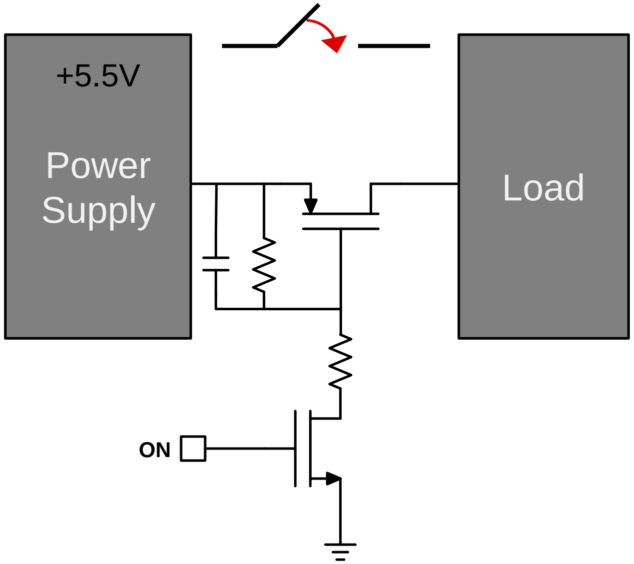
Load Switch Deep Dive

Texas Instruments

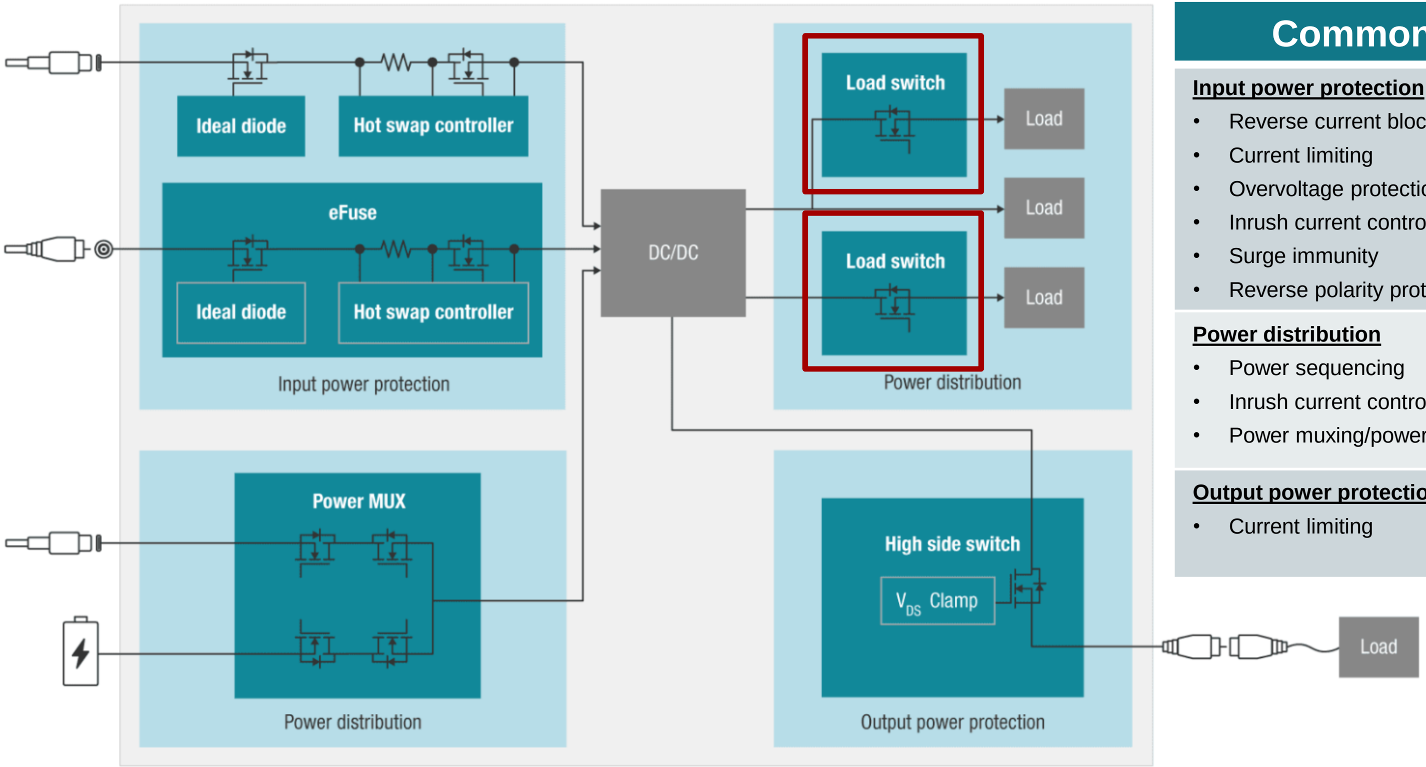
What is a load switch?

A device that turns DC power OFF and ON to a load



The two main functions a **load switch** can provide to a system is **power protection** and **power distribution**

Power switches | use cases



Common design challenges

Input power protection

- Reverse current blocking
- Current limiting
- Overvoltage protection
- Inrush current control
- Surge immunity
- Reverse polarity protection

Power distribution

- Power sequencing
- Inrush current control
- Power muxing/power ORing

Output power protection

- Current limiting

Load switch overview

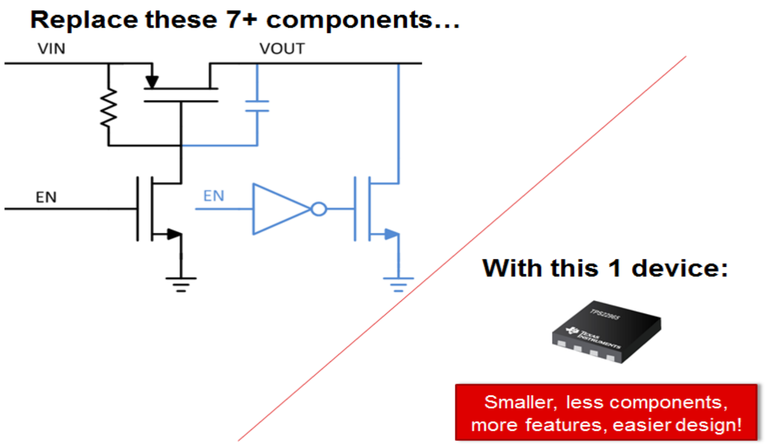
Extend battery life by reducing standby leakage current. Turn off unused subsystems w/load switches: WiFi/BT, LCD, SD Card

Save space and reduce solution size by integrating discrete circuitry into a load switch (2+ FETs w/Resistors & Capacitors)

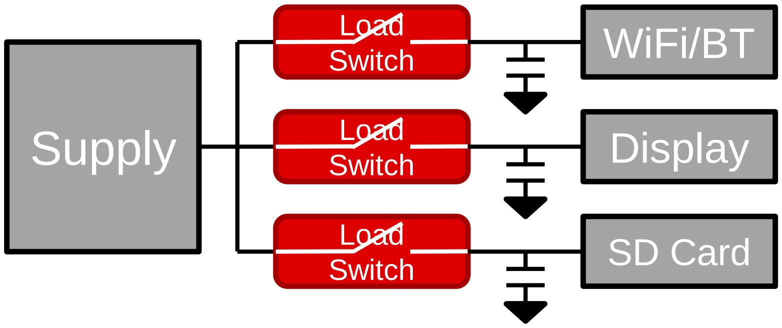
Simplify power sequencing by implementing point of load control with load switches. Power on/off each rail with GPIO

Mitigate inrush current damage to the system with integrated "Soft Start" slew rate /rise time control.

Load switch features	
Slew rate control	Adjust the slew rate of your device to meet your systems timing requirements, and limit inrush current
Power good	Use power good and fault indicators to ensure reliability of your system
Thermal shutdown	Protects the device from permanent damage from overheating by shutting down
Short circuit protection	Prevents hard/soft shorts from damaging the device
Reverse current protection	Prevents current from flowing from the output to the input of the device and damaging it
Current limit	Limits the current through the device
Quick output discharge	Discharges the output of the load switch to ground through some resistance



Reduce BOM count and board layout



Manage power distribution for subsystems

Inrush current control

- Significant output capacitance causes inrush current
- Load switches **reduce inrush current** by controlling output slew rate & increasing T_R

$$I_{INRUSH} = C_{LOAD} \times \frac{dV}{dt}$$

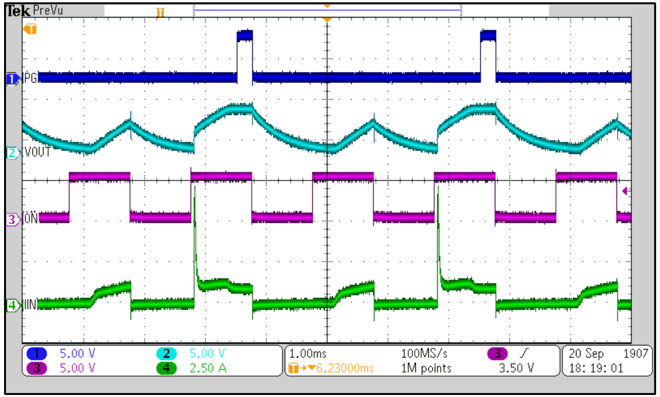
Where

I_{INRUSH} = amount of inrush current caused by a capacitance
C = total capacitance
dV = change in voltage during ramp up
dt = rise time (during voltage ramp up)

- For example: C_{OUT} = 100 μF at 5V you want to limit at a max of 1A

$$T_R = \frac{100\mu F * 5V}{1\ A} = 500\mu S$$

- You will need a T_R of 500 μS to keep the inrush current to 1A

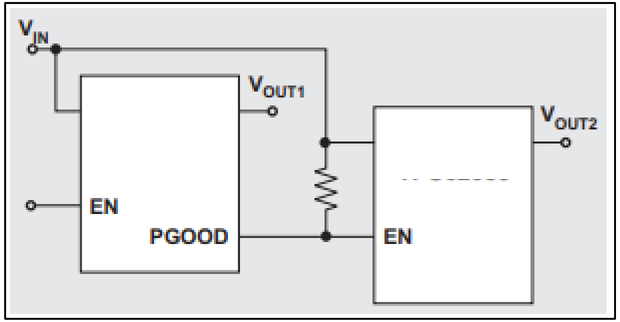


Power good

Functionality:

- Indicates that the **output voltage** of the device has risen to 90% of its final value. Some devices may have internal delays built in

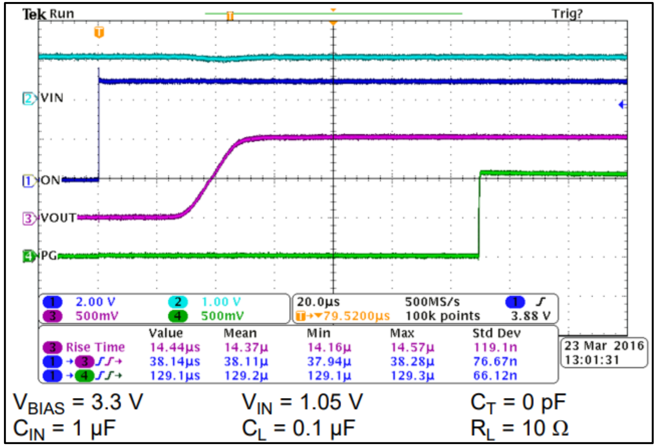
- Open drain output



Applications:

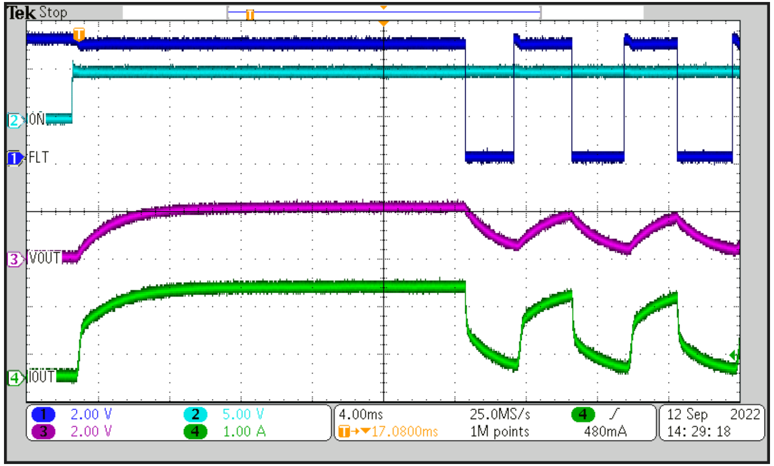
- Power sequencing (For example: DDR)

- Logic control (For example: power multiplexing)



Thermal shutdown

- T_{SD} **prevents** the junction temperature of the device from exceeding a fixed threshold to protect the device
- Includes auto-retry when T_J < falling temperature threshold



Thermal Shutdown (TSD)					
TSD	Thermal Shutdown	Rising	N/A	170	°C
		Falling (Hysteresis)	N/A	150	°C

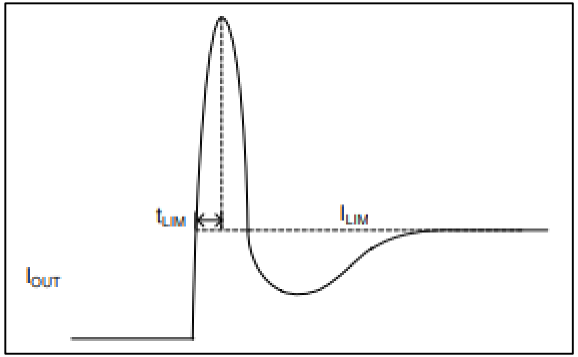
TPS22950

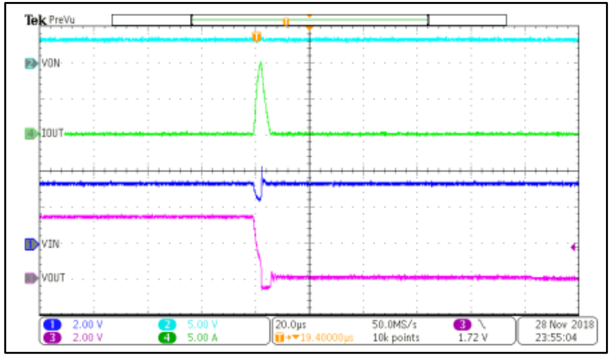
Short circuit protection (SCP) Vs. current limit

- SCP trigger method: $V_{IN} – V_{OUT} > V_{sc}$ compares input and output voltage until it exceeds a specified amount and enters a regulation state.

- Current limit trigger method: Will have an integrated sense circuit that moves the device into a regulation state when current exceeds a specified value.

- Devices with the current limiting feature will also have SCP, but devices with SCP may not have current limiting.





Load switch current limiting

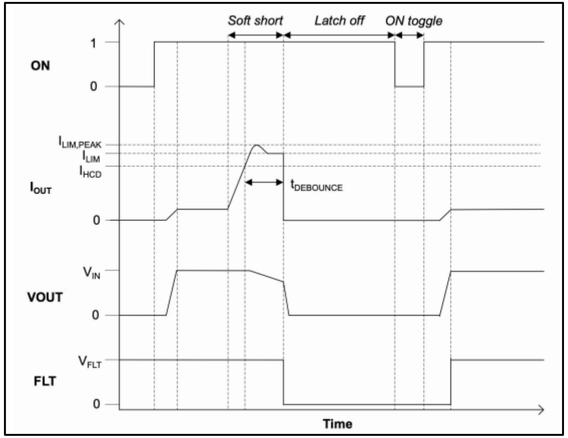
Latch off current limit:

- Over current fault causes the device to turn off after a short period of current limiting at a set value until the ON pin is toggled

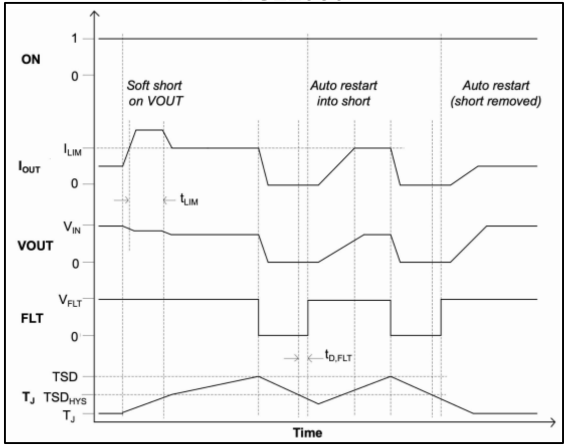
Current regulation:

- Over current fault causes the device to limit at a set current value until the fault is removed or the device hits T_{SD}

TPS22950L



TPS22950



Load switch current limiting

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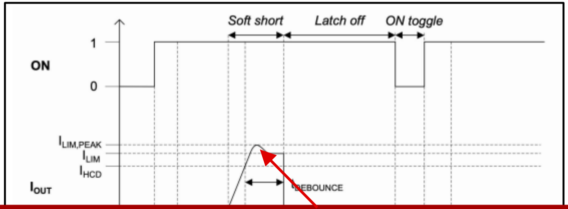
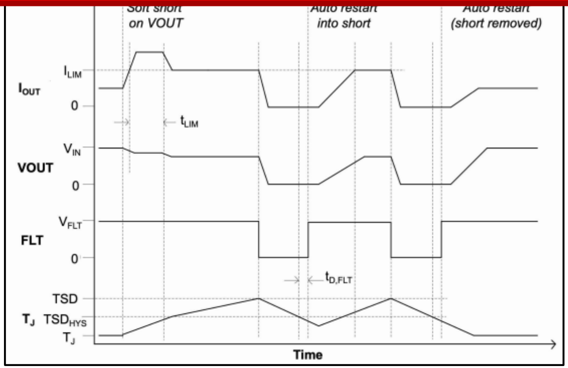
TPS22950L



$I_{LIMPEAK}$ is the overshoot of current that occurs just before the current limit is engaged

Current limit hold:

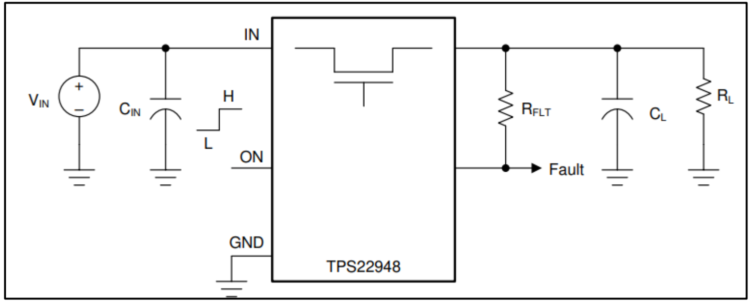
- Over current fault causes the device to limit at a set current value until the fault is removed or the device hits T_{SD}



Load switch current limiting

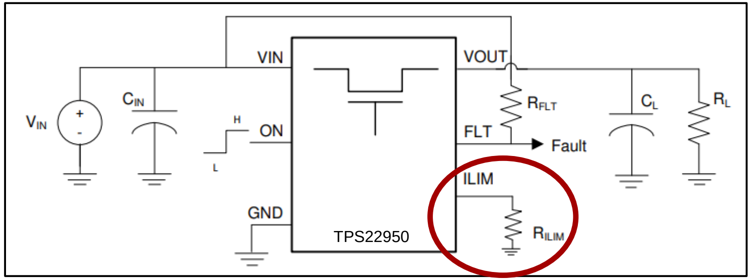
Fixed current limit:

- Some devices have a fixed current limit such as the TPS2294x series



Adjustable current limit:

- Other devices, through an “I_{LIM}” pin, have an adjustable current limit such as the TPS22950



Reverse current protection (RCP)

RCP activation:

- For RCP to enable: $V_{OUT} > V_{IN} + V_{RCP}$ where V_{RCP} is device specific and dependent on the R_{ON} of the device. This means some reverse current will occur

RCP when disabled:

- When ON < V_{IL} the device enables RCP, otherwise it is disabled

Always-ON RCP:

- Regardless of ON the device enables RCP

r_{ON}	On-resistance	V_{IN} = 5.25 V, I_{OUT} = –200 mA	25°C		60	80	mΩ
			Full			110	
		V_{IN} = 5.0 V, I_{OUT} = –200 mA	25°C		60	80	
			Full			110	
		V_{IN} = 4.2 V, I_{OUT} = –200 mA	25°C		60	80	
			Full			110	
		V_{IN} = 3.3 V, I_{OUT} = –200 mA	25°C		60.7	80	
			Full			110	
		V_{IN} = 2.5 V, I_{OUT} = –200 mA	25°C		63.4	90	
			Full			120	
		V_{IN} = 1.8 V, I_{OUT} = –200 mA	25°C		74.2	100	
			Full			130	
		V_{IN} = 1.5 V, I_{OUT} = –200 mA	25°C		83.9	120	
			Full			150	

$$V_{RCP} = 44mV$$

$$R_{ON} = 60m\Omega$$

$$I_{RCB} = \frac{44mV}{60m\Omega} = 733mA$$

V_{RCP}	Reverse current voltage threshold	TPS22910A, TPS22913B/C		44	mV
		TPS22912C		54	

Quick output discharge

Benefits:

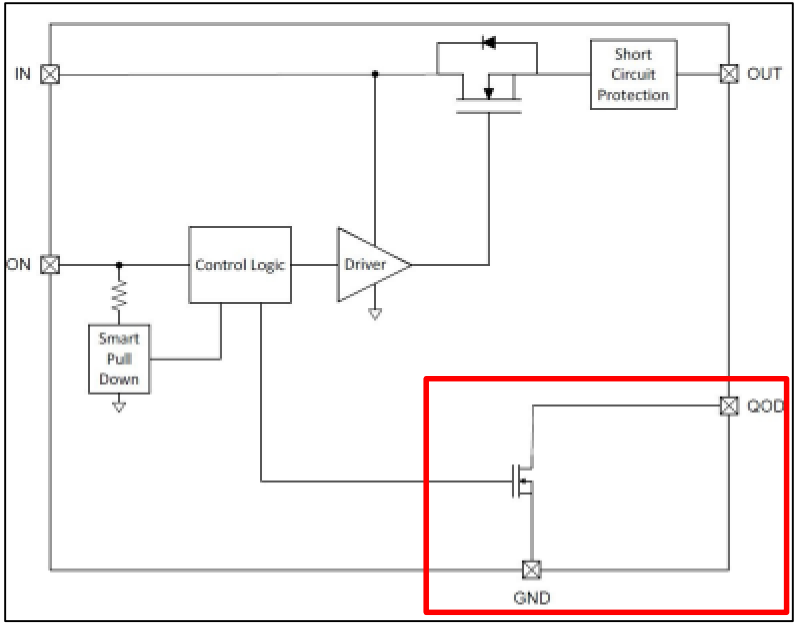
- QOD ties the output of the device to ground through resistance when $V_{EN} < V_{IL}$
- Known state
- Ensures downstream devices are turned off

Cons:

- Batteries and super charge capacitors on output
- Power multiplexing

Equation for fall time:

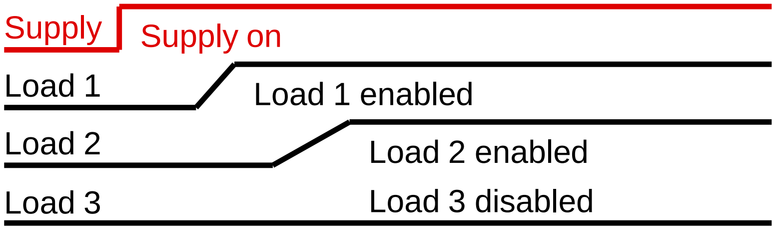
$$t_f = R_{L||QOD} \times C_L \times \ln\left(\frac{V_{10\%}}{V_{90\%}}\right)$$

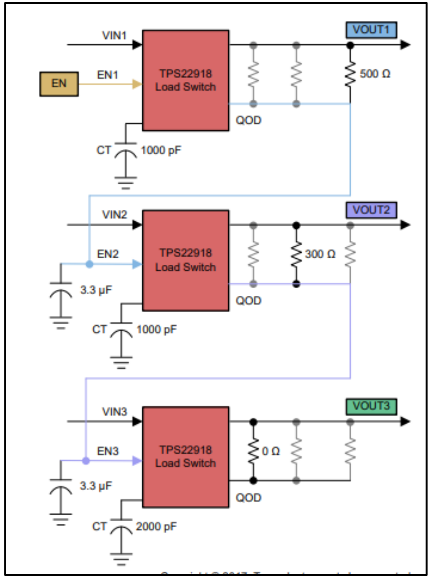


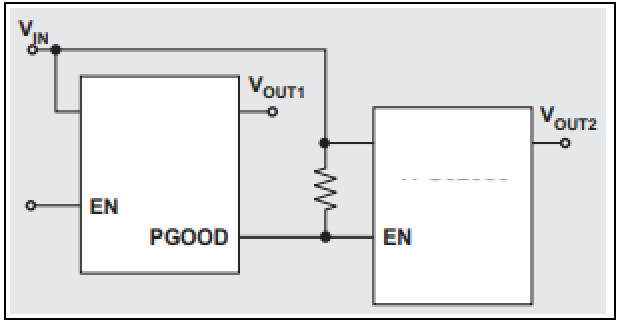
Power sequencing

- Some applications require power rails to be enabled in a specific order

- Load switches can help achieve sequencing needs using PG, QOD or slew rate control



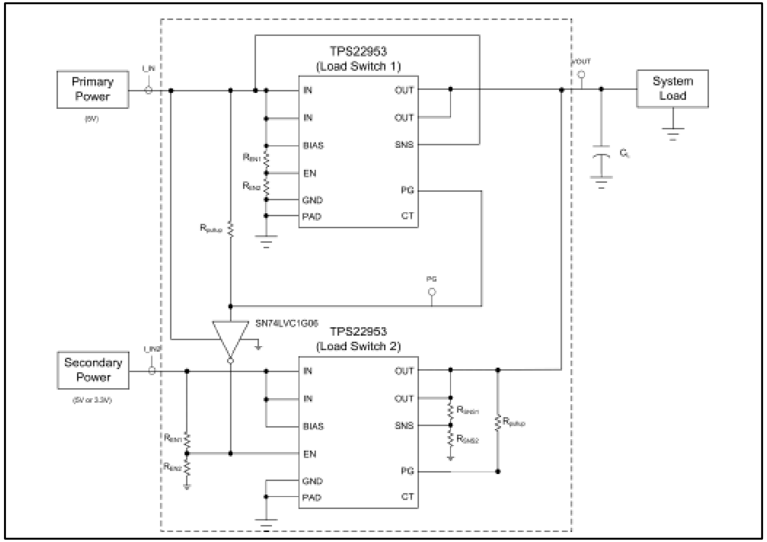




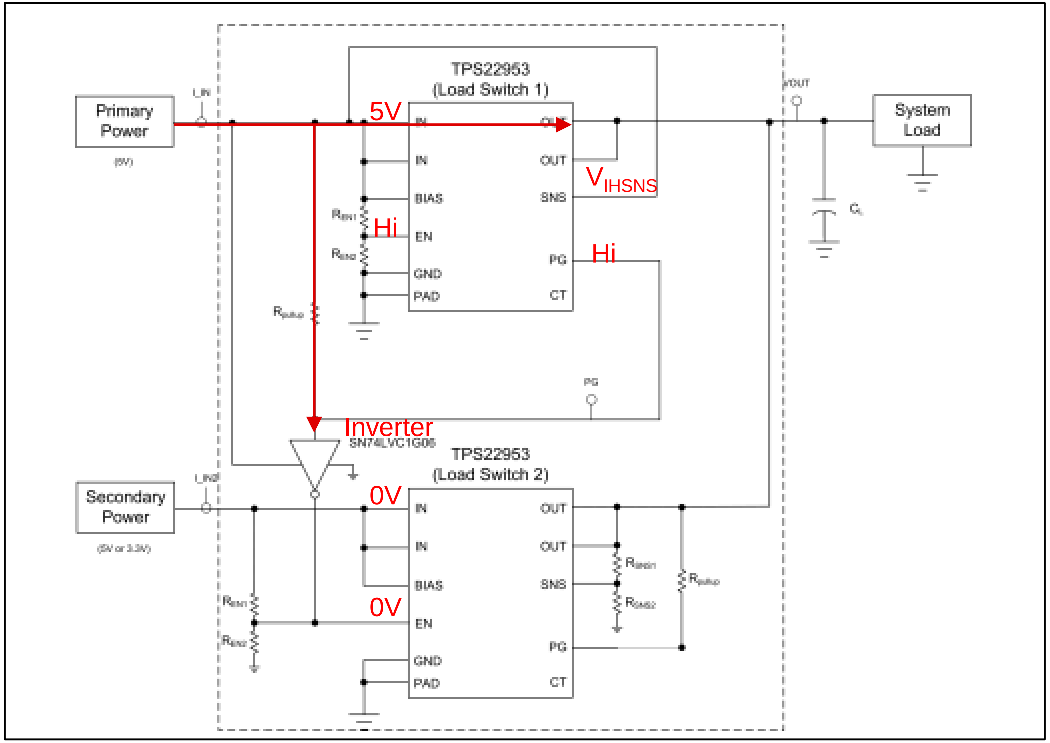
Logic control

- Power multiplexing applications often require break-before-make logic to prevent feeding power back into supplies

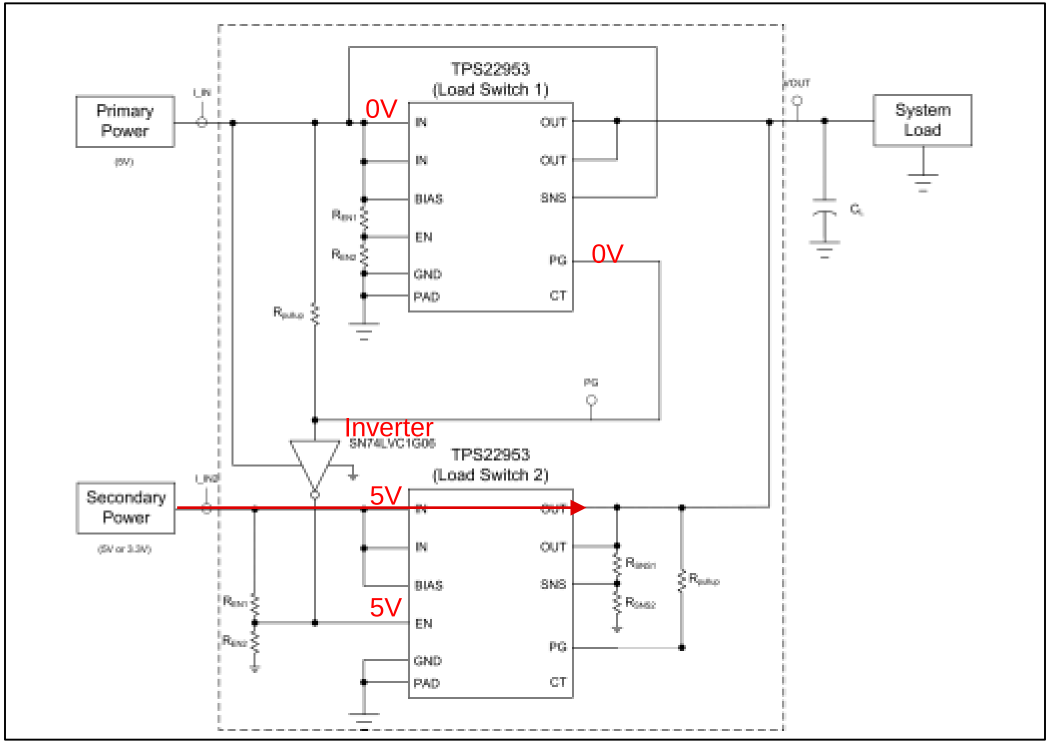
- Using the PG pin of TPS22953 and an inverter we can create a logic control scheme for power multiplexing application to ensure only one switch is enabled at a time



Power good logic control

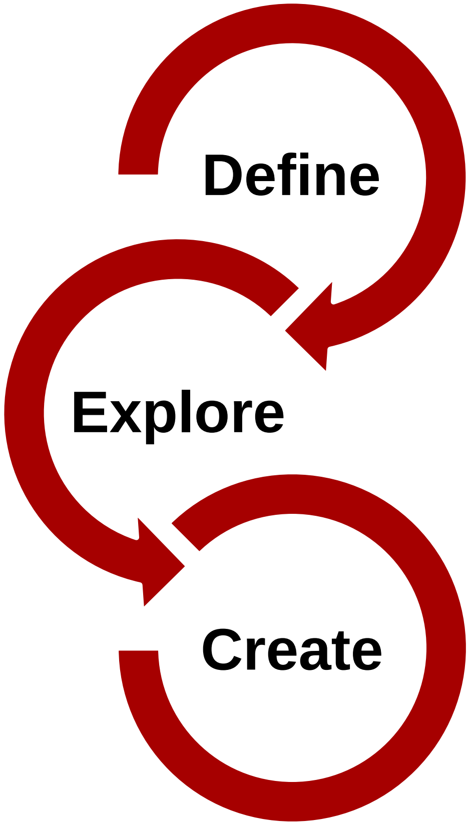


Power good logic control



Selecting a device

1. Define needs & desired features
2. Explore LDSW portfolio using parameter filters
3. Confirm selected device fits needs through calculations
4. Create schematic with recommended components & conditions
5. Layout the device with D/S recommendations in mind



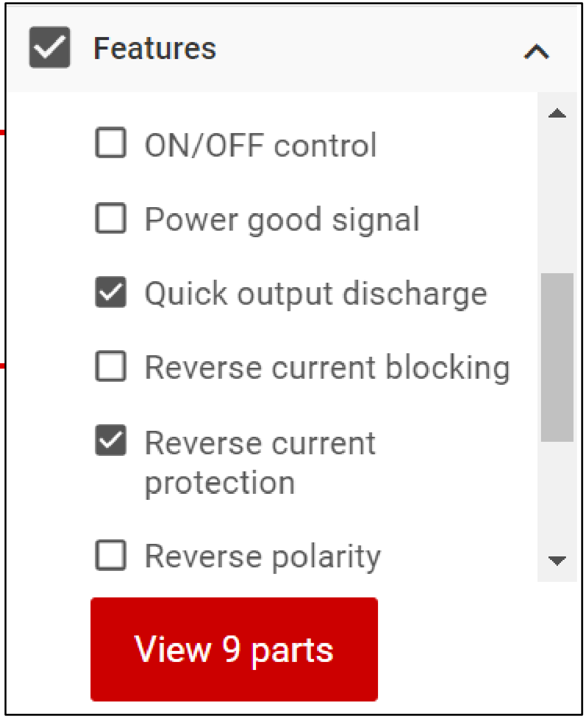
Needs defined

Device use case

- Power sequencing
- Inrush control

System needs & parameters

- Small size
- RCP for upstream modules/supply
- QOD to keep downstream modules from floating
- Limit inrush current
- C_L = 100µF
- V_{IN} = 5V
- R_L = 10 Ω
- I_{OUT} = 500mA



www.ti.com/loadswitches

Selecting a device

9 matching parts out of 69 total parts | Log in to view inventory | Log in

Part Number	Number of channels (#)	Vin (Min) (V)	Vin (Max) (V)	Approx. price (USD)	Imax (A)	Ron (Typ) (mOhm)	Shutdown current (ISD) (Typ) (uA)	Quiescent current (Iq) (Typ) (uA)	Soft start	Rise time (Typ) (us)	Current limit type	Features
TPS22968 - 2-ch, 5.5-V, 4-A, 25-mΩ load switch with adj. rise time and output discharge	2	0.8	5.5	$0.293 | 1ku	4	25	0.5	55	Adjustable Rise Time	65	None	Quick output discharge, Reverse current protection
TPS22968-Q1 - 2-ch, 5.5-V, 4-A, 27-mΩ, automotive load switch with adj. rise time and output discharge	2	0.8	5.5	$0.346 | 1ku	4	27	0.5	55	Adjustable Rise Time	65	None	Quick output discharge, Reverse current protection
TPS22925 - 3.6-V, 3-A, 9.2-mΩ load switch with output discharge	1	0.65	3.6	$0.173 | 1ku	3	10.3	0.5	60	Fixed Rise Time	61	None	Inrush current control, Quick output discharge, Reverse current protection
TPS22964C - 5.5-V, 3-A, 14-mΩ load switch with output discharge	1	1	5.5	$0.243 | 1ku	3	13.8	0.76	38	Fixed Rise Time	890	None	Quick output discharge, Reverse current protection
TPS22950 - 5.5-V, 2-A, 40-mΩ load switch with adjustable current limit	1	1.8	5.5	$0.200 | 1ku	2.7	40	0.2	40	Fixed Rise Time	550	Adjustable	Quick output discharge, Reverse current protection, Short circuit protection, Thermal shutdown
TPS22916 - 5.5-V, 2-A, 60-mΩ, 10-nA leakage load switch with output discharge	1	1	5.5	$0.112 | 1ku	2	60	0.01, 0.1	0.5	Adjustable Rise Time	65, 900	None	Active low, Quick output discharge, Reverse current protection
TPS22917 - 5.5-V, 2-A, 80-mΩ , 10-nA leakage load switch adj. rise time and adj output discharge	1	1	5.5	$0.141 | 1ku	2	80	0.01	0.5	Adjustable Rise Time	55	None	Quick output discharge, Reverse current protection
TPS22913 - 5.5-V, 2-A, 60-mΩ load switch with output discharge	1	1.4	5.5	$0.207 | 1ku	2	61	10	2	Fixed Rise Time	82, 838	None	Inrush current control, Quick output discharge, Reverse current protection, Under voltage lock out
TPS22929D - 5.5-V, 1.8-A, 115-mΩ load switch with output discharge	1	1.4	5.5	$0.232 | 1ku	1.8	115	10	2	Fixed Rise Time	3660	None	Inrush current control, Quick output discharge, Reverse current protection, Under voltage lock out

Selecting a device

Devices

- TPS22916B – 70µS t_r with QOD and active high
- TPS22916BL – 70µS t_r with QOD and active low

6.6 Switching Characteristics

Unless otherwise noted, the typical characteristics in the following table applies over the entire recommended power supply voltage range of 1 V to 5.5 V at 25°C with a load of C_L = 0.1µF, R_L = 10Ω.

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
TPS22916B, TPS22916BL						
t_{ON}	Turn On Time	V_{IN} = 5 V		115		µs
		V_{IN} = 3.6 V		140		
		V_{IN} = 1.8 V		250		
		V_{IN} = 1.2 V		350		
		V_{IN} = 1 V		510		
t_{RISE}	Rise Time	V_{IN} = 5 V		70		µs
		V_{IN} = 3.6 V		80		
		V_{IN} = 1.8 V		130		
		V_{IN} = 1.2 V		190		
		V_{IN} = 1 V		240		

$$Inrush_{Current} = \frac{100\mu F * 5V}{70\mu S} = 7.14A$$

I_{MAX} = 7.64 A outside of specifications

Selecting a device

Devices

- TPS22916C – 800µS t_r with QOD and active high
- TPS22916CN – 800µS t_r without QOD and active high
- TPS22916CL – 800µS t_r with QOD and active low
- TPS22916CNL – 800µS t_r without QOD and active low

6.6 Switching Characteristics (continued)

Unless otherwise noted, the typical characteristics in the following table applies over the entire recommended power supply voltage range of 1 V to 5.5 V at 25°C with a load of C_L = 0.1µF, R_L = 10Ω.

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
TPS22916C, TPS22916CN, TPS22916CL, TPS22916CNL						
t_{ON}	Turn On Time	V_{IN} = 5 V		1400		µs
		V_{IN} = 3.6 V		1700		
		V_{IN} = 1.8 V		3000		
		V_{IN} = 1.2 V		5000		
		V_{IN} = 1 V		6500		
t_{RISE}	Rise Time	V_{IN} = 5 V		800		µs
		V_{IN} = 3.6 V		900		
		V_{IN} = 1.8 V		1400		
		V_{IN} = 1.2 V		2300		
		V_{IN} = 1 V		3000		

$$Inrush_{Current} = \frac{100\mu F * 5V}{800\mu S} = 625mA$$

I_{MAX} = 1.125 A within specifications

Thermal calculations

Power dissipation

$$P_D = I_{LOAD}^2 \times R_{ON}$$

$$P_D = 0.5^2 \times 80 = 20mW$$

Thermal resistance

$$T_J = R_{\theta JA} \times P_D + T_A$$

$$T_J = 193 \times 0.02 + 25 = 28.9\ °C$$

Considerations

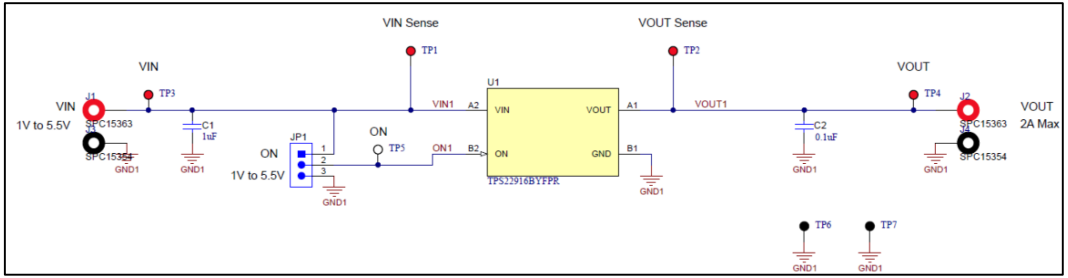
$R_{\Theta JA}$ is based on a JEDEC standard board with thin power traces and limited thermal dissipation. It's also helpful to get a general idea of a devices thermal performance, but can be significantly improved through methods mentioned in the layout section

ON-RESISTANCE (R_{ON})							
R_{ON}	ON-Resistance	I_{OUT} = 200 mA	V_{IN} = 5 V	25°C	60	80	mΩ
				–40°C to +85°C		100	
				–40°C to +105°C		120	
			V_{IN} = 3.6 V	25°C	70	90	
				–40°C to +85°C		120	
				–40°C to +105°C		140	
			V_{IN} = 1.8 V	25°C	100	125	
				–40°C to +85°C		150	
				–40°C to +105°C		175	
			V_{IN} = 1.2 V	25°C	150	200	
				–40°C to +85°C		250	
				–40°C to +105°C		300	
			V_{IN} = 1 V	25°C	200	275	
				–40°C to +85°C		325	
				–40°C to +105°C		375	

Thermal Parameters[(1)]		TPS22916xx YFP (WCSP) 4 PINS	UNIT
θ_{JA}	Junction-to-ambient thermal resistance	193	°C/W
θ_{JCtop}	Junction-to-case (top) thermal resistance	2.3	°C/W
θ_{JB}	Junction-to-board thermal resistance	36	°C/W
ψ_{JT}	Junction-to-top characterization parameter	12	°C/W
ψ_{JB}	Junction-to-board characterization parameter	36	°C/W

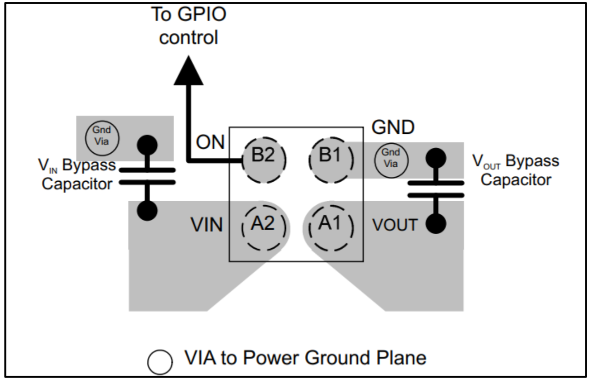
Schematic

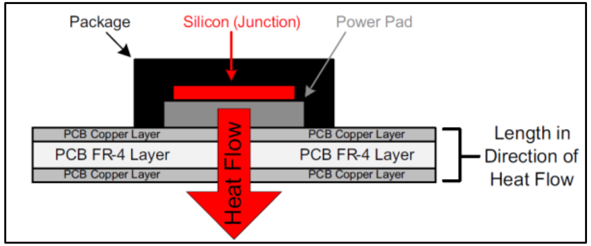
- C_{IN} – 1μF recommended
- C_{OUT} – 0.1μF recommended
- C_{IN}:C_{OUT} – 10:1 ratio for weak supplies that are unable to provide inrush current without dropping in voltage
- These are recommendations but not mandatory for device performance

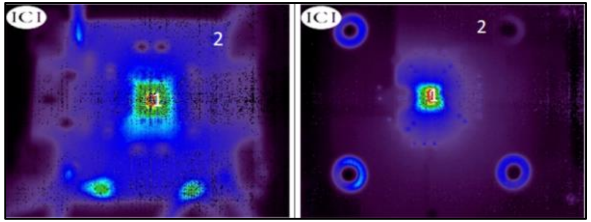


Layout

- Polygon pour planes
- Via stitching GND pour to GND plane
- Capacitance close to pins minimizes current loops
- Copper and FR-4 layer thickness & amount of layers connected to increases the devices ability to dissipate heat
- Board area increases have diminishing returns







Load types

Capacitive

- Inrush current is the main concern as shown previously
- Weak supplies are concerning with significant output capacitance

Resistive

- Maintaining conditions within recommended specifications when including base R_L and any inrush current or inductive swinging from line inductance

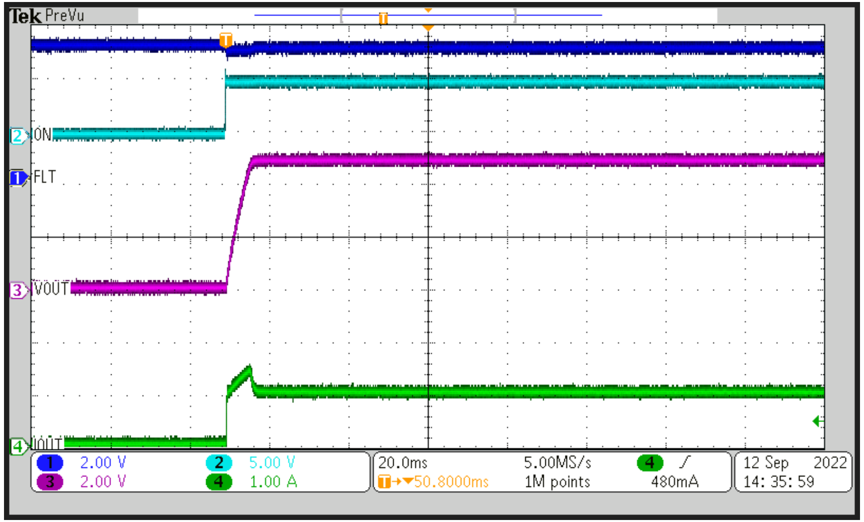
Inductive

- Not recommended with load switches as there isn't a V_{DS} clamp; however, possible provided other protections in place exterior to the load switch

Capacitor charging

Slew rate control: Significant inrush current due to capacitance can be controlled by controlling the slew rate of the output voltage, preventing significant spikes in current to charge capacitors.

Current limit: Allowing the device to charge a capacitor quickly by limiting the current at a set value



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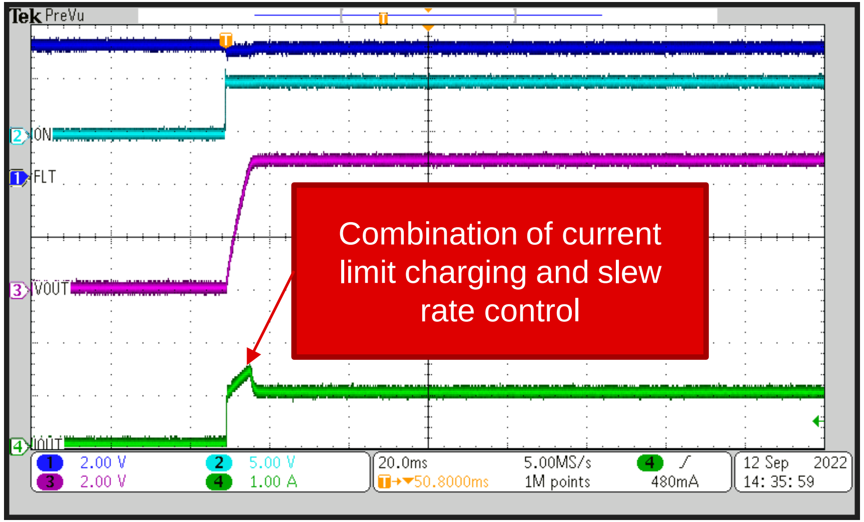


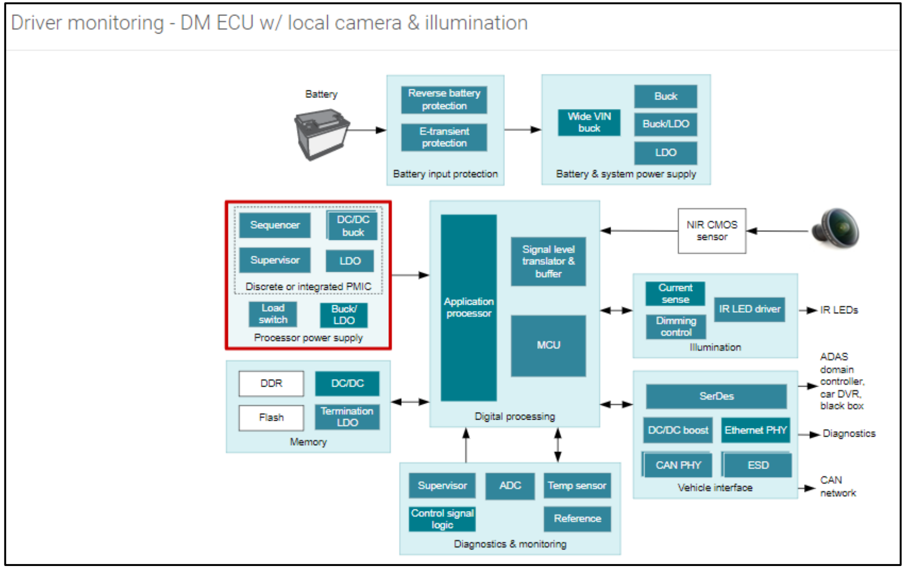
Automotive Standards & Specifications

- AEC-Q100 is an automotive standard that specifies the stress test qualifications a device must pass without any true failures
- ISO, and IEC specifications do not apply since supply is from DC/DC & load is on same ECU

AEC - Q100-007 -	Fault Simulation and Test Grading
AEC - Q100-008 -	Early Life Failure Rate (ELFR)
AEC - Q100-009 -	Electrical Distribution Assessment
AEC - Q100-010 -	Solder Ball Shear Test
AEC - Q100-011 -	Charged Device Model (CDM) Electrostatic Discharge Test
AEC - Q100-001 -	Wire Bond Shear Test
AEC - Q100-002 -	Human Body Model (HBM) Electrostatic Discharge Test
AEC - Q100-004 -	IC Latch-Up Test
AEC - Q100-005 -	Non-Volatile Memory Program/Erase Endurance, Data Retention, and Operational Life Test
AEC - Q100-012 -	Short Circuit Reliability Characterization of Smart Power Devices for 12V Systems

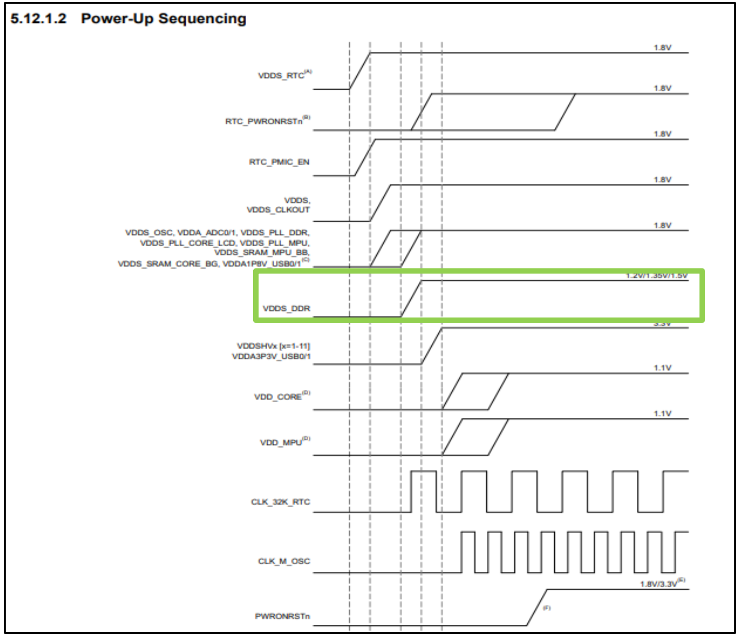
ADAS specific design

- DC/DC buck (12V lead acid battery to 3.3V)
- Load switch enables rail to processor for DDR
- Supply/load on same ECU
- AEC-Q100 requirement



DDR requirements

- Voltage requirements: 1.5V & 3.3V
- Current requirement: 300mA
- Power sequencing
- TPS22995H-Q1



NO.	PARAMETER	MIN	MAX	UNIT
1	VDDS_DDR bulk bypass capacitor count	2		Devices
2	VDDS_DDR bulk bypass total capacitance	20		µF

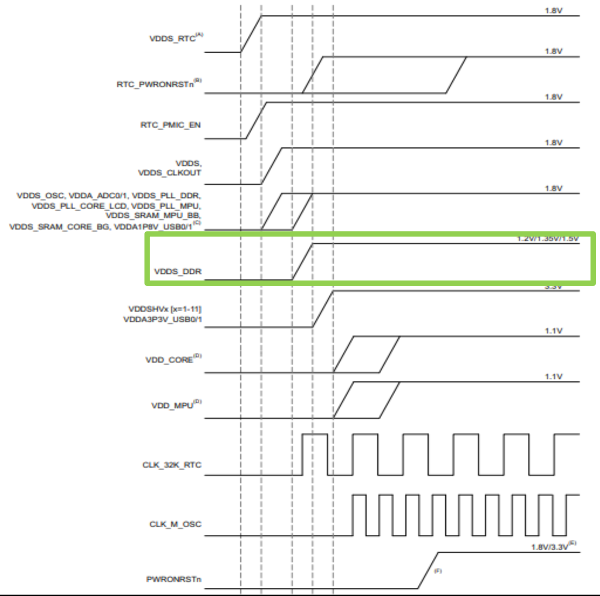
VDDS_DDR	Supply voltage range for DDR IO domain (DDR3)	1.425	1.500	1.575	V
	Supply voltage range for DDR IO domain (DDR3L)	1.283	1.350	1.418	
	Supply voltage range for DDR IO domain (LPDDR2)	1.140	1.200	1.260	

VDDS_DDR	Maximum current rating for DDR IO domain; DDR3/DDR3L	300	mA
	Maximum current rating for DDR IO domain; LPDDR2	150	

DDR requirements

- Voltage requirements: 1.5V & 3.3V
- Current requirement: 300mA
- Power sequencing
- TPS22995H-Q1

5.12.1.2 Power-Up Sequencing

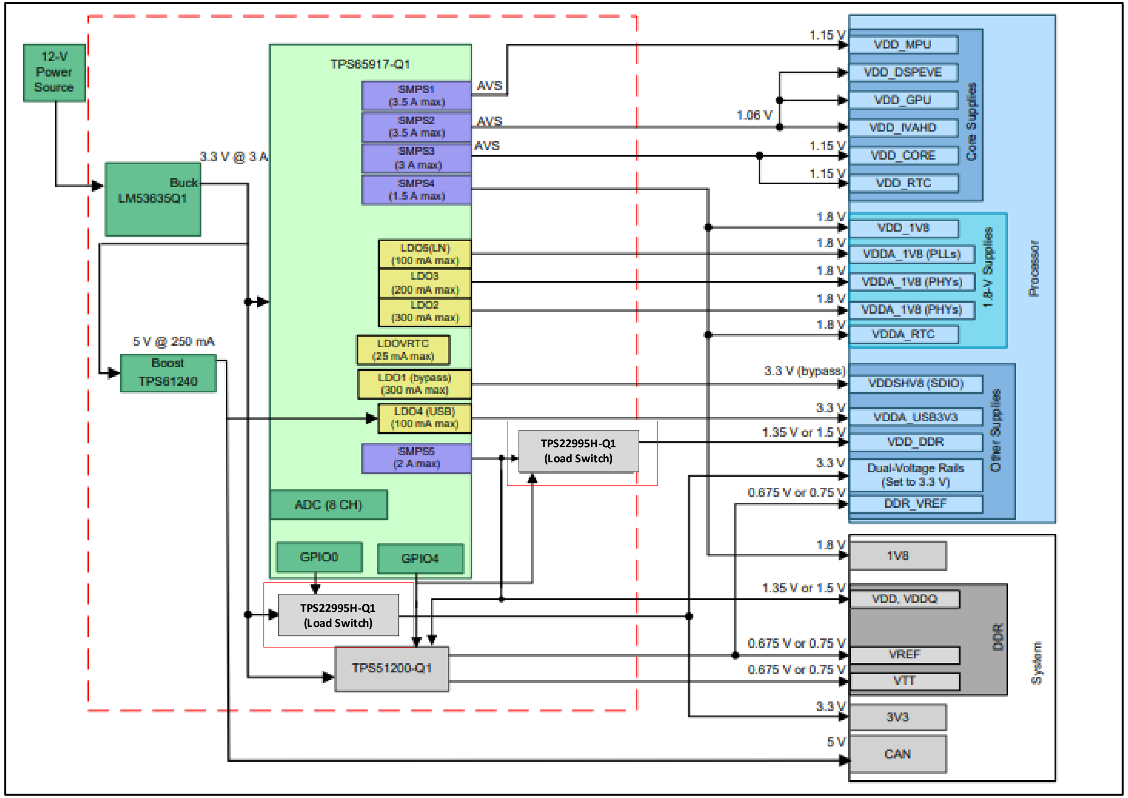


6.3 Recommended Operating Conditions TPS22995H-Q1

over operating free-air temperature range (unless otherwise noted)

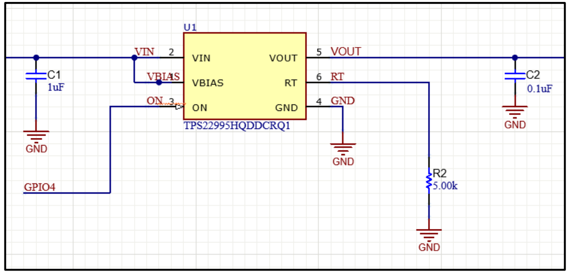
		MIN	NOM	MAX	UNIT
V_{IN}	Input Voltage	0.8		5.5	V
V_{BIAS}	Bias Voltage	1.5		5.5	V
V_{IH}	ON Pin High Voltage Range	0.8		5.5	V
V_{IL}	ON Pin Low Voltage Range	0		0.35	V
T_A	Ambient Temperature	–40		125	°C

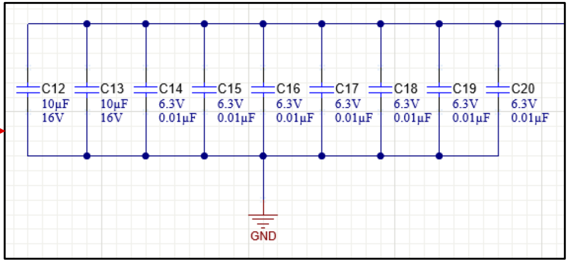
ADAS block diagram

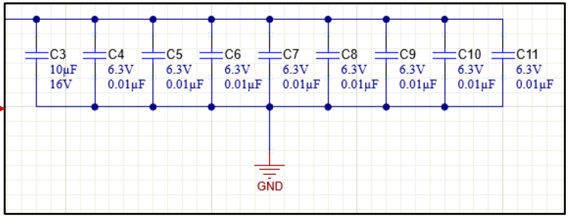


ADAS TPS22995H-Q1 schematic

- V_{IN} and V_{BIAS} are tied together and supplied by SMPS5 of PMIC
- GPIO4 controls ON signal to power sequence the device
- Bulk capacitance on output of PMIC ensures the rail doesn't dip in voltage when power is provided
- Bypass capacitors are required near processor DDR input pin (usually on topside/backside of processor)







ADAS TPS22995H-Q1 layout

- Polygon pours for V_{IN}/V_{OUT} > 0.5 In^2
- C_{IN} and C_{OUT} capacitors as close to V_{IN} and V_{OUT} pins as possible
- GND polygon pour with vias to GND plane
- RT resistor placed close to RT pin