

Design for reliability - how to get rid of gremlins!

Best design practices for automotive electronics
Hai-Yue Han

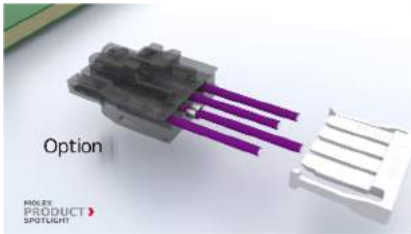
Topics

- Connectors
- Automotive rated parts
- Passives selection
- Over current
- Over voltage
- ESD, surge and input protection
- Decoupling caps
- High side switch
- Watchdogs/Power On Reset
- Touch screen user interface
- Communications
- Electronics architecture for field service
- Board rework
- Wire harnesses
- Test fixtures
- Diagnostic tools

Connectors - terminal position assurance (TPA)

- Terminals will back out of connectors under vibration
- Use connectors with TPA to make sure terminals don't back out
- Favorite line: Molex Nanofit, Microfit, Minifit with TPA

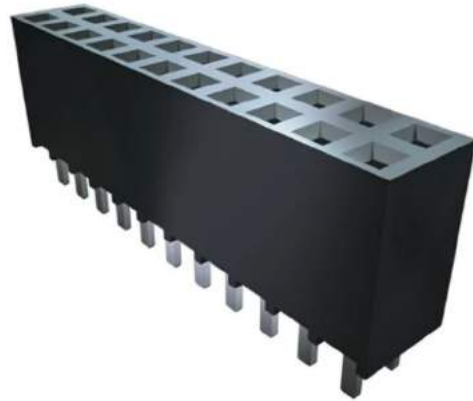
Good!



Bad!!



Connectors - things to avoid



High current connectors

- Anderson PowerPole connectors work well for vehicle applications
- Used in race cars, solar cars, and other custom vehicles
- They are not waterproof, but are robust
- Always recommended stranded wire gauge
- For very high current connections use solder and a blow torch to attach wire to terminal



30A Connectors



350A Connectors

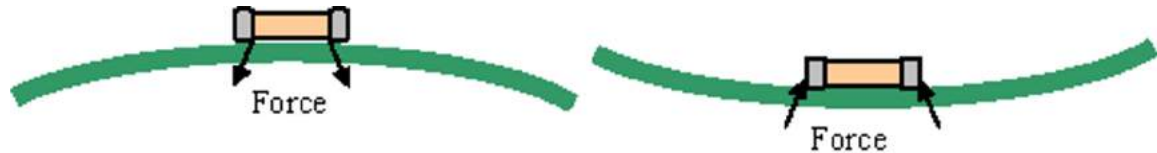
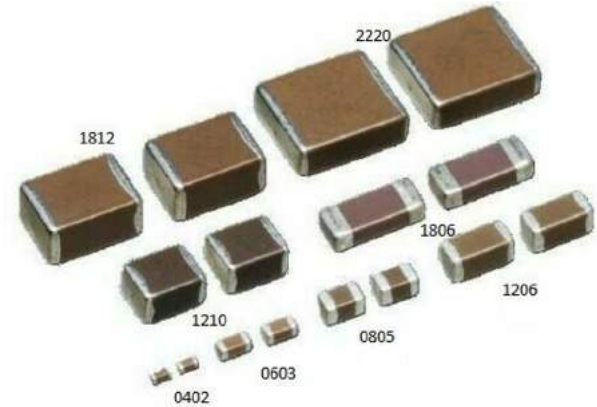
AEC-Q

- Parts that are rated “[AEC-Q](#)” are designed, rated and produced with automotive applications
- High temp range, high vibration rated, high reliability
- Choose AEC-Q for **relays**, semiconductors, passives, connectors whenever possible; only choose non AEC-Q when you have no other option
 - Relays need to be rated for road vibe; critical to get AEC-Q
- One of the most vulnerable component in car and most overlooked: decoupling capacitors

The screenshot shows the Digi-Key Electronics website interface. At the top, the Digi-Key logo is visible on the left, and a search bar contains the text "All Products" with a dropdown arrow. Below the logo, navigation links for "Products", "Manufacturers", "Resources", and "Tools" are displayed. The breadcrumb trail indicates the current location: "Product Index > Discrete Semiconductor Products > Diodes - Rectifiers - Arrays". The main heading is "Diodes - Rectifiers - Arrays", and the results count is "Results: 12,950 1,443 Remaining". A search bar labeled "Search Within Results" is present. Below this, two filter panels are shown: "Manufacturer" and "Series". The "Manufacturer" list includes Bourns Inc., Central Semiconductor Corp., Cornchip Technology, Cree/WolfSpeed, Diodes Incorporated, Diotec, Diotec Semiconductor, Fairchild Semiconductor, GeneSiC Semiconductor, and Harris Corporation. The "Series" list includes Amp+™, Automotive, Automotive, AEC-Q100, Automotive, AEC-Q101, Automotive, AEC-Q101, ECOPACK@2, Automotive, AEC-Q101, eSMP®, Automotive, AEC-Q101, eSMP®, TMBS®, Automotive, AEC-Q101, FRED Pt®, Automotive, AEC-Q101, SBR®, and Automotive, AEC-Q101, SWITCHMODE™. A "Clear" link is located below the Series list. Below the filters, there is a "View Prices At:" section with an "Enter Quantity" input field. At the bottom, there are four sections of checkboxes: "Stocking Options" (In Stock, Normally Stocking, New Product), "Media" (Datasheet, Photo, EDA/CAD Models), "Environmental Options" (RoHS Compliant, Non-RoHS Compliant), and "Marketplace Product" (Exclude). At the very bottom, there are buttons for "Clear Selections", "Apply All", and a remaining count of "1,443 Remaining".

Passives selection (too big = crack)

- Large passives will crack under vibration
- Rule of thumb: do not exceed 1206 surface mount package without FEA (e.g. ANSYS Sherlock)
- If you need more capacitance or heat dissipation from resistors, split up into multiple components in series/parallel



Overcurrent protection - fuse types

- Know what you are protecting against; most overcurrent events comes from damaged harnesses
- Thermal fuse
 - Pros: cheap
 - Cons: large trip range based on temperatures
- PTC resettable fuse
 - Pros: cheap, resettable
 - Cons: large trip range based on temperatures (including board geometry)
- E-fuse
 - Pros: Precise trip point, resettable, some have current monitoring
 - Cons: slightly expensive, but very much worth it



TPS25982  ACTIVE

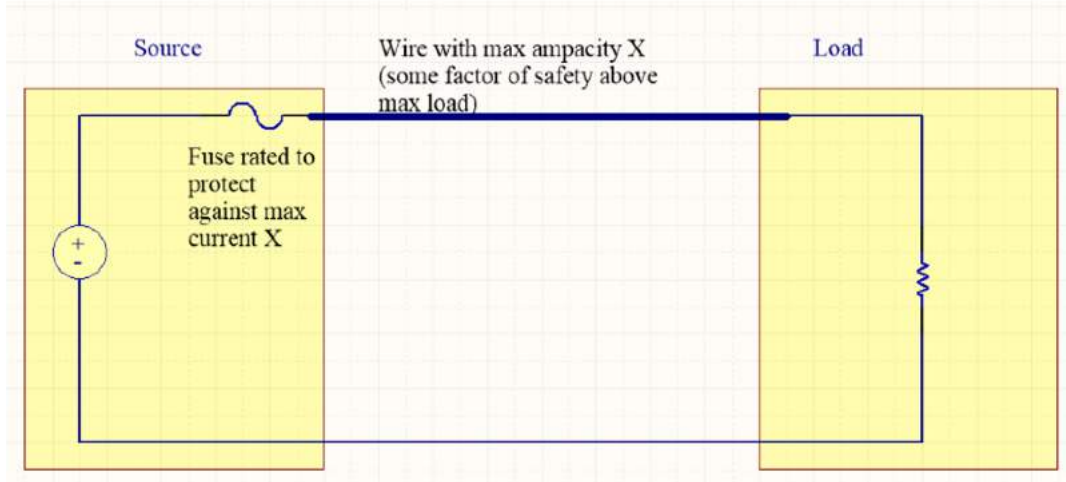
 [Download data sheet](#)

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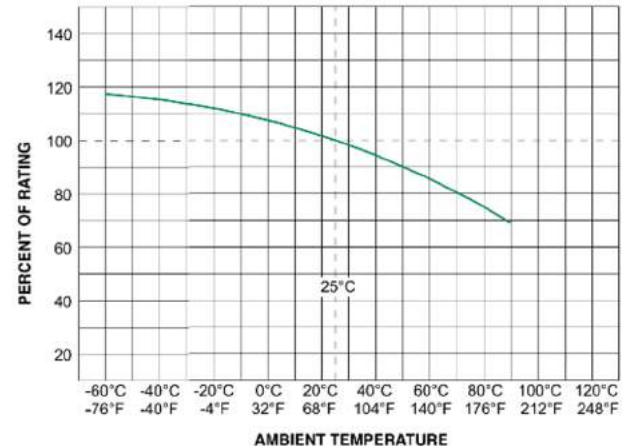
 [Ordering & quality](#)

Over current protection - fuse locations and rating

- Fuse at the source of current (otherwise fuse does no good)
- Beware of derating curve (especially on the high side)



Temperature Re-rating Curve



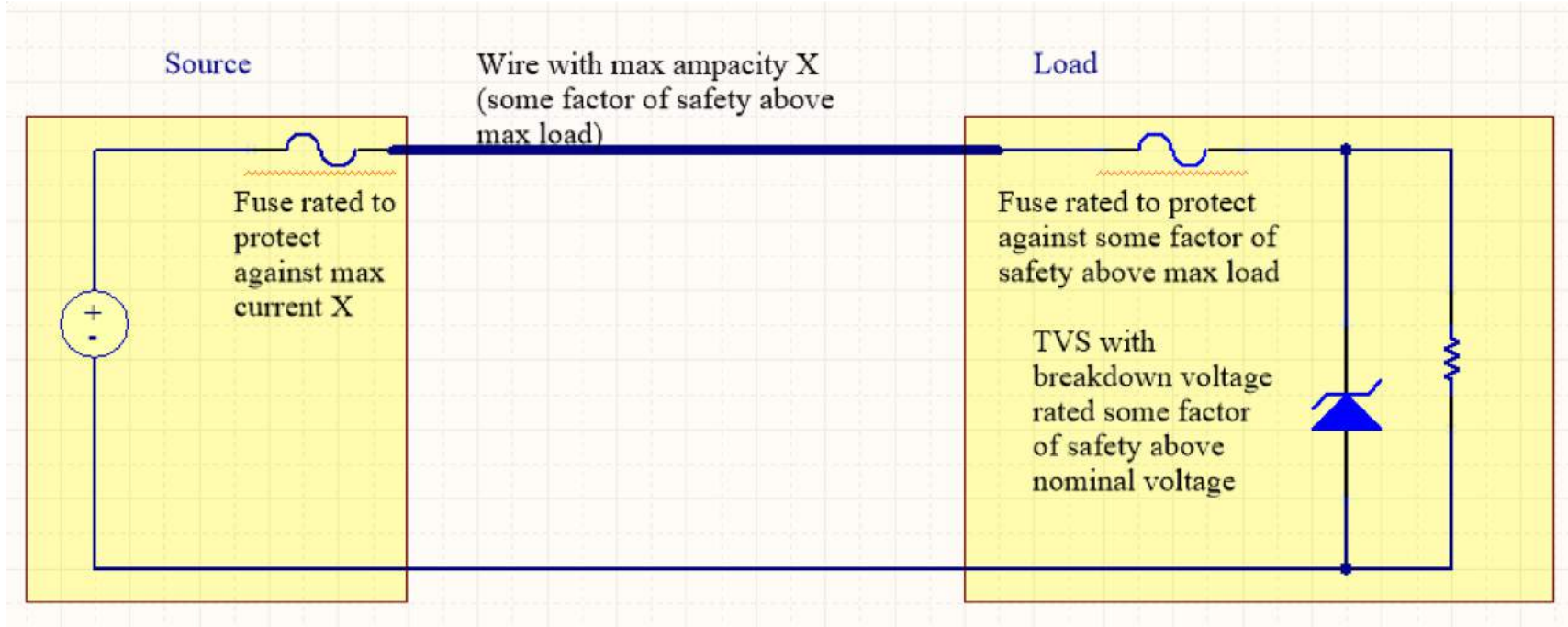
Over voltage protection - types of devices

- Over voltage protection actually over current device in parallel with something that makes a short circuit when a high voltage is applied to it
- TVS
 - Open circuit below breakdown voltage
 - Closed circuit above breakdown voltage
 - Useful for low voltage protection
- MOV
 - Open circuit below breakdown voltage
 - Closed circuit above breakdown voltage
 - Useful for high voltage protection (less precision on trip point)
 - Self sacrificial (has energy rating)



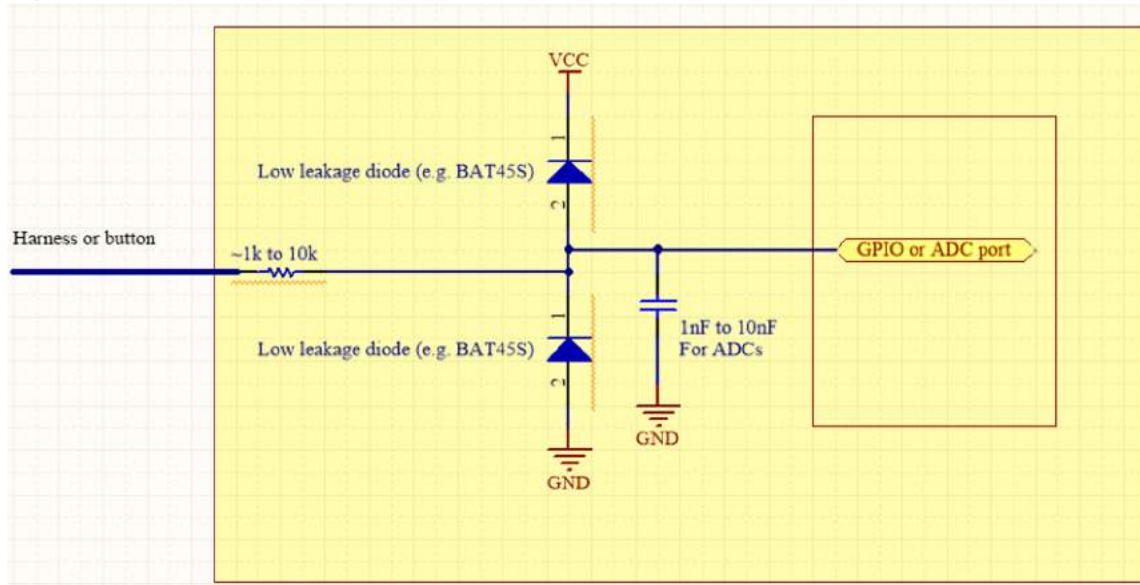
Over voltage protection - typical circuit

- Electricity flows the path of least resistance - load is protected by TVS/MOV



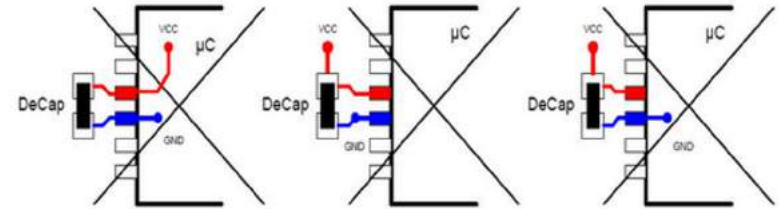
Input protection (surge, ESD, over voltage)

- Use clamp diodes to shunt excess energy to VCC or ground
- Current limiting resistor in series to prevent diode and power rails from overloading



Decoupling caps - location is crucial

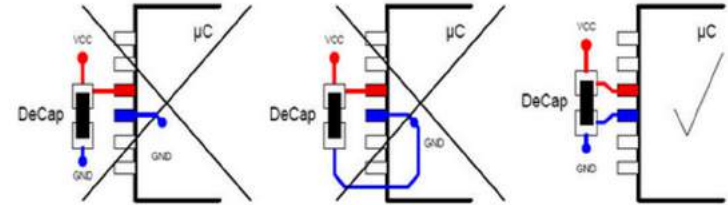
- Capacitor is variable resistor with respect to frequency; higher the frequency, the lower the resistance
- Electricity flows path of least resistance; want capacitor to be able to dissipate high frequency noise
- **Ensure** to add decoupling caps to **reset** line on uC - noise, ESD, etc can reset uC when do you don't want it
- Make sure caps are rated for applied voltage with at least 25% margin (12V nominal must have 16V rated caps)



a) VCC and GND lead to supply noise current flows not via DeCap, DeCap has not effect

b) GND lead noise to system GND noise current flows partly via DeCap, DeCap has hardly effect

c) GND lead noise to System GND noise current flows partly via DeCap, DeCap has hardly effect



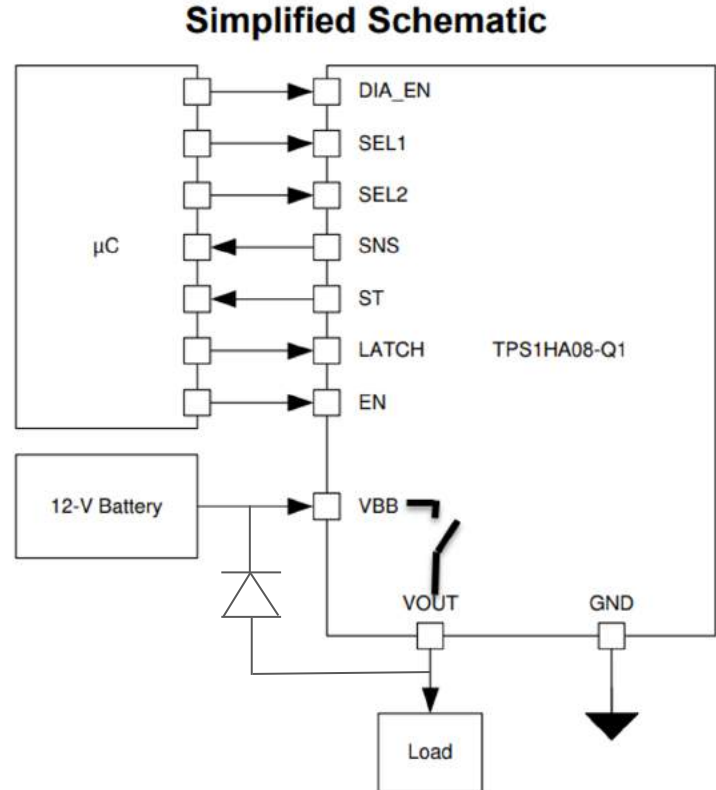
d) VCC and GND lead to supply noise current flows not via DeCap, DeCap has not effect

e) GND is not short connected to DeCap, between GND and DeCap flows a loop current DeCap has hardly effect

f) DeCap correct connected to μC and power supply. high speed current will be supported from DeCap

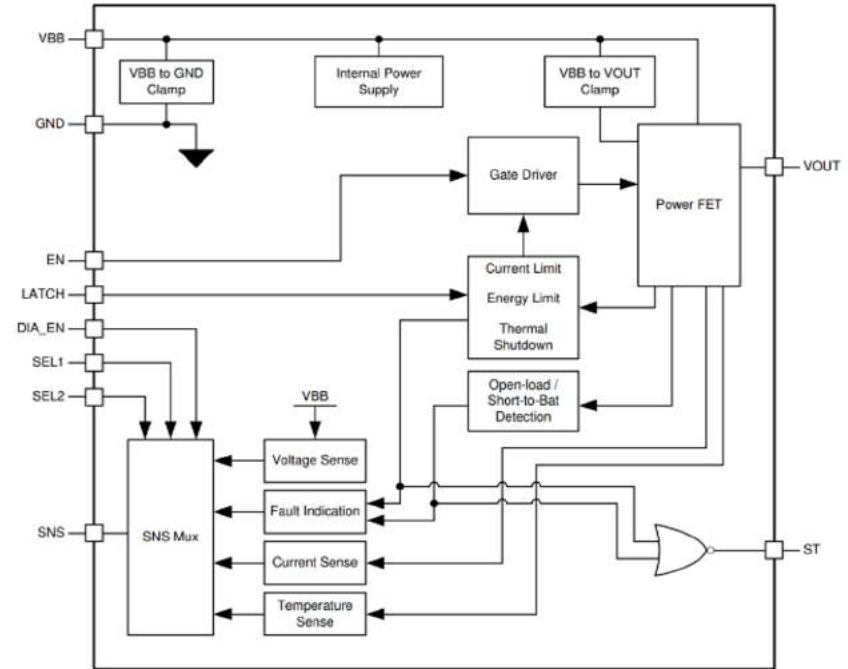
High side switch - much better than a MOSFET

- Current limited, high side on/off switch with current sense feedback
- Used heavily in modern electric cars
- Still need recirculating diode between Vout and GND if driving inductive load (e.g. horns, motors, fans, etc)



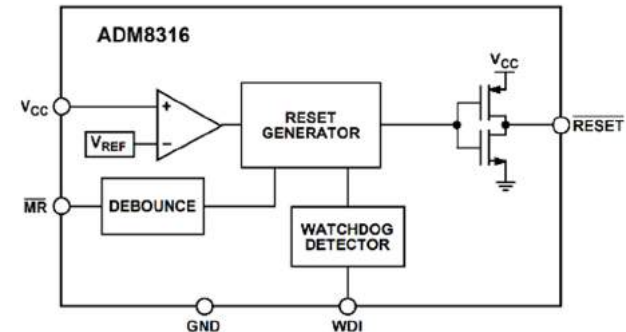
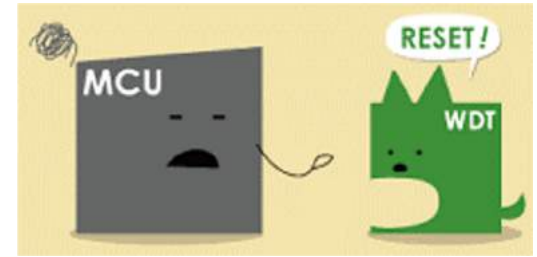
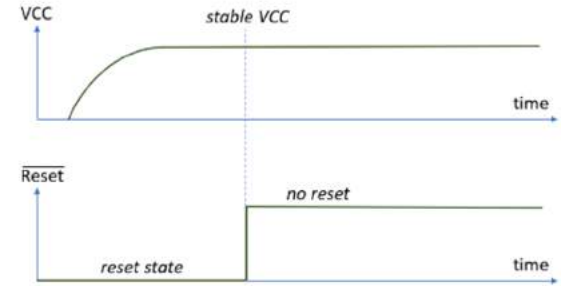
High side switch - much better than a MOSFET

- Current sense feedback:
 - Provide “anti-jam” feature for motors being controlled by uC (higher motor current = higher torque; uC can be programmed to cut off EN switch at certain current)
 - Useful for diagnostics (e.g. higher currents over time can mean part wearing out)
- Also has voltage sense and temp feedback
- Just so much better than a FET



Watch dogs/power on reset

- Microcontrollers need to be reset after power on because registers can be in a weird state due to ramping supply voltage
- Microcontroller also need to be reset if they're frozen; watchdog timer hits the reset button if it's not regularly "pet" by code
- There are combo circuits that perform both functions - ADM8316 is a good example
- Be careful about watchdog behavior in safety critical applications such as BMS and motor controllers; a reset can cause loss of power or mechanical damage of motor and vehicle when inverter is reset (e.g. uncontrolled regen)



Touch screen user interface simplifies cockpit hardware

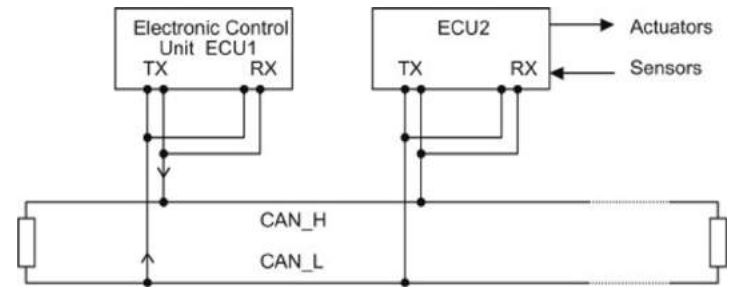
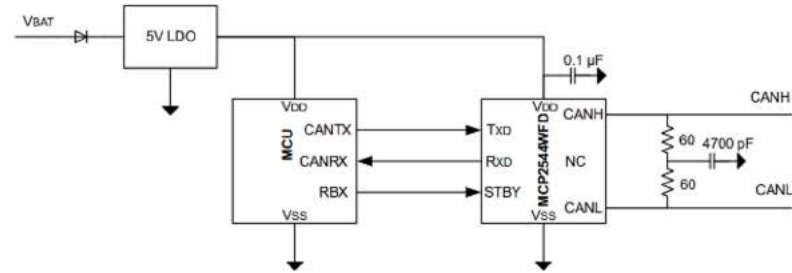
- Use a tablet or single board computer for cockpit display, rear view camera and control
- Fewer switches, harnesses connectors to break
- Allows for user interface redesign without electronics hardware work



Communications - CAN network

- Two wire differential , 120 ohm terminated loop
- Highly robust, tons of debug software
- Compact data transfer
 - AAALDDDDDDDDCRC
 - <Address, length, data, CRC>
 - Example: 4508F1E6BFCA

Variables	Layout	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Byte 0	PitchRate	7	6	5	4	3	2	1	0
Byte 1	PitchRate	15	14	13	12	11	10	9	8
Byte 2	RollRate	23	22	21	20	19	18	17	16
Byte 3	RollRate	31	30	29	28	27	26	25	24
Byte 4	YawRate	39	38	37	36	35	34	33	32
Byte 5	YawRate	47	46	45	44	43	42	41	40
Byte 6		55	54	YawRateFigureOfMerit	RollRateFigureOfMerit	PitchRateFigureOfMerit			
Byte 7	AngularRateMeasurementLatency								



Communications - PCAN Explorer (or CANapy)



Track Diagnostic - PCAN Explorer

File Connections Edit Transmit View Project Macro Trace Tools Window Help

Macro: WatchForID100

C:_Temp\2016-06-01_11-30-16_515.trc | C:_Engine_Vehicle Speed.pit | Receive / Transmit

Project Manager

- New Add Properties
- Project 'Track Diagnostic'
- Connections
 - FMS Connection
 - CAN FD Connection
 - PCAN-Gateway Connection
- Message Filters
 - FMS Stack
 - Incoming Gateway Data
- Macros
- Active Symbols
 - J1939 Default Database
- Signal:
 - 2WheelSteerActuatorState
 - 4WheelSteerActuatorState
 - AboveNominalLevelFrontAxle
 - AboveNominalLevelRearAxle

Project Files | Project Items

Properties

ReceiveMessage ReceiveMessage Properties

CAN

CAN-ID: 418882348
CAN-ID (hex): 1F000400
Data Length: 8
DLC: 8
IsExtended: Yes
LRTR: No
Bus: 1

Names Value Meter

EngineSpeed 1536.3 rpm
WheelSpeedFrontSpeed 71.0 km/h
TailhookupWheelSpeed 71.0 km/h

Watch Watch1 Watch2 Watch3 Watch4

Time (rel.) Bus ID (hex) / Symbol Rv/Tx Type

Time (rel.)	Bus	ID (hex) / Symbol	Rv/Tx	Type
59,9657	1	TC01	Rx	Data
59,9044	1	ECC1	Rx	Data
59,9045	1	ECC1	Rx	Data
59,9055	1	CCV3	Rx	Data
59,9058	1	ECC2	Rx	Data
59,9361	1	TC01	Rx	Data
59,9456	1	ECC1	Rx	Data
59,9647	1	ECC1	Rx	Data
59,9837	1	ECC2	Rx	Data
59,9840	1	TC01	Rx	Data
59,9843	1	ECC1	Rx	Data
59,1037	1	ECC1	Rx	Data
59,1238	1	ECC1	Rx	Data
59,1353	1	CCV3	Rx	Data
59,1356	1	ECC2	Rx	Data
59,1359	1	TC01	Rx	Data
59,1443	1	ECC1	Rx	Data
59,1645	1	ECC1	Rx	Data

Engine Speed

Vehicle Speed

Time

Receive / Transmit

Filter: None

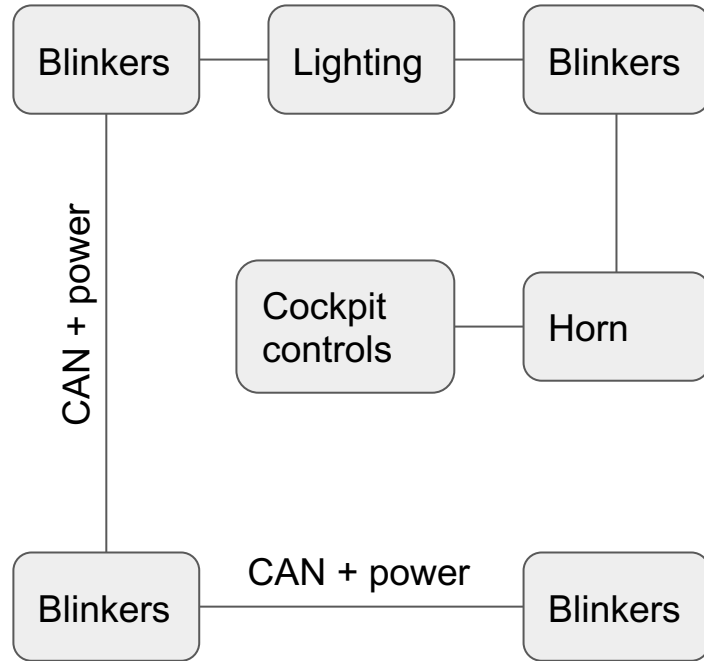
Bus	CAN-ID (hex)	PGN	Len	Symbol	Data	Timing Errors	Cycle Time	Count
1	1F000400	61404	8	ECC1	EngineTorqueMode = 0 ActualEnginePercentTorqueFract = -0.0002% DriverDemandEnginePercentTorque = -125 % ActualEnginePercentTorque = -125 % EngineSpeed = 1536.3 rpm SteerAckChillingDevForEngCyl = 0 EngineStarterMode = start not requested EngineDemandPercentTorque = -125 %		200	60070
1	18F6C00	6513e	8	TC01	DriverWorkingState = Work		482	32782

Connections

Bus	Name	Protocol	Connection	Bit Rate	Status	Overruns	ClErrFulls	Bus Load
1	FMS Connection	J1939	BlackBox1 - 500@pcan_usb	500 kBit/s	OK	0	0	3.1%
2	CAN FD Connection	CAN	CAN FD B - 500@12M@pcan_usb	Nominal 500 kBit/s...				0.0%
3	PCAN-Gateway Connection	CAN	WhiteLAN1 - 500@pcan_lan	500 kBit/s				0.0%

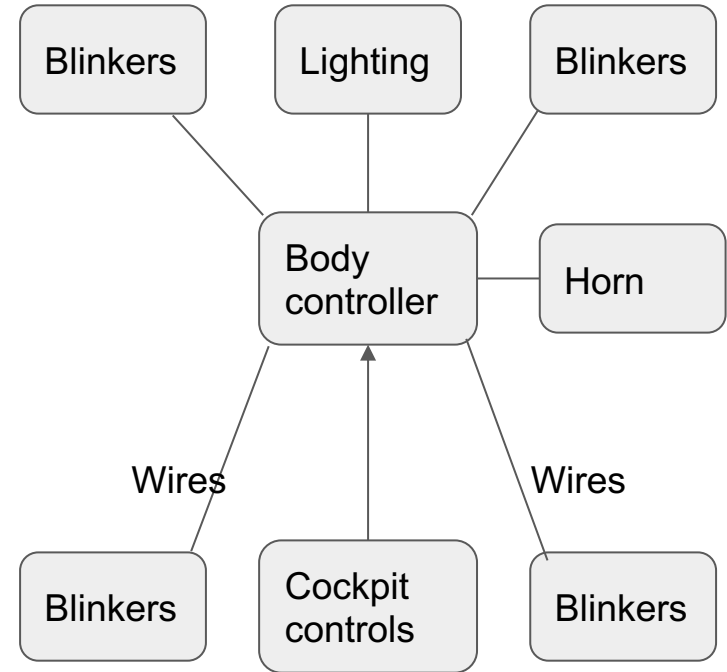
Electronics architecture for field service

First and second gen Tesla Model S/X



- Generalized microcontroller + switch modules
- Easy for field service on side of road
- Higher cost

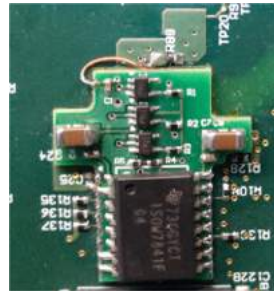
Tesla Model 3/Y and new Model S/X (probably)



- Specialized body controller + wires
- More wiring
- Complex board

Board rework

- Use thin gauge (30 AWG) transformer wire for logic level reworks
- Use UV cure adhesive pen to tack down long wires, components floating on board, etc.
- Can use quick turn PCBs to perform complex patches (definitely solder/glue patch board to main board)



Wire harnesses

- Splice using [solder heat shrink butt connectors](#)
- Use [automotive electrical tape](#) (high temp)
- Do not leave harness any freedom to rattle; this will eventually wear out the harness insulation and cause a short circuit



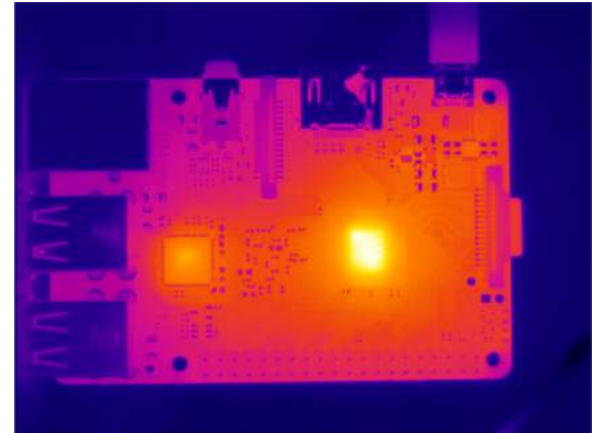
Fixtures for electronics testing

- Make fixture with correct harness lengths for all electronics boards on test bench
- Allows electronics team to be unblocked if car isn't done
- Can test all electronics of the car on bench, then transfer known working electronics hardware, harness and firmware to car



Diagnostics tools - for when things fail anyways

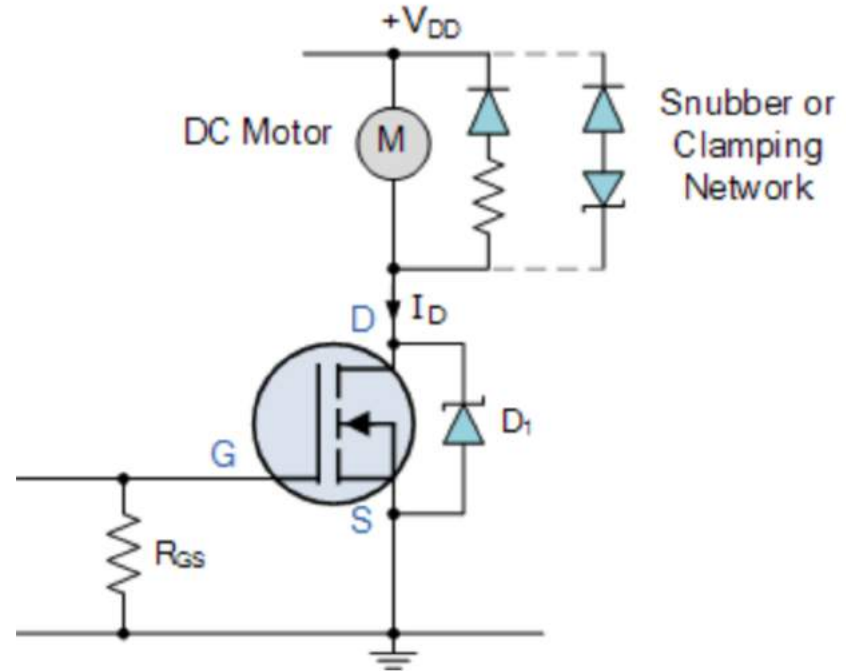
- [ShortSniffer](#)
 - Electricity flows path of least resistance
 - Shortsniffer injects audible signal onto circuit and has inductive wand to pick up where the signal goes
 - Useful for finding shorts in: harnesses, board components, ECUs, and anything else
- [FLIR infrared camera](#)
 - Finds short circuits on boards
 - Finds solar cell hot spots
 - Identify loose connectors (high series resistance on high current wires)



Appendix

MOSFETs as a switch

- MOSFETs can act as electronic “on/off” switch
- N-FET:
 - When voltage between gate and source is above threshold: very low resistance between drain and source
 - Between 0V and threshold: variable resistor
 - Zero volts: very high resistance between drain and source
- Use N-FET to connect the load’s negative terminal to ground



MOSFETs as a switch

- Important parameters:
 - Drain to source breakdown voltage
 - Higher than this voltage and MOSFET can short
 - Drain to source on resistance:
 - R_{DSON} : resistance of FET when it's on
 - Gate threshold voltage:
 - $V_{GS(TH)}$: the voltage in which MOSFET mostly **stops being a variable resistor**
 - Max threshold: the max voltage MOSFET **could still be a variable resistor**
 - Check R_{DSON} for values; typical gate voltages are listed there. Look for logic level FETs for easy of implementation (FETs designed to be activated with 3.3V or 5V)

	Parameter	Min.	Typ.	Max.	Units	Conditions
$V_{(BR)DSS}$	Drain-to-Source Breakdown Voltage	55	—	—	V	$V_{GS} = 0V, I_D = 250\mu A$
$\Delta V_{(BR)DSS}/\Delta T_J$	Breakdown Voltage Temp. Coefficient	—	0.056	—	V/°C	Reference to 25°C, $I_D = 1mA$
$R_{DS(on)}$	Static Drain-to-Source On-Resistance	—	—	0.14	Ω	$V_{GS} = 10V, I_D = 6.0A$ ④
		—	—	0.21		$V_{GS} = 4.5V, I_D = 5.0A$ ④
$V_{GS(th)}$	Gate Threshold Voltage	1.0	—	3.0	V	$V_{DS} = V_{GS}, I_D = 250\mu A$

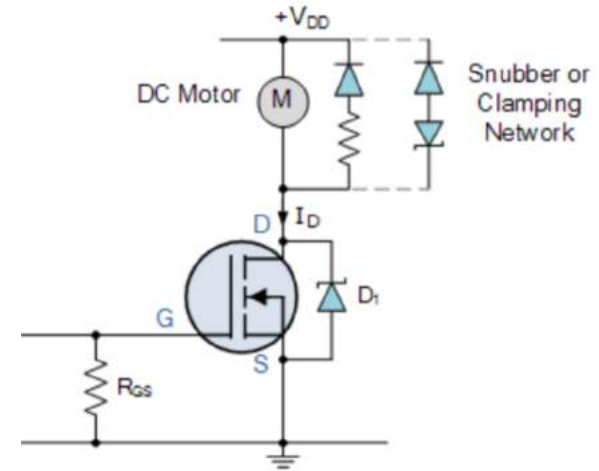


D-Pak
AU1RLR014N

More info [here](#)

MOSFETs as a switch - gotchas

- Need gate resistor (usually pull down)
 - No gate resistor = variable gate voltage if not driven
- Heat sink
 - Need to be soldered down to board with vias or attached to heat sink typically (or else FET could over heat)
- FET will conduct from source to drain as a diode!
- Add recirculating diode and snubber on load being controlled (especially bad for inductive loads)



Isolation

- Used for safety as well as ground loop isolation
- Usually used in between high voltage ground (BMS) and low voltage ground microcontrollers
- Power supply must also be separate or have isolated power supply - SN6501 in conjunction with isolation transformer is a good solution

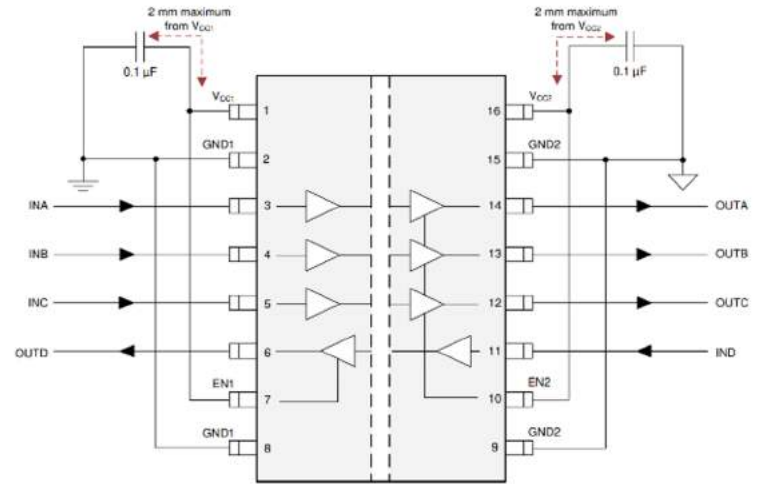


Figure 9-2. Typical ISO674x-Q1 Circuit Hook-up

