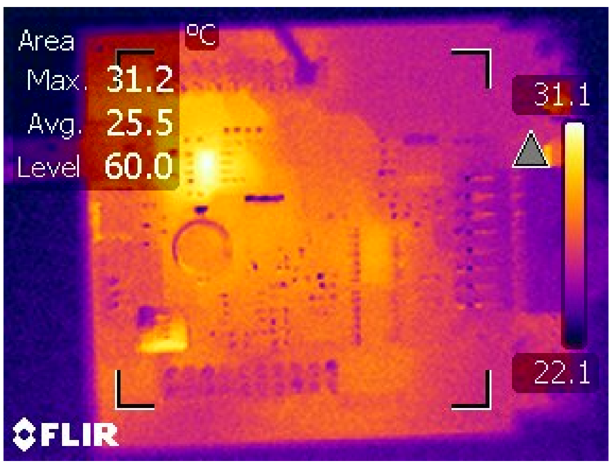


Figure 3-8. Reference Thermal Image of PCB

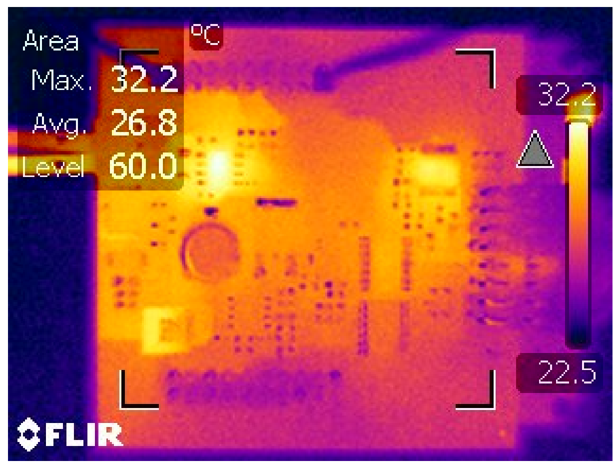


Figure 3-9. Thermal Image of PCB While Driving the Mirror Heater

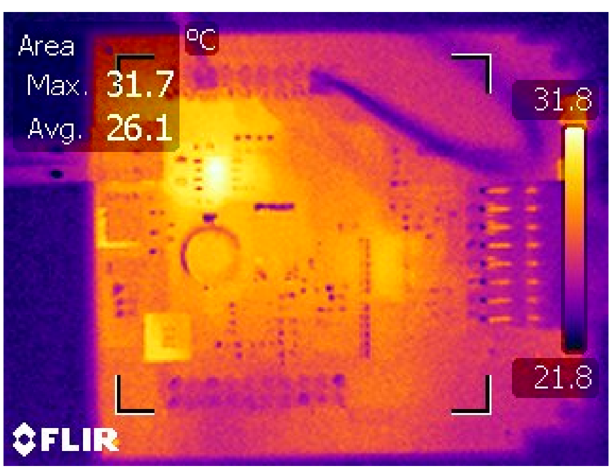


Figure 3-10. Thermal Image of PCB While Driving the Fold Motor

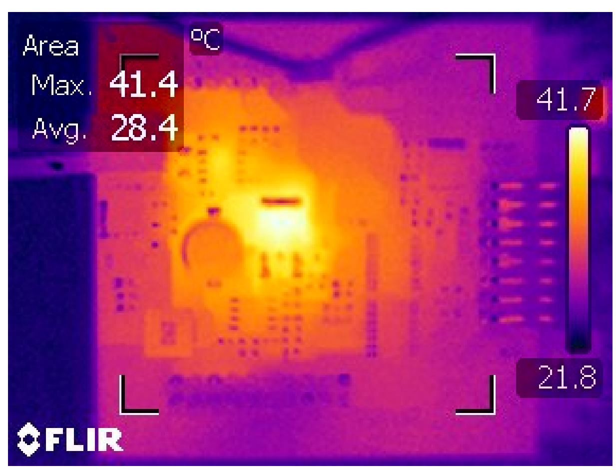


Figure 3-11. Thermal Image of PCB While Driving the Electrochromic Mirror

4 Design Files

4.1 Schematics

To download the schematics, see the design files at TIDA-020027.

4.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-020027.

4.3 Altium Project

To download the Altium Designer® project files, see the design files at TIDA-020027

4.4 Gerber Files

To download the Gerber files, see the design files at TIDA-020027.

4.5 Assembly Drawings

To download the assembly drawings, see the design files at TIDA-020027.

5 Software Files

To download the software files, see the design files at TIDA-020027.

6 Related Documentation

1. Texas Instruments, *Automotive Auto-Dimming Mirror Reference Design for Electrochromic Mirrors*

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7 Terminology

BJT-Bipolar junction transistor

EC- Electrochromic mirror

FET- Field-effect transistor

GPIO- General-purpose input/output

LDO- Low-dropout linear voltage regulator

LIN- Local interconnect network

MCU- Microcontroller

SBC- System Basis Chip