Application Note

Efficiently Driving Automotive Dashboard Loads with TPS1HC100-Q1

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ABSTRACT

This application note includes the design process of a small, easy to package power distribution board using the TPS1HC100-Q1 100 mOhm Automotive High Side Switch. This board powers multiple lower power ADAS loads such as heaters, motors and LED strips that require less than 2 A of DC current per load. The board is communicated to and from using an external standalone application that can control multiple loads and receive information from them. The loads are triggered using sensors that notify if an object is too close to a vehicle. Using TPS1HC100-Q1 allows for accurate current sensing and current limiting to drive these loads all while being offered in a space saving 14 PWP (HTSSOP) package.

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1 Introduction

Automotive loads include a wide range of resistive, capacitive and inductive loads across a wide power band. From incandescent headlights to traction inverters to on-board chargers, the unifying requirement is AEC-Q100 compliance for devices that drive these loads. A major push in the automotive industry is to increase the number of driver assistance systems that provide additional information to the user about the status of the vehicle. Such systems take advantage of more than one methods of feedback to the user like touch, sound and sight to provide quick feedback and therefore can be used to improve safety and handling of the automobile. These loads are commonly referred to as ADAS loads or *Advanced Driver Assistance Systems* loads. A vital piece of a circuit is the switch used to drive the load. The switch can be placed either on the high side of the circuit, (for example, between the source and the load) or on the low side (for example, between the load and ground) of the circuit. A high side switch is usually preferred because it does not leave the load energized in the off state. This is vital since a common use case failure mode is an unintentional short to GND and if the short happens before the low side switch, then the switch cannot protect against this event. The high side switch is therefore placed closer to the power supply and the downstream loads are often further away from the control unit or switch board. A critical function of the switch is to protect the load and the source from one another.

TI high side switches integrate a NMOS based power FET along with various protection features to support switching off-board loads. TI's high side switch portfolio includes devices with on resistances as high as 1 Ohm and as low as 8 mOhm. This choice of devices allows the user to select the right device depending on the protection features required and on the power requirements of the load. TPS1HC100-Q1 is a 100mOhm high side switch built for 12 V nominal systems that integrates protection features like a user set current limit and a high accuracy current sense output in one device. The current sensing allows for the user to have instant feedback on the condition of the device and the power flowing into the load without the need of higher power rated sensors or amplifiers. Current limiting allows for the user to drive loads that are susceptible to high current events by clamping them to the user set value. This works in hand with the integrated thermal protection of the device to automatically turn off the power path if required (for example, long fault event). The switch also has the ability to protect the load against surge events like load dump up to 35 V. TPS1HC100-Q1 also integrates a system that tracks the MCU voltage using the input to the DIAG EN pin so as to not output a voltage higher (such as during a fault event) than what the MCU or controller can safely handle. For more information on TPS1HC100-Q1, please view the data sheet here. For more information on high accuracy current sensing and high accuracy current limit of high side switches, please view their respective applications notes.

2 Automotive Dashboard and ADAS Loads

The idea of advanced driver assistance systems is to take advantage of more than one sensory input of the user. Since the user and or driver is the intended audience, the loads are usually lower wattage systems. Dashboard and ADAS loads can range from buzzers to motors to lighting cluster warnings taking advantage of hearing, touch and sight respectively. Not all loads are integrated into a vehicle with the goal of safety. Loads like steering wheel heaters and steering column movement motors or pedal box movement motors are integrated to increase driver comfort and overall ease of use. Some systems like gauge lighting cluster can perform double duty of adding interior lighting for comfort but also respond to external sensor stimuli. Therefore, ADAS and dashboard loads can be resistive, capacitive and inductive in nature. A high side switch like TPS1HC100-Q1 is tailor made to drive lower power ADAS loads since it is compatible with resistive, capacitive and inductive loads. Examples of these loads are shown in Figure 2-1

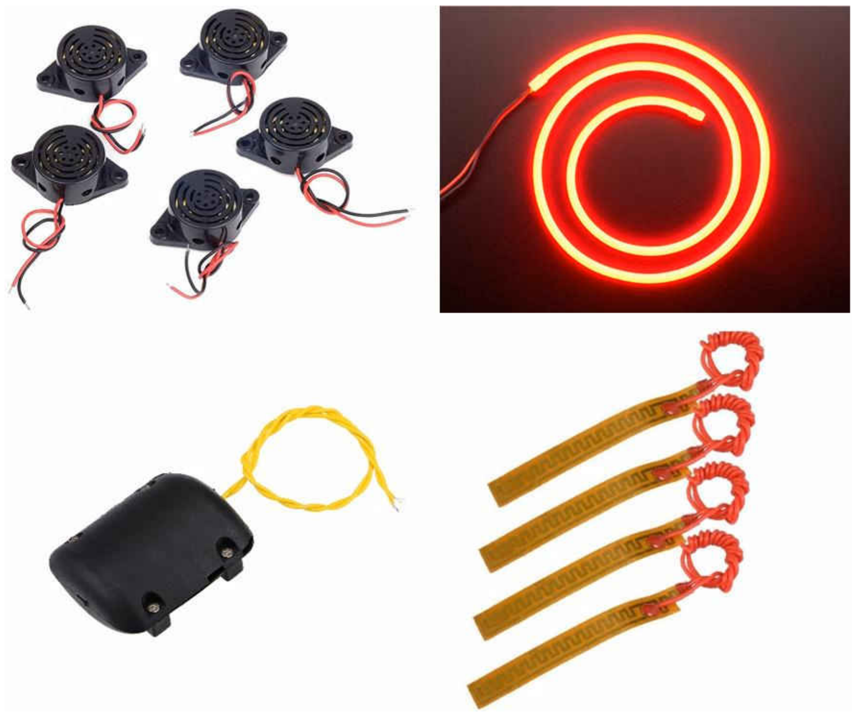

Figure 2-1. Examples of Some Conventional Low-Power Automotive Dashboard Loads

Resistive Loads

Resistive loads are the most common loads for a high side switch. They are the simplest loads to drive as they are linear systems. A common resistive load is a steering wheel heater. A long resistive coil is placed around the steering wheel or patches of resistive elements are placed on certain touch points. When current is passed over these coils or elements they heat up with respect to the square of the DC current multiplied with the specified resistance of the element. Since the voltage of the system is known and the on resistance of the element is specified, the current passing through the coil is easily calculated using Ohm's Law.

In this situation, using a TI high side switch like TPS1HC100-Q1 is beneficial not only because of its in-built current limit protection but more so due to the integrated high accuracy current sensing of the system. This system measures the current flowing through the power FET and by using an internal current mirror, it outputs a proportional current through the SNS pin of the device. Using an accurate sense resistor from the SNS pin to GND, it is possible to convert this proportional current output into a measurable proportional voltage signal. This voltage can then be read into a controller or an ADC and further processing can be performed.

An application example taking full advantage of this system is to change how much heat is dissipated across the steering wheel heater. The heater can be held in the DC on state initially to heat up the wheel to a comfortable temperature and then after a while the switch can be PWM'd to drop the average current flowing through the heater. The accurate current sense is then able to tell the controller what the temperature is and if there is any fault in the system. All this is performed without the need of a dedicated current sense circuit saving valuable PCB space.

Capacitive Loads

TI's high side switch offerings like TPS1HC100-Q1 can be used to drive both bulk as well as hold up capacitive loads. It is common to see speakers, buzzers, displays and lighting clusters often have a noticeable amount of input capacitance. Depending on the rise time at power up when connected to battery voltage, it is possible to see high inrush currents in these systems as the current is only limited by cable parasitic inductance and resistance. The inrush current can be significantly higher than the DC current required by the system and this results in accounting for larger cables, larger traces and a switch that can handle higher inrush currents.

TPS1HC100-Q1 circumvents these issues by offering high accuracy current limiting. This feature is also useful to protect the load and source during a short event but is extremely useful to turn on capacitive loads. The device includes an ILIM pin from which the user connects a current limiting resistor to ground. Similar to the current sensing system, there exists an internal current mirror that pushes a proportion of the load current out of the pin and over this resistor. When the voltage at this pin is higher than the internal threshold for current limiting, the device moves away from a linear mode of operation to a resistive mode to hold current at the specified value. The amount of current limit resistance is related to the value at which the device limits.

An application example of this is turning on a capacitive display or lighting cluster. Rather than experiencing a large inrush spike during turn on, the current through the device is held constant and the output rises slowly as the capacitor is charged up. This allows for the internal cabling, trace width and PCB area to be designed for lower currents. In the case that the capacitor to be charged is very large or in the event that there exists a failure more like a short to GND, the device will limit current to the set level. As this involves power dissipation across the FET, the device will heat up and eventually hit thermal shutdown which turns off the device and protects the system.

Inductive Loads

Inductive loads are loads that store energy in the form of a magnetic field. These loads are very common for high side switches especially in high power systems as the length of cable that connects the switch board to the off-board loads can more often have sufficient parasitic inductance for it to hold high energy. For ADAS systems, the power levels are lower and the length of cable is insufficient and as such dedicated inductive loads like motors and relays are of particular concern.

An inductor tries to resist against any change of current that flows through it. This means that during a turn on event, the inductor will result in slower charging time and slower turn on. Once the DC current is reached, the inductor is seen as a small resistive element. The issue arises during the turn off event of an inductive load. The inductor will once again resist the change of current flowing through it even though the switch has turned off. The magnetic energy stored within the inductor is turned into potential energy and causes a large transient voltage to be generated across the inductor. The switch therefore sees a large unregulated voltage spike on the output which can damage the switch.

TI high side switches like TPS1HC100-Q1 are built to withstand such events. When the circuit is turned off, the voltage on the output of the high side switch begins to drop instantaneously. The device integrates a voltage clamp across the drain and the source of the FET which keeps an active discharge path over which the inductive energy can be demagnetized. The voltage drop is therefore regulated to the clamp voltage and large negative spikes are not seen in the system. The current is able to recirculate through the clamp and the energy is dissipated away as heat. This integrated clamp means that there is no requirement for a flyback or high-power recirculation diode which saves on board and PCB cost.

For more information on driving resistive, capacitive and inductive loads please view this application note here. For more information on setting current limit and current sensing resistors for TPS1HC100-Q1, please view the data sheet here.

3 Constructing the TPS1HC100 Power Distribution Board

Table 3-1 describes the integrated circuits used to construct the TPS1HC100 Power Distribution Board and provides a quick summary of their purpose.

Table 3-1. Integrated Circuits

Part Number	Qty	Purpose
TPS1HC100-Q1	8	High side switch for 2-A max load, each
TPL0102	8	Set unique RSNS, RILIM for each TPS1HC100-Q1
TCA9539-Q1	1	IO expansion, controls DIA_EN, LATCH for each TPS1HC100-Q1
TPS629210-Q1	1	Convert battery voltage to 3.3-V system VDD

The TP1HC100 power distribution module is constructed of 4-2-oz copper layers with an FR4 core and PP-006 prepreg. 2-oz copper was chosen to reduce current crowding in the power path (VBB and GND). GND is constructed as an inner plane layer both for ease of routing and current distribution, while VBB is routed as polygons on the top and bottom layer to minimize path impedance. Both GND and VBB signals utilize via stitching to mitigate bottlenecks during layer changes. The other inner layer serves as a plane for VDD exclusively to alleviate routing constraints. Finally, the top layer is primarily a low current signal layer for fanning out IO signals from the CC2652R7 LaunchPad to the peripheral ICs. Additional low-power signal routing was moved to the VDD plane and bottom layers as top-layer space grew limited. IC_GND is routed on the top layer as a polygon pour to provide thermal mass to dissipate heat from each of the TPS1HC100 devices.

There are a total of 18 integrated circuits on the distribution module. 8-TPS1HC100-Q1 are used to drive 8 loads, up to 2-A DC each. Each TPS1HC100-Q1 is paired with a TPL0102 2CH I2C-enabled digital potentiometer. Each of the 8 TPL0102 are used to set RSNS and RILIM in lieu of discrete resistors. This allows for software controllable resistances in the event a new load is desired for a given channel. RSNS and RILIM can be resized in software to best suit whichever load is applied. TPL0102 has 3 address pins to avoid address conflicts on the I2C bus. A single TCA9539-Q1 I2C-GPIO expander is placed to provide additional digital IO between the CC2652R7Launchpad and each TPS1HC100-Q1. TCA9539-Q1 communicates over the I2C bus to set or read any of it’s 16 IO pins. In this instance all IO pins are set as output to control the DIAG_EN and LATCH pins of each channel. These pins typically do not have strict timing requirements, so the time to send an I2C transaction does not drastically impact the performance of the system. In contrast, EN pins are connected directly to the LaunchPad for more precise timing/PWM control.

Finally, a TPS629210-Q1 1A adjustable VOUT buck-converter is used to provide 3.3 V to the TCA9539-Q1, 8-TPL0102, and CC2652R7 LaunchPad. A buck-converter was selected over linear regulator to reduce losses in the voltage conversion. For example, the system has an idle current draw of 30 mA. Assuming 90% efficiency with TPS629210-Q1, PLOSS = PIN-POUT = PIN-0.9*PIN … PLOSS = 0.1*PIN = 0.1*(12 V*0.03 A) = 36 mW. Contrast this with an LDO, where power can be approximated as PLOSS = (VIN-VOUT)*IIN = (12 V-3.3 V)*.03 A = 261 mW.

TPS1HC100-Q1 is powered directly from the automotive battery/DC supply. All other ICs and the launchpad receive power via the TPS269210-Q1 3.3 V output. This output level also dictates the logic level and FLT voltage level in the system. TI LaunchPads come populated with 2 sets of 100mil headers. A matching set of headers was placed on the TPS1HC100 Power Distribution Module to create a clean interface for all signals to/from each board. There are five signals that must be communicated between each TPS1HC100-Q1 and the CC2652R7 LaunchPad – EN, DIAG_EN, LATCH, FLT, and SNS. The interface between each signal is as follows:

1. EN: LaunchPad digital IO set as OUTPUT
2. FLT: LaunchPad digital IO set as INPUT
3. DIAG_EN: TCA9539-Q1 digital IO OUTPUT, I2C bus mastered by LaunchPad
4. LATCH: TCA9539-Q1 digital IO OUTPUT, I2C bus mastered by LaunchPad
5. SNS: LaunchPad analog input (ADC)

EN and FLT are directly connected to the LaunchPad since these signals are most time critical. For example, the user may want to control their load with a pulse width modulated EN signal, which would not be feasible over the I2C bus. Additionally, FLT might be used to trigger an interrupt. Detection is quicker with a digital edge at the uC rather than an I2C transaction. Finally, SNS is connected to an ADC input since it is an analog signal

4 Overview of Embedded System

In the reference design system, a couple if different wireless microcontrollers are used in peripheral mode. A CC2652R7 ARM Cortex-M4F microcontroller is used on the steering wheel to control and configure the series of TPS1HC100B-Q1 high side switches. The CC2652R7 advertises a set of BLE services/characteristics for the host the manipulate and configure. For the distance sensors attached to the model car, a scaled down CC2651P3 ARM Cortex-M4F microcontroller is used to continuously measure the current of the array of sensors and report the reading values to a BLE host. The BLE host in this system is a standard Apple iPad® running a simple Swift application with a CoreBluetooth backend. The iOS application acts as the central brain of the system by reading the sensor values from the CC2651P3, performing analysis/processing to determine how close an object is, and then alerting the CC2652R7 microcontroller on the steering wheel in the event that an alert event should occur. A block diagram of the embedded portions of this system is shown in Figure 4-1.

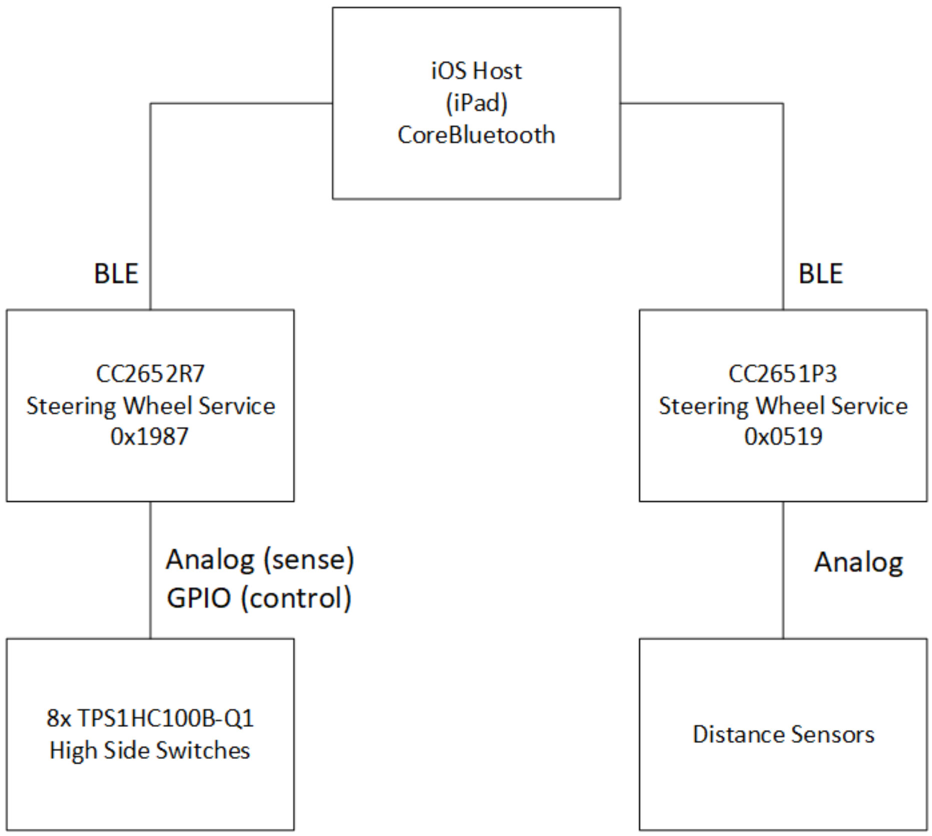

Figure 4-1. Software Block Diagram (iOS Host)

Additionally, a software flowchart of the distance detection can be seen below in Figure 4-2. This flowchart is from the perspective of the iOS host controlling both the CC2652R7 and CC2651P3 microcontroller.

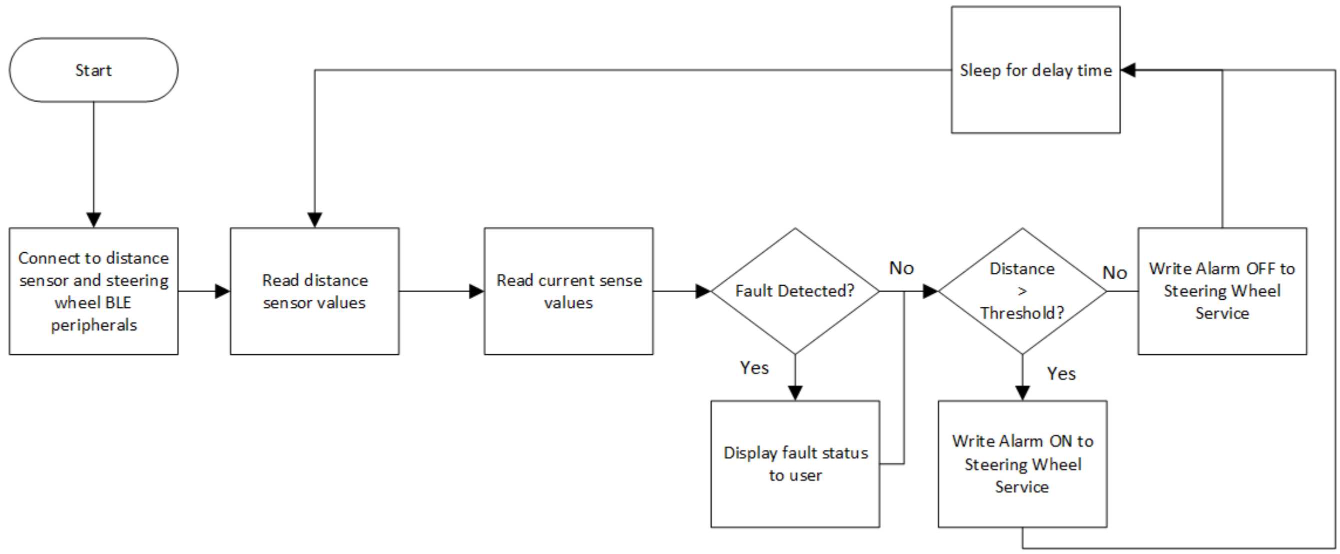

Figure 4-2. Flowchart (Distance Detection)

The CC2652R7 attached to the steering wheel advertises over BLE the following service with the listed characteristics as shown in Table 4-1.

Table 4-1. Steering Wheel Service (0x1987)

Characteristic	UUID (Hex)	Format	Description
Sensor Alarm	0xFFF1	uint8_t	Value to enable/disable driving of alarm loads.
Sense Values	0xFFF2	uint16_t [8]	Raw ADC conversion results of sense current
Gyrometer Values	0xFFF3	uint16_t [6]	Raw gyrometer values from BOOSTXL-SENSORS
Heater Enable	0xFFF4	uint8_t	Enable/disable steering wheel heater

The CC2651P3 attached to the model car advertises the services/characteristics shown in Table 4-2.

Table 4-2. Sensor Distance Service (0x0519)

Characteristic	UUID (Hex)	Format	Description
Sensor Distance #1	0xFFF1	uint16_t	Left distance sensor
Sensor Distance #2	0xFFF2	uint16_t	Center distance sensor
Sensor Distance #3	0xFFF3	uint16_t	Right distance sensor

The CC2652R7 BLE microcontroller embedded in the steering wheel controls all aspects of the array of TPS1HC100B-Q1 high side switches connected to the system. The tasks that the CC2652R7 includes the following:

- Enabling/disabling power to the automotive loads on distance events
- Continuously measuring the load current of attached loads
- Advertise configuration BLE services and characteristics
- Manage attached gyrometer from BOOSTXL-SENSORS BoosterPack
- Monitor fault status of the attached TPS1HC100B-Q1 automotive loads (overcurrent, open load, and so on.)

As the CC2652R7 is a microcontroller designed for low-scale embedded systems, no algorithm intensive computations or CPU heavy calculations are performed on the CC2652R7 itself. Instead, the iOS host is used to perform all the heavy lifting with respect to the data processing and distance detection. The CC2652R7, instead, takes the read values from the TPS1HC100B-Q1's current sense and places them in a buffer for the iOS host to read. To do this efficiently for all eight TPS1HC100B-Q1 devices attached to the system, a *sequence of channels* conversion is performed using the ADC_convertChain function from the SimpleLink SDK drivers package. This conversion can be seen in the snippet below:

```
adc[0] = ADC_open(SNS1, &params);
adc[1] = ADC_open(SNS2, &params);
adc[2] = ADC_open(SNS3, &params);
adc[3] = ADC_open(SNS4, &params);
adc[4] = ADC_open(SNS5, &params);
adc[5] = ADC_open(SNS6, &params);
adc[6] = ADC_open(SNS7, &params);
adc[7] = ADC_open(SNS8, &params);

  while(1)
{
    ADC_convertChain(adc, sampleBuffer, 8);
    SteeringWheelProfile_SetParameter(STEERINGWHEEL_CHAR2, 16,
                                      &sampleBuffer);
    Task_sleep(1000);
}
```

The iOS software running on the iPad will periodically poll the value in STEERINGWHEEL_CHAR2, parse out the various load currents represented by ADC conversion results, and then display them on the iPad frontend for the user to see.

The distance detection itself is done on the iOS host using a simple threshold algorithm. Each sensor has a corresponding threshold value associated with it for *far*, *medium*, and *close*. If the value read from the CC2651P3 crosses any of these threshold, a value of 3, 2, or 1 is written to the STEERINGWHEEL_CHAR1 characteristic of the CC2652R7 MCU in the steering wheel. These values correspond to the intensity at which the alert should trigger on the steering wheel system. A *close* value, for example, corresponds to a *collision eminent* event where the loads/alarms would trigger on the steering wheel at full intensity. A code snippet of the iOS code that handles the thresholding follows:

```
if(characteristic == leftChar)
{
    let intValue = (UInt16(data[1]) << 8) | UInt16(data[0])

    leftValues[frontPos] = intValue
    leftPos+=1

    if(leftPos == NUM_DIST_VALS)
    {
        leftPos = 0
        leftPasssed = true
    }

    var curSum: Int = 0
    for curVal in leftValues
    {
        curSum += Int(curVal)
    }

    let curAvg = curSum / NUM_DIST_VALS

    if(curAvg >= LEFT_THRESH3)
    {
        leftLevel = 3
    }
    else if(curAvg >= LEFT_THRESH2)
    {
        leftLevel = 2
    }
    else if(curAvg >= LEFT_THRESH1)
    {
        leftLevel = 1
    }
    else
    {
        leftLevel = 0
    }
}
```

In this snippet, the left sensor is compared to a set of threshold values from *far*, *medium*, and *close* distances. Depending on the corresponding level, an integer value is assigned to the ***leftLevel*** variable. This variable is later combined into a single 8-bit integer and written to the alarm characteristic of the steering wheel if an alarm is triggered. Also note that the distance algorithm implements an elementary form of averaging/integration over ***NUM_DIST_VALS*** number of values (default five). This is to avoid any *false triggers* resulting from the sensitivity of the distance sensors. The actual writing of alarm is done using the standard CoreBluetooth APIs shown in the following wrapper function:

```
func writeAlarm(command: UInt8)
{
    if((autoPeripheral != nil) && (autoPeripheral.state == .connected))
    {
        autoPeripheral.writeValue(Data([command]),
                                  for: autoAlarmChar, type: .withResponse)

    }
}
```

5 Applying the TPS1HC100 Power Distribution Board in a Reference Design

Combining the embedded system as described above and the power distribution board, it is possible to create a reference dashboard system to provide a real time example of the features and benefits of the TPS1HC100-Q1. The reference design uses a variety of loads to represent the different challenges faced as described in Section 2. The loads in this reference design are steering wheel heaters, haptics motors, buzzers and LEDs which represent a large proportion of resistive, capacitive and inductive loads. Furthermore, the power distribution board along with the microcontroller is packaged within a conventional steering wheel. While such a system can only be achieved by removing the driver airbag and airbag ignition system which is not realistic, this highlights another major benefit of using TI High Side switches namely, the low small PCB footprint and the high-power density. Figure 5-1 shows a block diagram of the reference design.

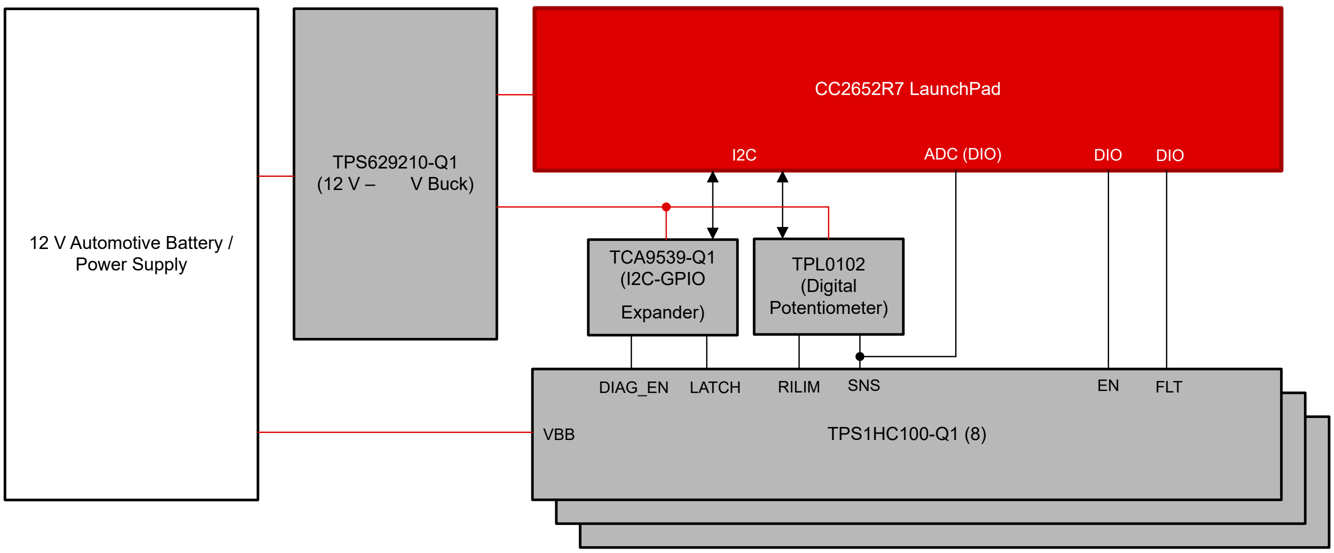

Figure 5-1. Reference Design Block Diagram

The distance sensors are not directly driven by the power distribution board. While it is possible to use TPS1HC100-Q1 to drive these devices, this reference design uses two independent circuits that communicate with one another through the iOS host. To this end, the distance sensors are mounted on an RC car which can be placed in various locations to trigger different responses on the loads driven by the power distribution board. They are mounted on the front left, front right, and center front of the RC car. The sensor data is sent to a secondary MCU which then sends this data to the iOS Host. The user also has the ability to manually turn on the steering wheel heater with the iOS host as this load is not triggered by any proximity warnings. The onboard gyroscope also provides rotation data which is sent to the iOS host and is represented with a steering wheel which updates its position in real time.

When the distance sensors are triggered on the RC car, the proximity data is sent to the iOS Host. Depending on how close and the location of the sense item, that is, left, right, or center, the iOS Host determines which set of loads needs to be enabled and the severity of the proximity warning. There are three levels of severity which have increasing PWM frequency higher the level of severity. The most severe warning results in a DC on signal sent to the loads. The LEDs, buzzers and haptics motors all respond simultaneously to this proximity trigger. Information is easily parsed by the user on the location of the item as well as its severity as the loads on the left side are triggered based on proximity on the front left sensor and loads on the right side are triggered based on proximity on the front right sensor. If both the left and right loads are enabled, the implication is that the proximity warning is generated from something straight ahead.

6 Schematics

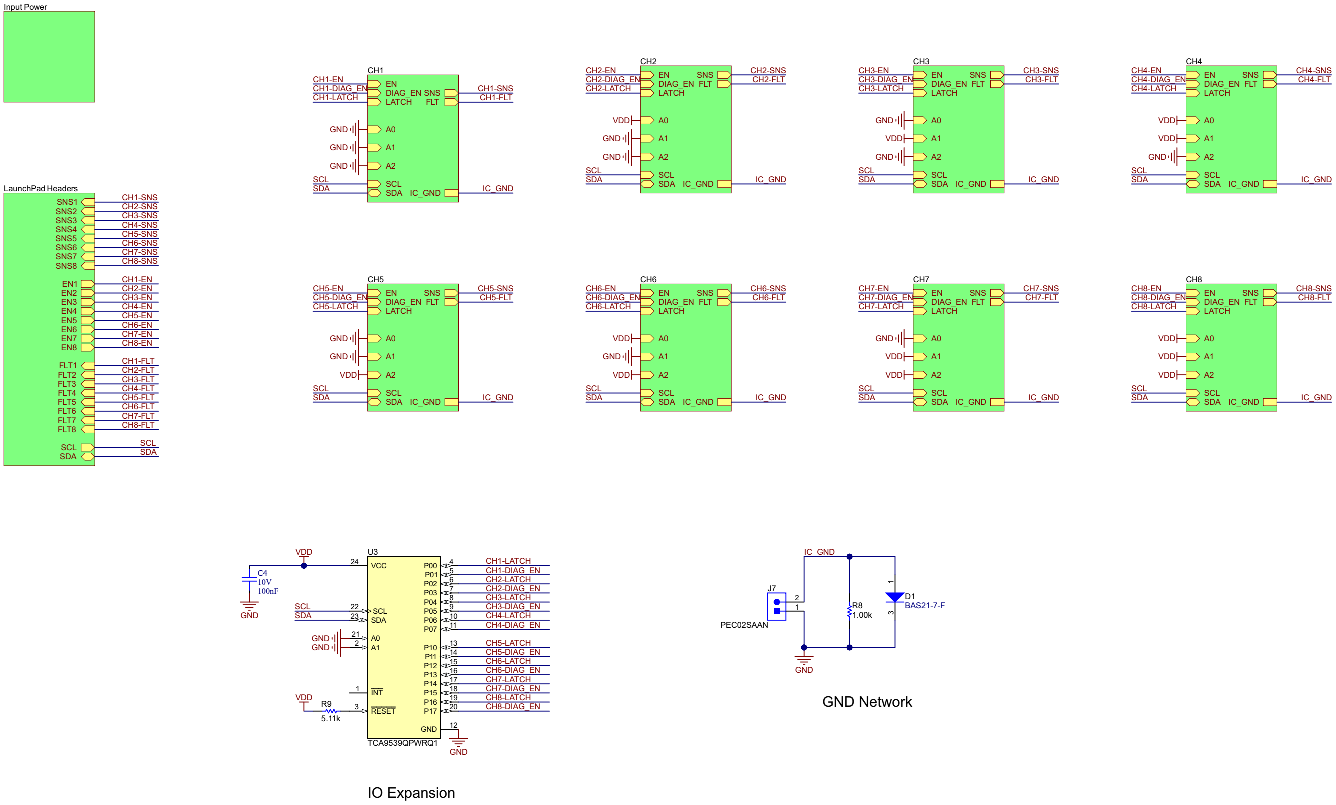

Figure 6-1. Top Level Schematic of TPS1HC100 Power Distribution Board

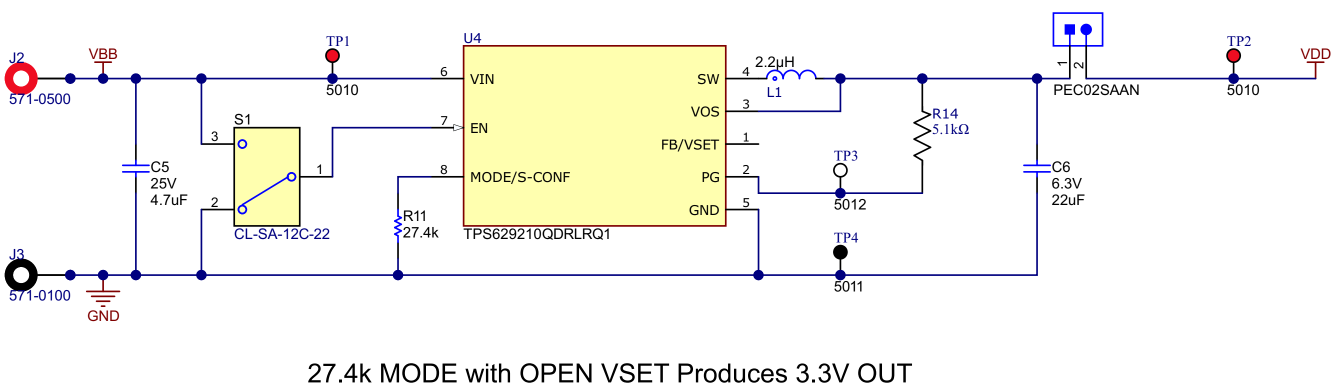

Figure 6-2. Input Power Block Schematic

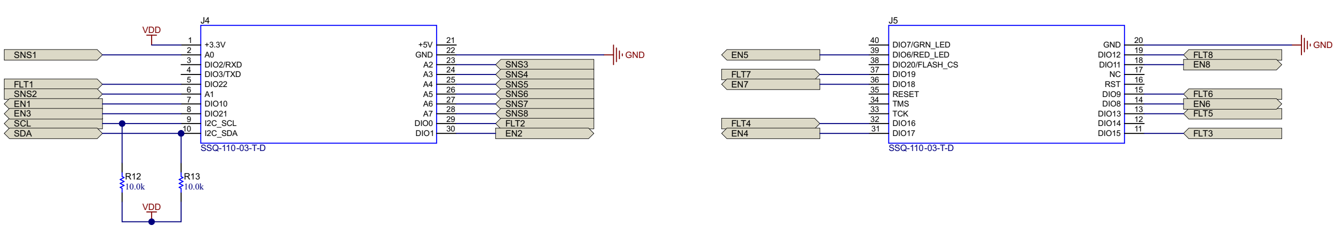

Figure 6-3. LaunchPad Headers Block Schematic

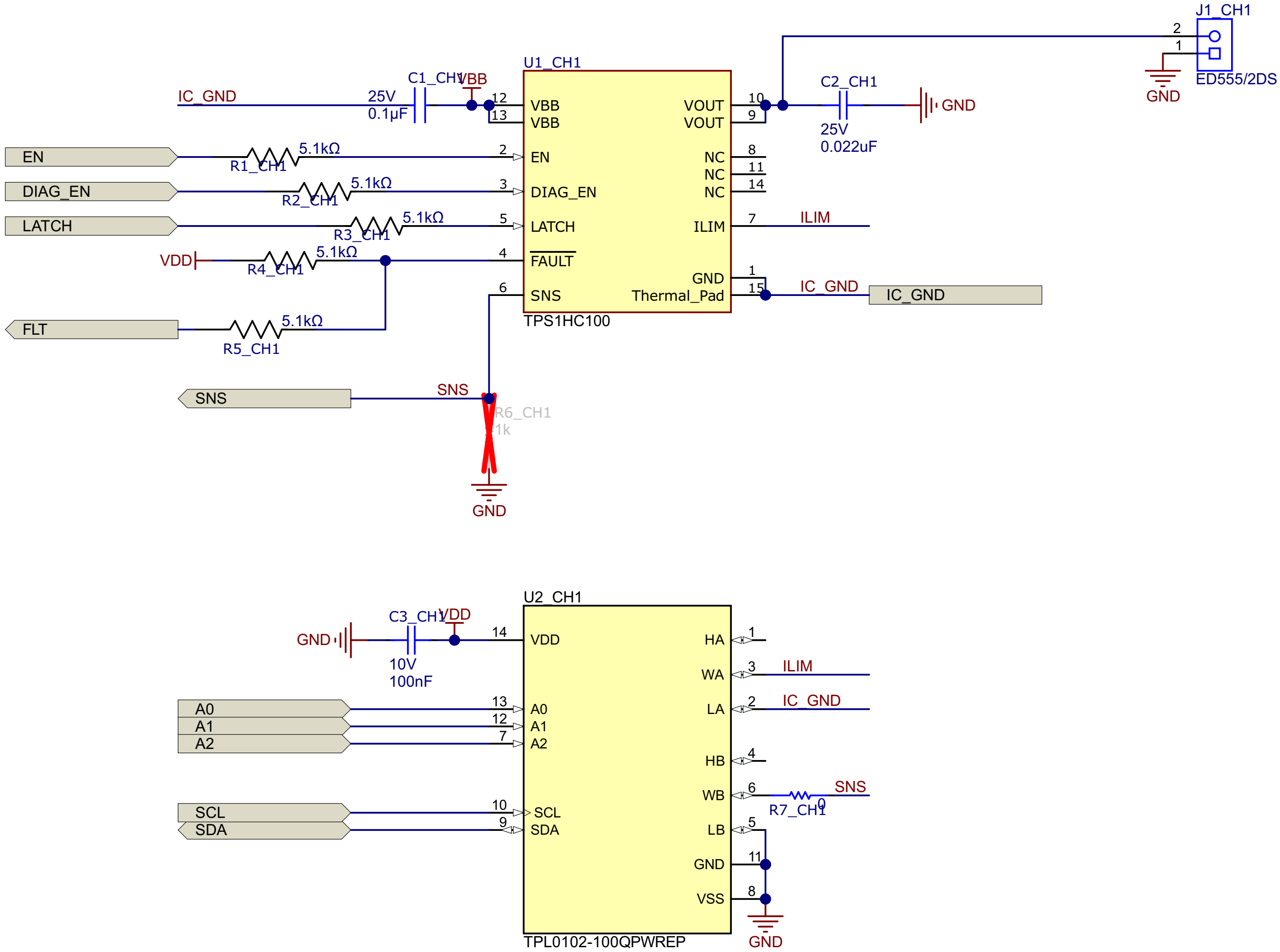

Figure 6-4. TPS1Hc100-Q1 Channel Block Schematic

7 Layout

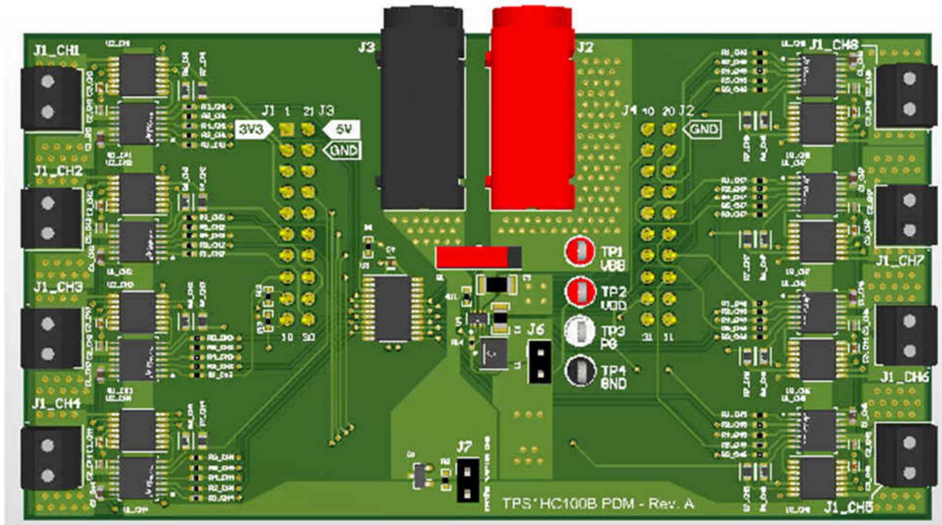

Figure 7-1. TPS1HC100 Power Distribution Board PCB Top

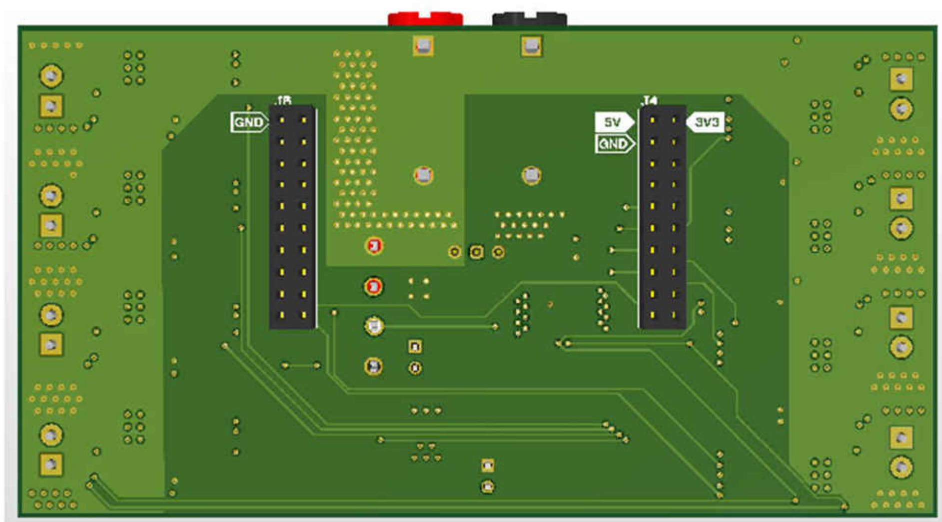

Figure 7-2. TPS1HC100 Power Distribution Board PCB Bottom