Design for reliability - how to get rid of gremlins!

Best design practices for automotive electronics

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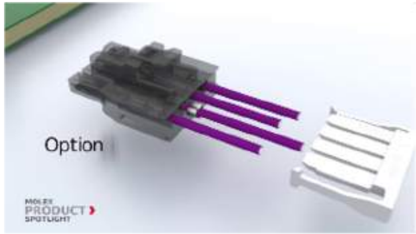
Topics

- 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)

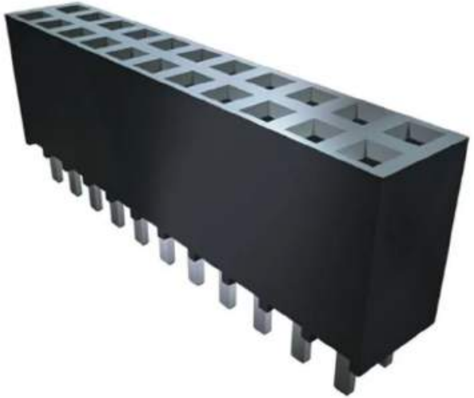
- Terminals will back out of connectors under vibration
- Use connectors with TPA to make sure terminals don’t back out
- Favorite line: Molex Nanofit, Microfit, Minifit with TPA

Good!



Bad!!

Connectors - things to avoid



High current connectors

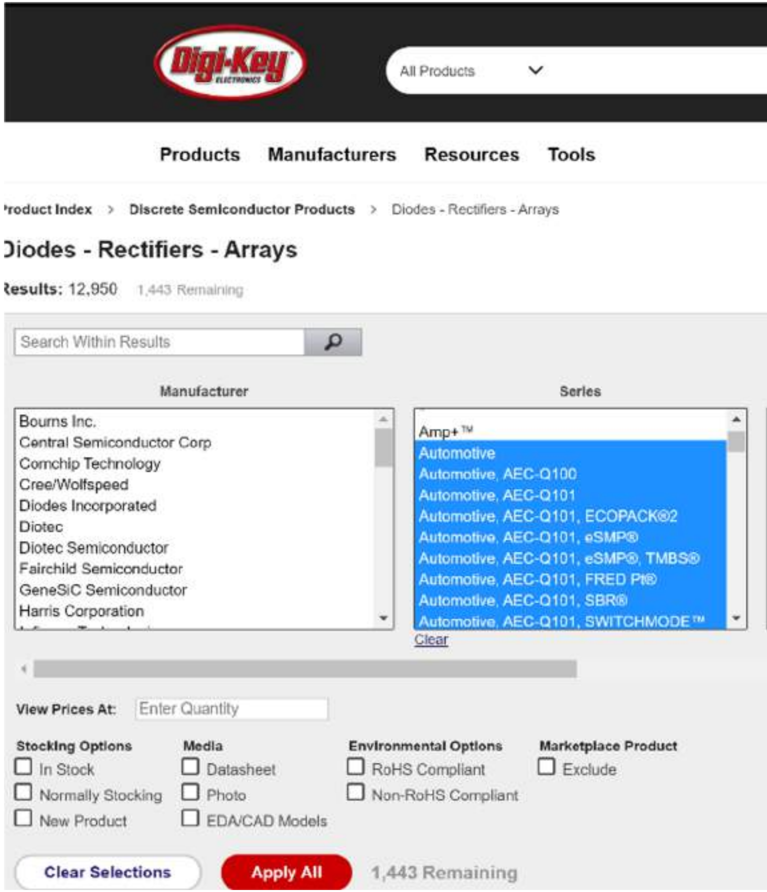
- Anderson PowerPole connectors work well for vehicle applications
- Used in race cars, solar cars, and other custom vehicles
- They are not waterproof, but are robust
- Always recommended stranded wire gauge
- For very high current connections use solder and a blow torch to attach wire to terminal

30A Connectors

350A Connectors

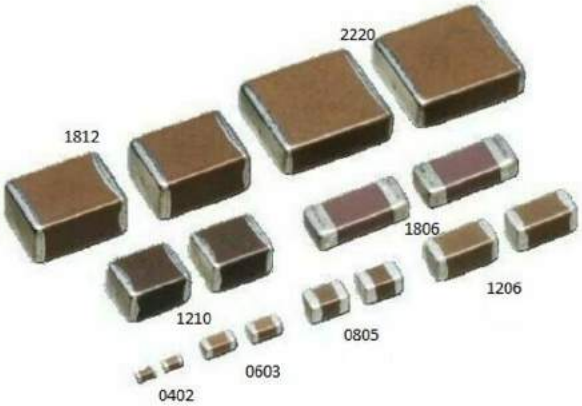
AEC-Q

- 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



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

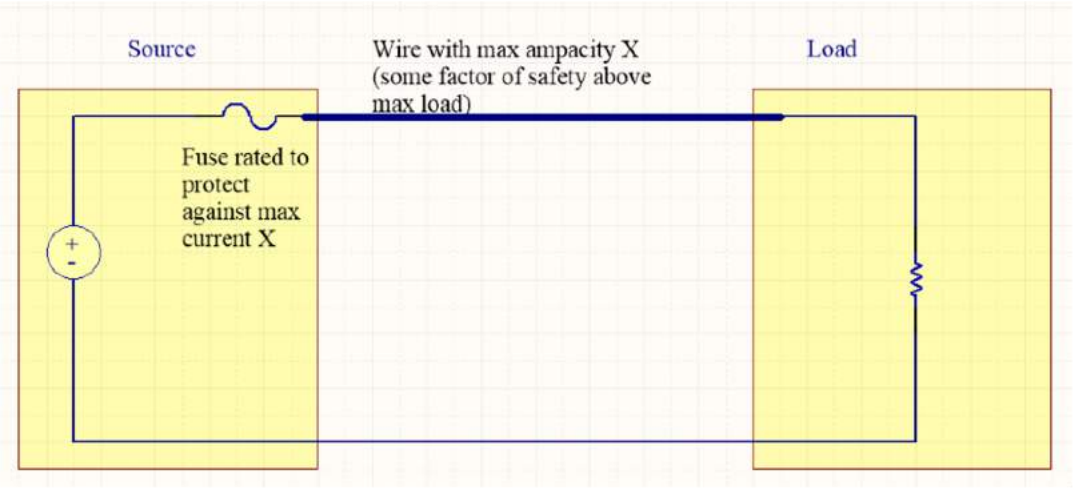


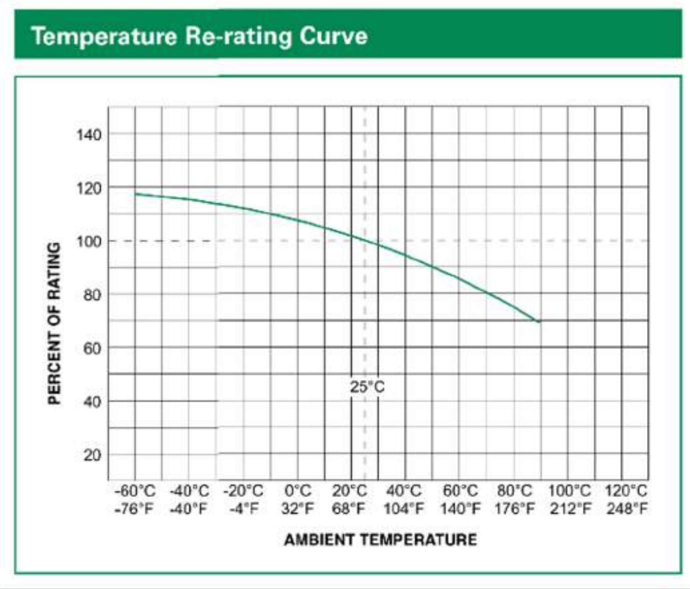
Overcurrent protection - fuse types

- 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

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)



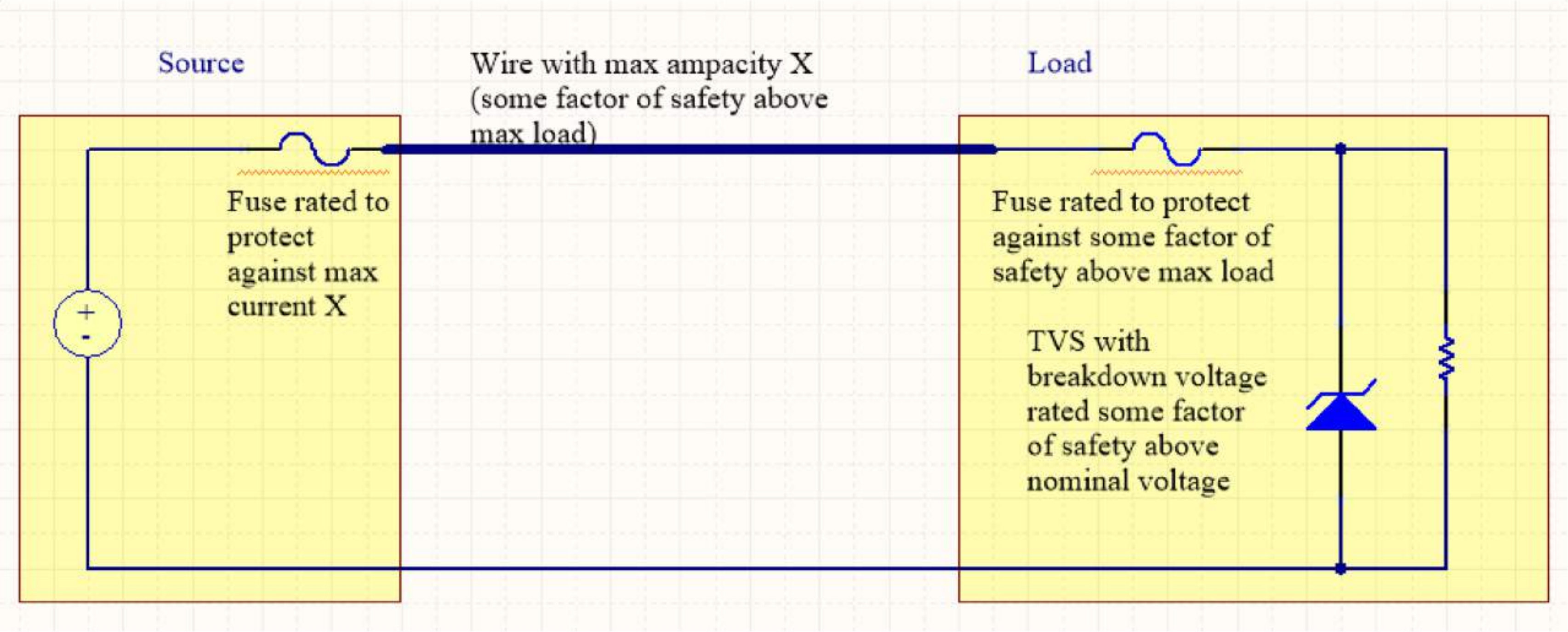


Over voltage protection - types of devices

- 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)

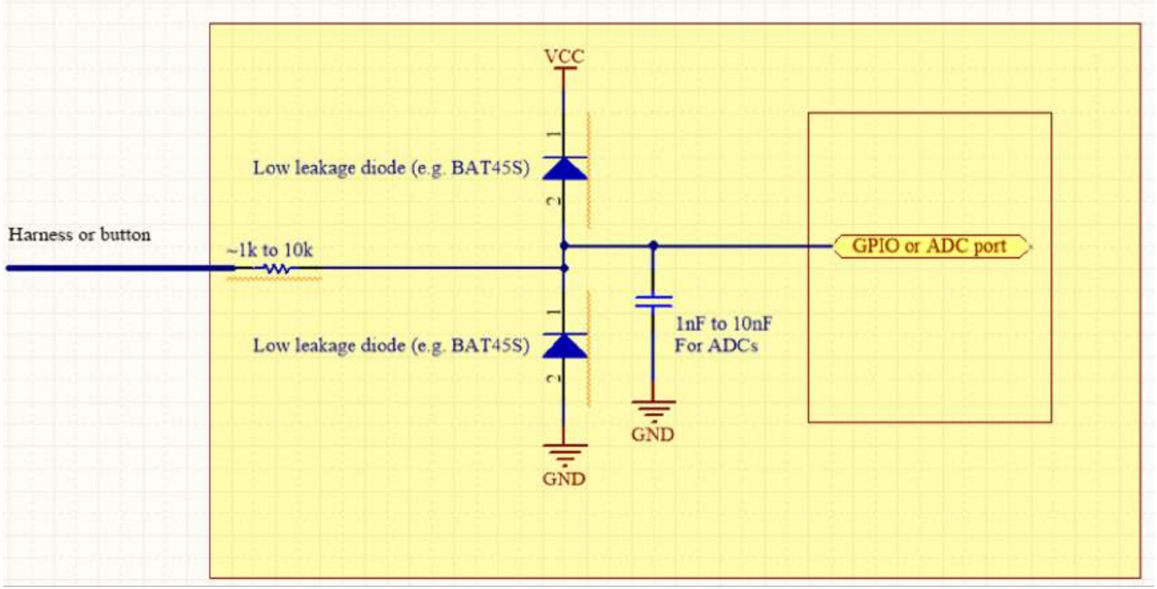
Over voltage protection - typical circuit

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



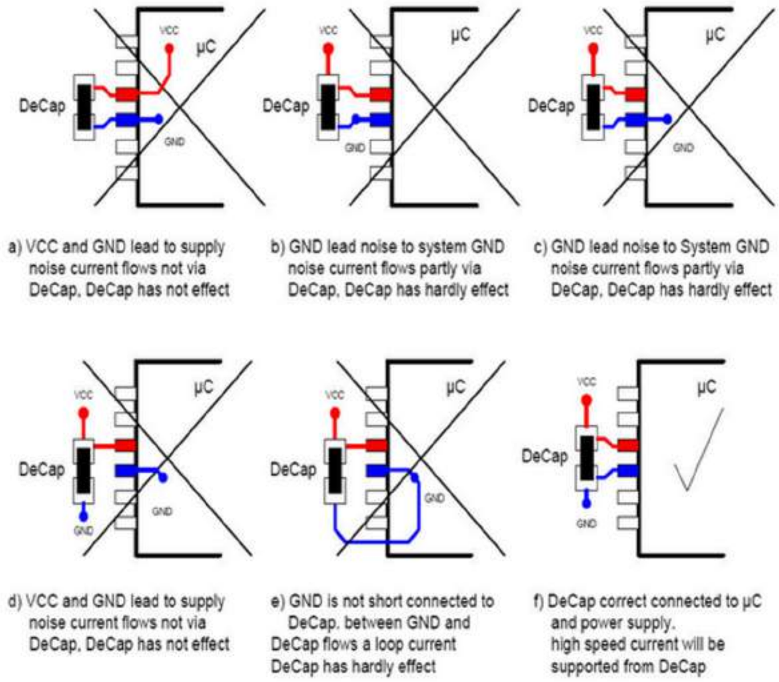
Input protection (surge, ESD, over voltage)

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



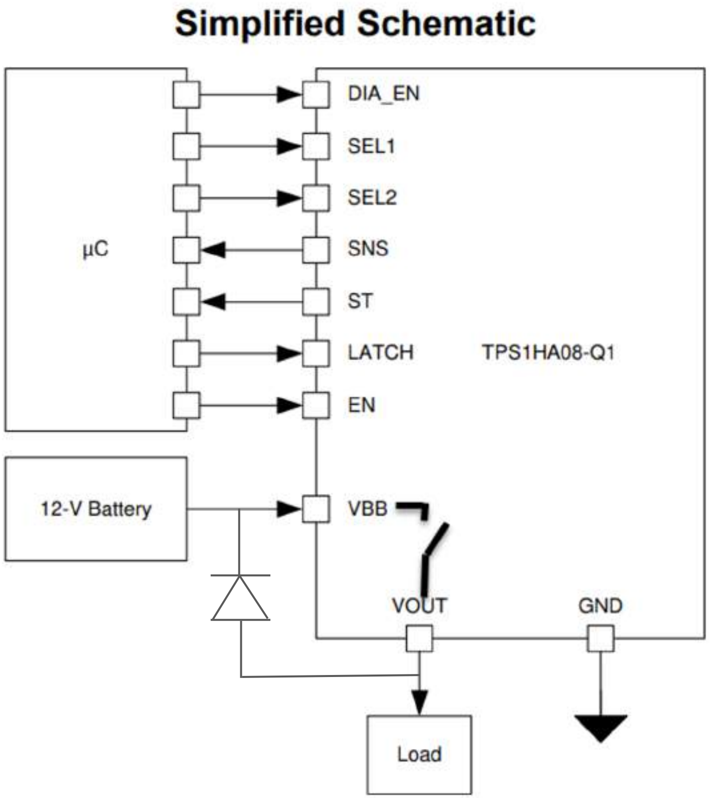
Decoupling caps - location is crucial

- 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)



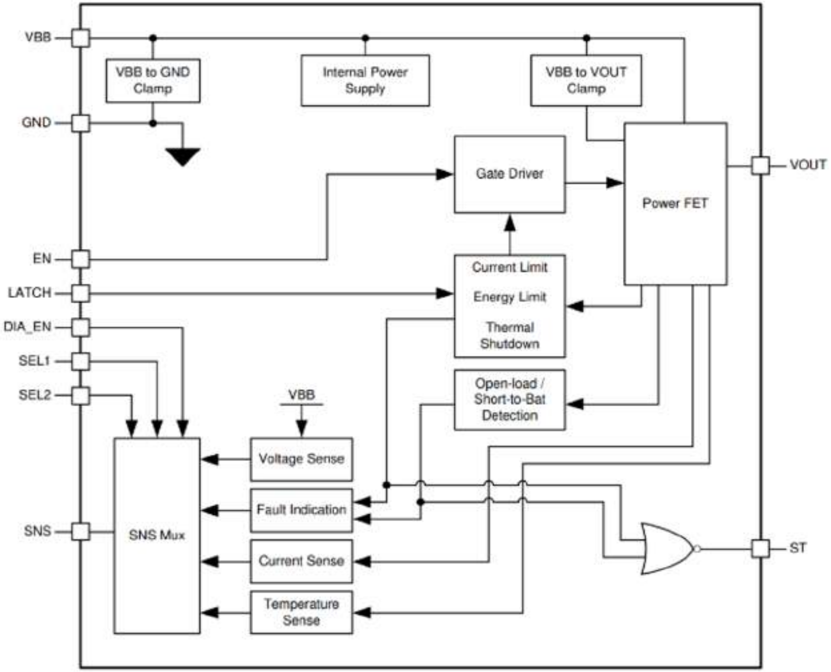
High side switch - much better than a MOSFET

- 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)



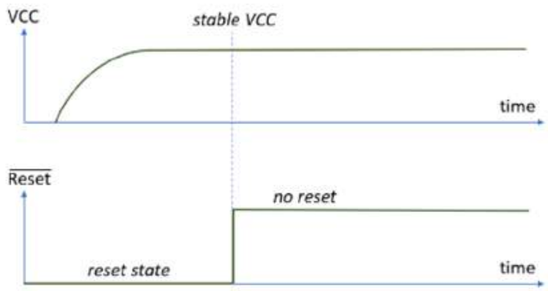
High side switch - much better than a MOSFET

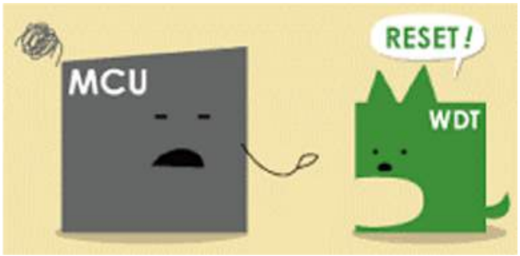
- Current sense feedback:
  - Provide “anti-jam” feature for motors being controlled by uC (higher motor current = higher torque; uC can be programmed to cut off EN switch at certain current)
  - Useful for diagnostics (e.g. higher currents over time can mean part wearing out)
- Also has voltage sense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

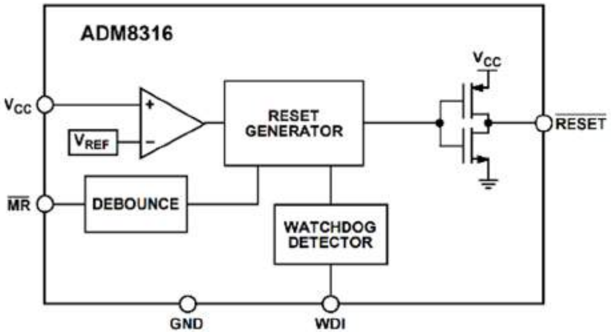


Watch dogs/power on reset

- 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)





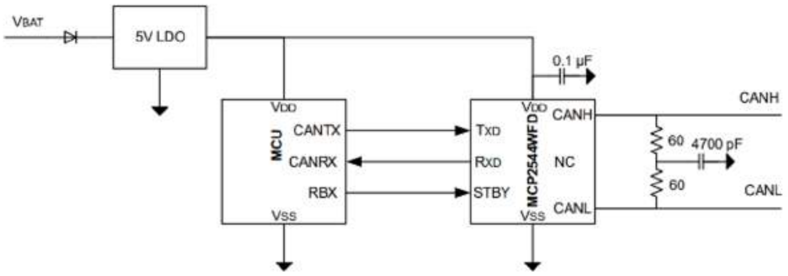


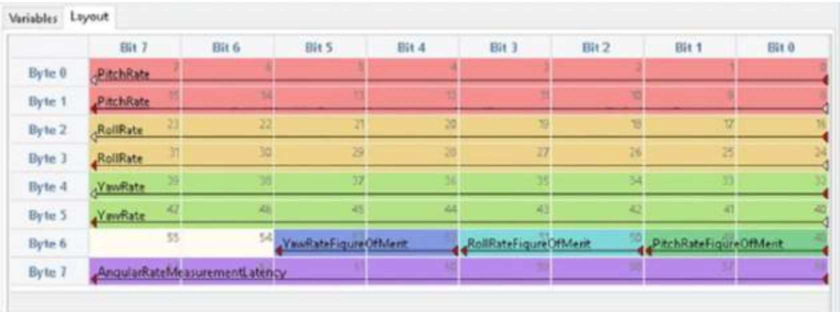
Touch screen user interface simplifies cockpit hardware

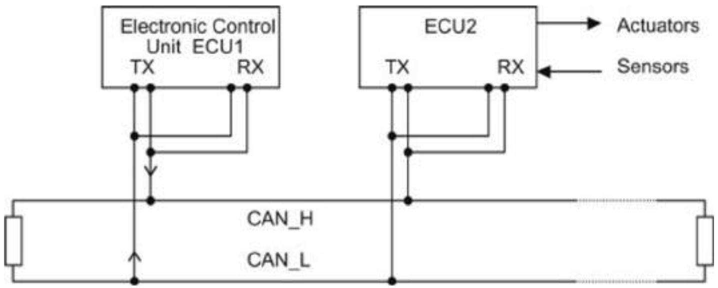
- Use a tablet or single board computer for cockpit display, rear view camera and control
- Fewer switches, harnesses connectors to break
- Allows for user interface redesign without electronics hardware work

Communications - CAN network

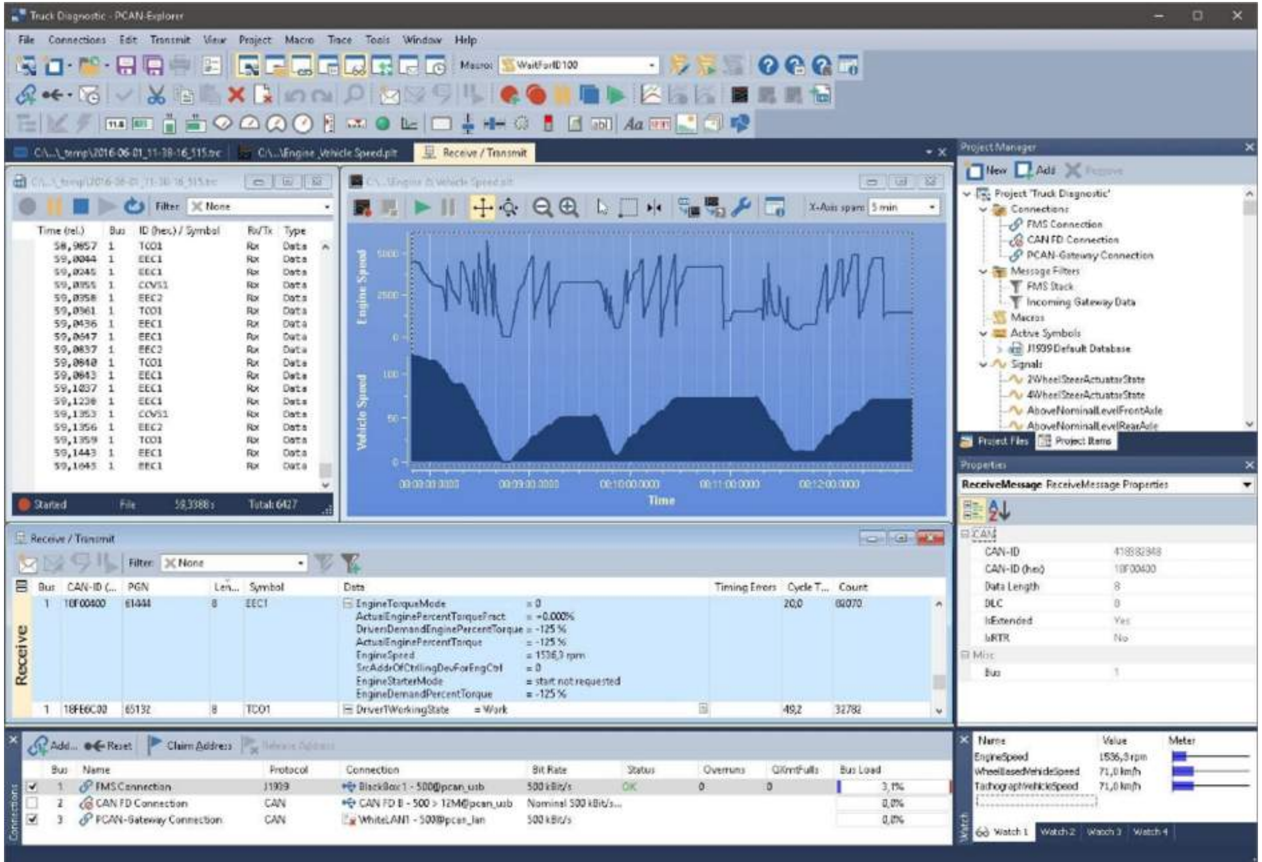
- Two wire differential , 120 ohm terminated loop
- Highly robust, tons of debug software
- Compact data transfer
  - AAALDDDDDDDDCRC
  - <Address, length, data, CRC>
  - Example: 4508F1E6BFCA





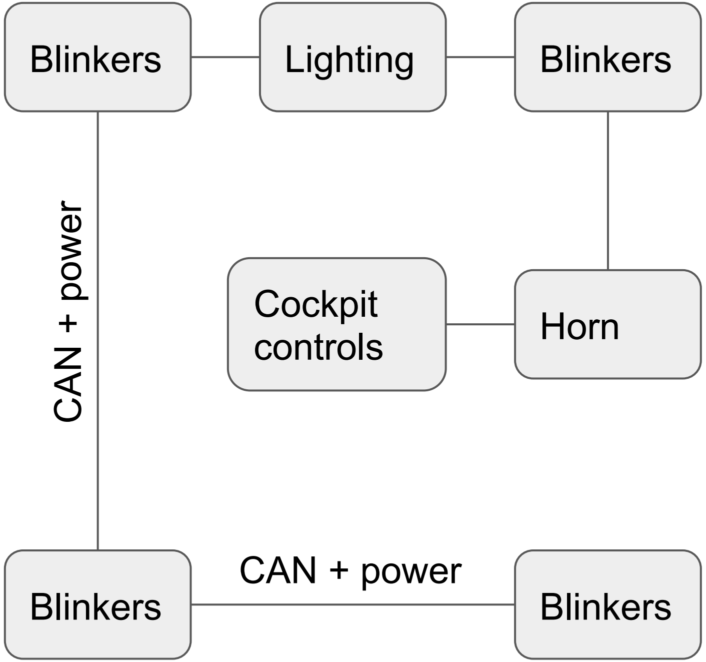


Communications - PCAN Explorer (or CANapy)



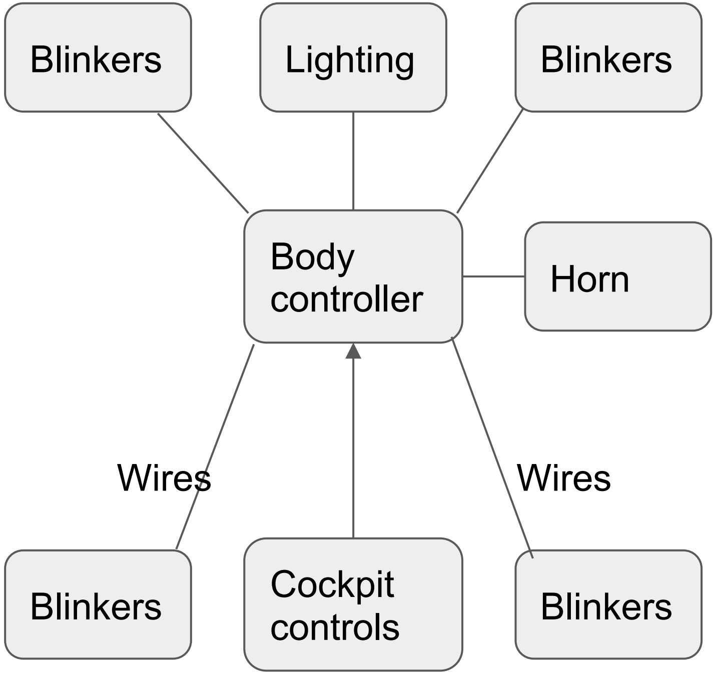
Electronics architecture for field service

First and second gen Tesla Model S/X



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

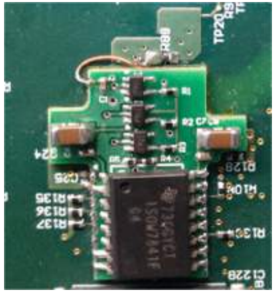
Tesla Model 3/Y and new Model S/X (probably)



- 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)

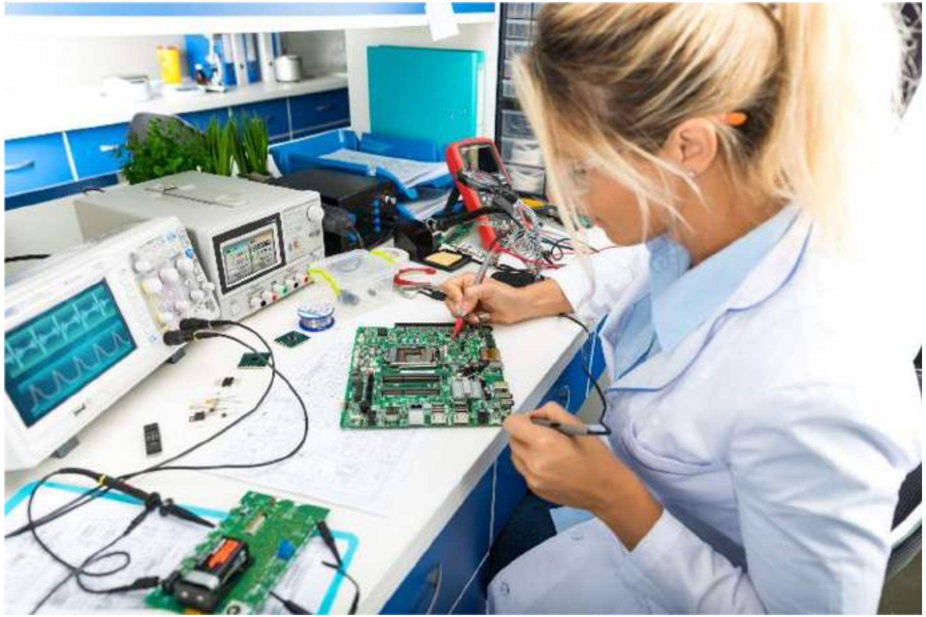


Wire harnesses

- 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

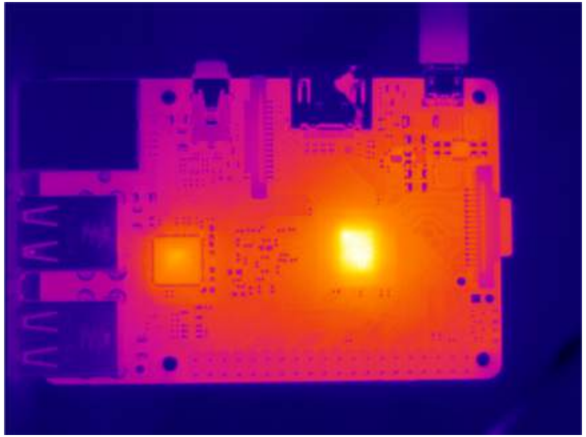
Fixtures for electronics testing

- 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

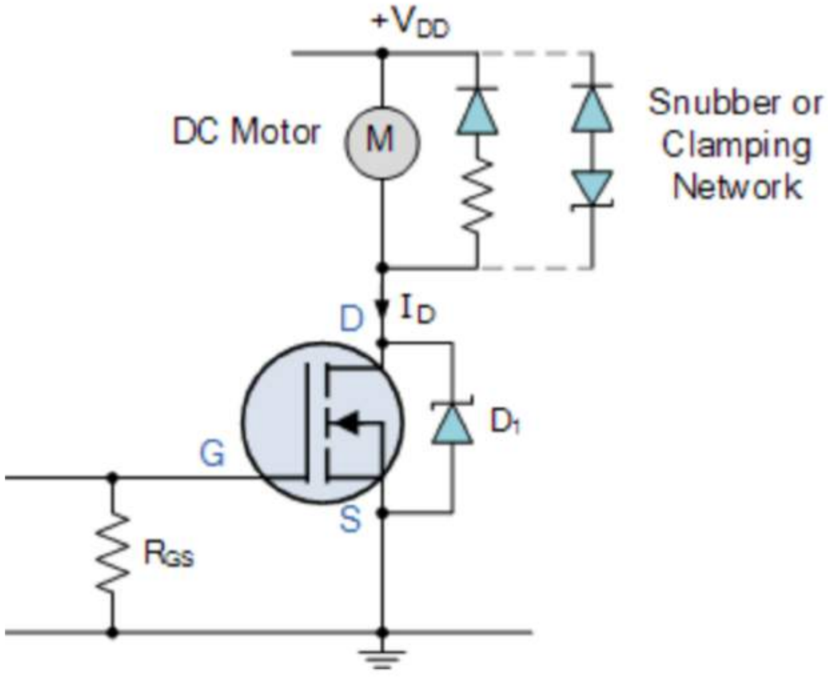
- ShortSniffer
  - Electricity flows path of least resistance
  - Shortsniffer injects audible signal onto circuit and has inductive wand to pick up where the signal goes
  - Useful for finding shorts in: harnesses, board components, ECUs, and anything else
- FLIR infrared camera
  - Finds short circuits 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)

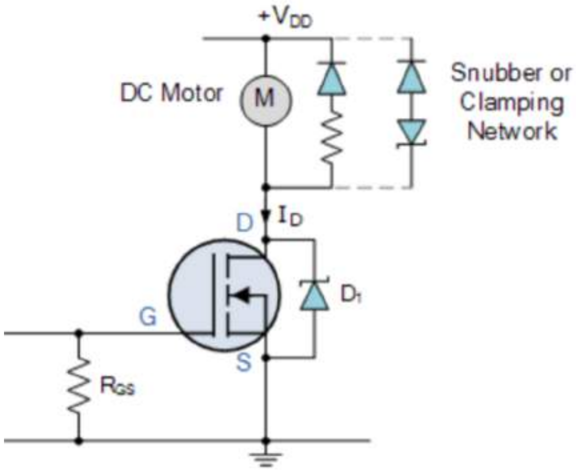
	Parameter	Min.	Typ.	Max.	Units	Conditions
$V_{(BR)DSS}$	Drain-to-Source Breakdown Voltage	55	–––	–––	V	V_{GS} = 0V, I_D = 250μA
$\Delta V_{(BR)DSS}/\Delta T_J$	Breakdown Voltage Temp. Coefficient	–––	0.056	–––	V/°C	Reference to 25°C, I_D = 1mA
$R_{DS(on)}$	Static Drain-to-Source On-Resistance	–––	–––	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 = 250μA

D-Pak
AUIRLR014N

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

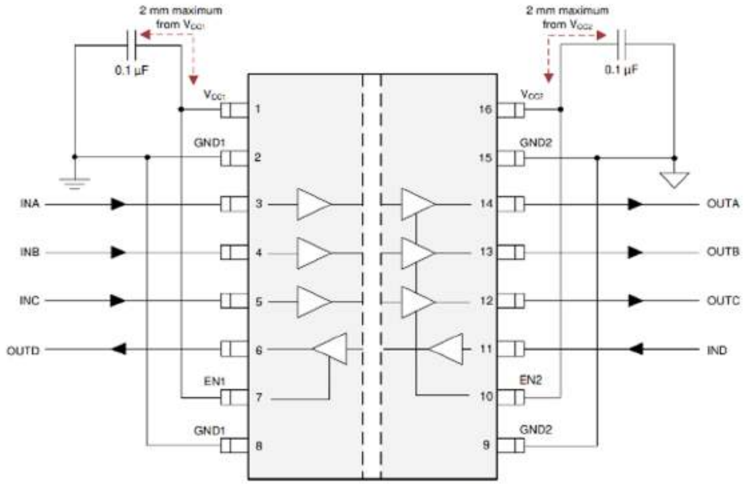


Figure 9-2. Typical ISO674x-Q1 Circuit Hook-up