Design Analysis

SAT0103 – BCM Reference Design

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TEXAS INSTRUMENTS

Overall Design - Specifications

- Format: Single printed circuit board, compatible with LaunchPad BoosterPack pinout format
  - BoosterPack format gives a degree of modularity, as this BCM design has a layer of abstraction for MCU POV – MCU chosen by user should not matter to the BCM board

- Platform: 40-pin MSP430 LaunchPad (MSP-EXP430F5529LP)
  - MCU is app/user choice, however for reference design testing, documentation and demonstration an MSP430 platform is used for simplicity on software side, utilizing tools such as Energia. Due to this purpose an automotive qualified MCU is not required.
  - 40-pin format allows full range of functionality due to increased number of GPIOs – 29 (F55) vs. 11 (G2) (maximum)
    - Alternative: use MSP430G2 with several I^{2}C expanders.
      However, F55 is a much neater solution – avoids serialization issues with driving high switching frequency loads, quicker error detection, and demonstrates a more suitable solution to customers!

TEXAS INSTRUMENTS

Overall Design - Specifications

- Power: 12V car battery operated
  - Typical continuous range: 9V – 18V
    - Designed to 8V – 20V
  - Max. transient handling: 6V – 40V
  - Reverse polarity protected
  - LaunchPad powered by USB connection to PC or 12V power (jumper switched)
- Communication: PC interface with MSP430 via USB UART
- Input: BoosterPack pins (GPIO, I^2C, SPI) and 12V power
  - Determined by devices used - I^2C and SPI used to save pins while keeping the number of diagnostics reported

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Overall Design – Auto Qualification

- Showcase devices fulfil at least one of the following requirements
    - Automotive qualified and tested (AEC Q10x/Q200 rated)
    - Automotive qualified version currently in development
    - Automotive qualified version ready to be put forward pending a customer with interest
- All other Texas Instruments ICs are auto qualified –*Q1* versions
- Extended temperature range passives used when available (X7R rated capacitors, AEC-Q200 rated resistors)

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Passives

- Resistors
  - 1% tolerance resistors used for sensitive circuits benefitting from high precision (reference circuits, resistor dividers, etc.)
  - 5% tolerance resistors used for all other less critical circuits (pull-up and pull-down) – saves cost
  - Power rating taken into account when possible. Power requirements overestimated for caution.

- Capacitors
  - All capacitors on 12V line rated to 50V or more, thereby handling 40V load dump transients and other voltage spikes
  - Other capacitors rated to the voltage of the line plus a buffer –10V capacitors for 5V rail, 6.3V capacitors for 3.3V rail, unless otherwise specified
  - Generally, 10% tolerance capacitors used unless specified

TEXAS INSTRUMENTS

Passives

- Package sizes
    - For reference circuits (where resistor values determine an IC parameter or characteristic), larger 0605 or above resistors are used
    - 0402 resistors are used for less critical circuits such as pull-up or pull-downs
    - Capacitance + X7R rating determine package size of capacitors; generally, 0605 or larger packages are used for capacitors (except bypass caps)

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Other

- Test points
  - Most beneficial when monitoring load drive signals to determine cause of fault (BCM board or load itself); however, test points are redundant due to the use of screw terminals which can facilitate testing clips on connected leads
  - Test points are used on sensitive I^2C and SPI communication lines in case of faulty input data from MCU POV
  - If manual override input line(s) are available, test points are accessible as an alternate to load driving via SPI. Further detail provided in TPIC44H01 section.
  - In addition to a ground ring, ground flags are provided around the board for reference
- Standoffs: clear the height of a LaunchPad without causing it to have excessive elevation

Power stage

TPS7A6650-Q, TLV70033-Q, SM74611

TEXAS INSTRUMENTS

Design Considerations

- The system requirements of this project defined the typical continuous voltage at **9V-18V**, to accommodate a standard automotive car battery

- The high end transient requirement is defined by the **40V** spike transients during a load dump event; this means the system must handle this event without damage to any components and be 100% functional afterwards

  - All the devices highlighted in this system are rated to 40V or above absolute max on the 12V input (see table 1)

  - The 5V power supply, TPS7A6650, features an operating range of 4-40V for 5V regulated output; thus, all 5V and 3.3V rails are protected against load dump conditions

TEXAS INSTRUMENTS

Design Considerations

- The low end requirement is defined by the **6V** the system may see during start/stop conditions. However, several of the devices are not rated to operate at this voltage (highlighted in table 1) and therefore will either need to shutdown for the duration of the event, or require a boost converter.
    - The first option was chosen due to increasing complexity of the system; from a marketing perspective, it is rare to see boost converters on BCM systems and illustrates a shortcoming of TI parts.
    - From an application standpoint, loads which are not critical during a start/stop transition (e.g. one would not need to adjust their seat or window during this short event) are recommended to be connected to these devices
    - The 5V LDO chosen features a 4V minimum input voltage and low-voltage tracking, which tracks the output voltage to input minus load voltage/current, when below 4V

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Design Considerations

Device	Operating voltage (V)	Absolute max (V)
DRV8865	4.7 - 45	-0.3 - 55
LM9061	5 - 40	0 - 45
TPIC44H01	7 - 26	60
TPL7407L	8 - 34	-0.3 - 40
TPS1H100B	7 - 28	-0.5 - 60 (80)
LMD18400	8.5 - 40	-0.3 - 42
TPS92630	5 - 40	-0.3 - 45
TCA9539*	1.65 - 5.5	-0.5 - 6
LDOs		
TPS7A6650	4 - 40	45
TLV70033*	2 - 5.5	–0.3 - 6

Table 1 – Power requirements of devices
Note – all other low level ICs (translators, buffers, etc.) do not operate off 12V line

* Devices that run off TPS7A6650 5V output rail

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Design Considerations

- Reverse polarity protection
  - Protection from negative voltages is achieved using a diode on the battery power input – however, this carries an associated voltage drop of approx. 0.5V.
  - The SM74611 smart diode is highlighted as an alternative; this part features shutdown of reverse voltages on the input, while only carrying a negligible 76mV forward voltage drop for 12A at 125ºC, negating the drawbacks of regular power diodes
  - The SM74611 in it's current state does not *fully* protect against negative voltages as it does not do 'smart' detection, only reactive shutdown with an associated lag. In addition, it is possible for the switching internal MOSFET to enter a state that causes the device to be fully 'on' with negative voltages under certain conditions
  - The product line intends to produce an automotive targeted version of this part, launching late 2014, that will feature a larger power range and full reverse polarity protection

Part Selection

- Requirements
  - **5V** rail for logic on TPIC44H01 and LMD18400, analog output on TPS1H100B
  - **3.3V** rail for all other logic lines, I^{2}C expander, MSP430

- Power Budget
  - In order to determine the topology for stepping down to these voltages, the total required current on the 5V rail (and 3.3V rail due to cascading design) needs to be taken into account for power efficiency considerations
  - The total maximum current requirements on these rails combined is <10mA; therefore, an LDO is suitable for a 12V to 5V buck due to minimal power dissipated through heat. LDOs have the benefit of simplicity (less external components are required allowing a lower BOM/board space cost), low noise and low Iq

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BOM Analysis

- J23: a larger 15A screw terminal was chosen to handle the peak currents of the system (estimated at approx. 12A if all loads are connected and driven concurrently), and ease of use with regular wires and testing clamps

- C30: 1uF, 50V – input decoupling capacitor (value from DS)

- C32: 10uF, 10V – output stability capacitor; >2.2uF in DS → larger value used for faster load steps to prevent reset from occurring

- C34: 1nF, 50V – programs reset delay on power up. Set for 1 ms using equation from datasheet: $t_{CT} = \dfrac{C_{CT} \times 1V}{1uA}$

- R54/R56: 10kΩ, 5% - pull-up resistors (always on operation on EN)

- SN74LVC1G07-Q – open-drain non-inverting buffer to drive status LED D5, as power good (PG) pin cannot source the required 5mA current

- C35: 0.1uF, 10V – input decoupling capacitor (standard value)

TEXAS INSTRUMENTS

BOM Analysis

- R57: 665Ω – standard LED resistor (MAVRK recommended), set D5 bias current for 5mA

- D5: 2.2V, 20mA rated – standard green status LED (MAVRK recommended)

- C33: 1uF, 10V – input decoupling capacitor (recommended in DS)

- C31: 1uF, 6.3V – output stability capacitor (recommended in DS)

- R55: 10kΩ, 5% - pull up resistor for enable line for always on operation

TEXAS INSTRUMENTS

Low Side Driver (ch 1-5)

TPL7407L

TEXAS INSTRUMENTS

Design Considerations & BOM Analysis

- In order to provide more flexibility with loads, four of the TPL7407L peripheral driver channels are connected to give 1A total current drive through two channels. This reduces the total output from 7 channels to 5 but as there is an abundance of drive channels in the overall system, a variety of output characteristics is useful to demonstrate

BOM Analysis

- J2, J3, J4, J5, J6: 6A rated screw terminal to handle 500mA and 1A loads, and ease of use with regular wires and testing clamps

- C5: 0.1uF, 50V – input decoupling capacitor (standard value)

TEXAS INSTRUMENTS

High Side Pre-FET Driver (ch 1)

LM9061

TEXAS INSTRUMENTS

Design Considerations – Pre-FET Drivers

- As a discrete FET solution provides more flexibility with load driving current requirements, the pre-FET drive channels can be used to drive loads directly at higher amps. As integrated FET drivers aren't usually high power, it is not possible to directly drive the variety of automotive loads in a BCM system (instead driving relays) using these drivers.

- Therefore, the strength of choosing a high current FET to match a direct load is demonstrated with both pre-FET devices driving a seat heater (3.5A at 12V, 4.5A at 20V).

- In a real application sense, BCM systems usually drive relays and not loads directly. This design demonstrates flexibility for unique cases where the user may require higher current capability.

TEXAS INSTRUMENTS

BOM Analysis

- Q1: 60V, 16A Q101 – chosen to suit output current requirement and maximum voltage passed through the FET, while satisfying the thermal requirements at an ambient temp. of 85 degrees (R_{DS})

- C13: 0.1uF, 16V – delay capacitor; delay set to 55ms default as specified from datasheet
  - Alternate delay times set using T_{delay} datasheet equation

- C14: 0.1uF, 50V – decoupling capacitor, from datasheet
  - Must be >10*FET gate capacitance & ≥0.1uF.

- R22: 1.13k Ω – Threshold resistor to set current protection threshold
  - Tailor V_{DS} to a maximum current using equation:
  $I_{MAX} = \dfrac{V_{DS(MAX)}}{R_{DS(on)(max)}}$ and then using V_{DS} to calculate $R_{THRESHOLD}$ value:
  $V_{DS(MAX)} = \dfrac{V_{REF} \times R_{THRESHOLD}}{R_{REF}} - (I_{SENSE} \times R_{SENSE}) + V_{OS}$
  where I_{MAX} = 5.5A, $R_{DS(on)(max)}$ = 0.0181, other values from datasheet

TEXAS INSTRUMENTS

BOM Analysis

- R20: 0Ω – In case of output ringing, change to set a delay on FET gate drive

- R21: 1.00kΩ – provides transient protection for Sense pin (-25V to 60V)

- R23: 15.4kΩ – R_{ref} resistor to program reference current for internal biasing and charge pump switching frequency; 15.4kΩ ensures datasheet rated performance characteristics with a 80uA ref. current

High Side Pre-FET Driver (ch 4-5)

TPIC44H01

TEXAS INSTRUMENTS

Design Considerations

(see "Design Considerations – Pre-FET Drivers" for general remarks)

- The TPIC44H01 features fault reporting via a serial interface (SPI) and dual drive inputs – FETs can be switched via 4 GPIO inputs or SPI

- Maximum SPI functionality is utilised to reduce the overall number of communication pins
  - SPI is used for the inputs FET switching and sleep mode enable, and the output fault conditions (over-voltage, open-load, over-current, short to ground) on each output channel (1-4)

- The analog device inputs are connected to test points to test/debug the device independent of SPI

- The device uses a 5V logic range, incompatible with the MSP430F5529. Two always on 4-bit voltage translators (TXB0104-Q1) are used to shift levels between 3.3V-5V. This device meets the requirement of auto-sensing bidirectional operation for SPI and Q1 status.

TEXAS INSTRUMENTS

Dual High Side (ch 6-7) & Low Side (ch 6-7) Driver

DRV8865

TEXAS INSTRUMENTS

Design Considerations

- The DRV8865 is a dual high-side and low-side driver, capable of operating in normal (1:1 input to output) or parallel (1:2 input to outputs) mode, in order to increase output power

- The mode selection is a design choice rather than user choice, as it is selected using a 100kΩ resistor on the MODE_SEL pin to ground. This design aims to demonstrate both possible applications of this device depending on the users preference simply by replacing the 0Ω resistor in series with a 100kΩ resistor.

- If run in parallel mode, jumpers are used to combine the current drive on each high-side and low-side output

- Separate terminals are used for GND and 12V paths for high-side and low-side respectively, in order to manage connections and dissipate heat

TEXAS INSTRUMENTS

Design Considerations

- Weak short detection/motor stall detection – detecting implemented with weak resistors on MOS_GND/VM_FET for HS/LS outputs
  - Set a 266mA threshold to trigger a WSD/MSD fault flag, to match the load (relays) maximum estimated current usage 250mA @ 20V.

High Side Driver (ch 1)

TPS1H100B

TEXAS INSTRUMENTS

Design Considerations

- The strength of the TPS1Hxxx-Q1 family is the comprehensive "smart" functionality, providing fully protected high side switching with diagnostics and accurate current sensing/limiting

- Therefore, this design utilises the full gamut of reporting available to give detailed updates on the load conditions

- As this device is single channel, it is restricted on the types of loads it can drive (as actuator type loads require 2 relays for bidirectional motion); it is designed for the brushed-DC HVAC blower

  – Due to the great current requirements of the blower (approx. 7.7A @ 12V), it is driven using an automotive relay

TEXAS INSTRUMENTS

Design Considerations

- Diagnostics reporting is run independent of the load state; therefore, the driver is capable of load off-state diagnostics
  - The diagnostics enable pin allows reduced power consumption, such as disabling reporting when the load is switched off, independent of MCU if the pin is tied to the drive input.
  - For this design, the diagnostics are always enabled as power consumption of this device is negligible in the overall system, as cases where the BCM is active and discharging the battery until shutdown are uncommon

- Current limit – set at 300mA
  - Current draw from relay is approximately 220mA @ 20V + overhead

BOM Analysis

- R14: Set as 300mA sensing range

TEXAS INSTRUMENTS

High Side Driver (ch 2-5)

LMD18400

TEXAS INSTRUMENTS

Design Considerations

- The LMD18400 design aims to make maximum use of the wide availability of diagnostics reporting, a combination of thermal and error flags and data output to identify specific faults

- The output logic pins operate with 5V logic. As the MSP430/I2C expander operate at 3.3V, when required the communication lines are translated through an open-drain buffer (SN74LVC3G07-Q1) using pull-ups to 3.3V.

- To maximize power efficiency, the enable pin is tied low to force sleep mode as a default state. Likewise, the active-low CS pin is pulled high.

TEXAS INSTRUMENTS

LED Driver (ch 1-3)

TPS92630

TEXAS INSTRUMENTS

Design Considerations

- The three channel LED driver demonstrates interior/exterior LED lighting using one IC to drive instead of multiple drivers + series resistors. PWM control, diagnostics and protection are also features of this device, providing a degree of flexibility where it may be required for daytime running lights, tail lights, etc.

- Colour – white LEDs were chosen to simulate illuminating lights

- Number of LEDs per string - as lighting typically has the most user exposure, having a robust lighting solution is important for a BCM; if lights flicker or cut out this is very noticeable for the user experience. Therefore, this design is compatible for the stop-start requirements of 6V.

  - Accounting for system protection diode voltage drop of 0.7V and device voltage drop, this leaves over 5V to drive each LED string. As white LEDs typically have a voltage drop of 3.4V, the number of LEDs per string is restricted to 1.

Design Considerations

- Device enable – the device enable pin is tied to voltage input, making the device enabled whenever the BCM system is up; control of lighting is important whenever the car is running.

I2C GPIO Expander

TCA9539

TEXAS INSTRUMENTS

Design Considerations

- An I^2C bus is required to provide the maximum number of diagnostics reporting and control from smart devices as possible. As the system features 6 of 7 smart drivers with the majority of communication through GPIO pins, a 40-pin LaunchPad is used in conjunction with a 16-pin I/O expander to accommodate these requirements.

- A singular 16-bit device was chosen over several 4-bit or 8-bit devices to reduce the number of slave devices on the I^2C bus. In the current configuration, a singular master-slave relationship is established to communicate to two devices (DRV8865 and LMD18400) as shown in the below diagram.

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